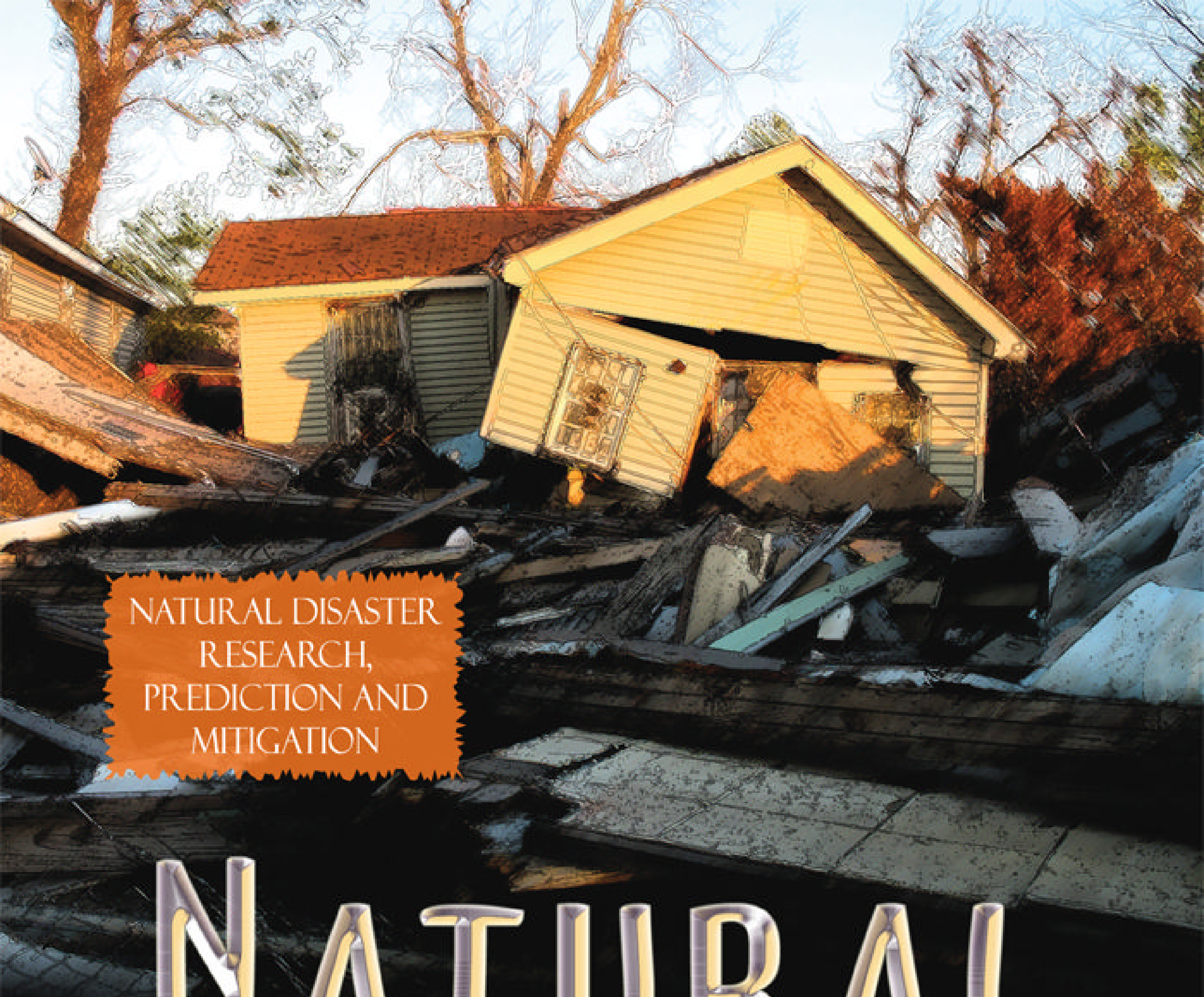

NATURAL DISASTER RESEARCH, PREDICTION AND MITIGATION

NATURAL DISASTERS

Prevention, Risk Factors and Management

Biljana Raskovic ✧ Svetomir Mrdja

Editors

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PREVENTION, RISK FACTORS AND MANAGEMENT

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BILJANA RASKOVIC
AND
SVETOMIR MRDJA
EDITORS

nova publishers
New York

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PREFACE

In this book, the authors present current research in the study of the prevention, risk factors and management of natural disasters. Topics discussed include typhoon and hurricane prediction; point-of-care testing in complex emergency and disaster resilience; management strategies for children during natural disasters; torrential floods prevention; information technology and simulation in disaster management; quantile approach application to seismic risk assessment; the increase of natural disasters as a result of global climate change; coping with disaster trauma; paleo-landslides in central Serbia; how the elderly cope during disasters and crises; and government involvement in Connecticut during Tropical Storm Irene.

Chapter 1 – As the World Meteorological Organization estimates that about 90 percent of all natural disasters are extreme meteorological hazards like typhoon, hurricane and tropical cyclone triggered disasters. Typhoon-induced disaster is one of the most important factors influencing the economic development and more than 250 million people in China.

In view of the existing extreme statistical theory can not satisfy typhoon disaster prediction, during the past 30 years research activities the authors derived Compound Extreme Value Distribution (CEVD) by compounding a discrete distribution (typhoon occurrence frequency) and the extreme distribution for typhoon induced disaster events as following types:

- Poisson-Gumbel CEVD for typhoon induced extreme wave prediction was widly used for coastal structures design and accepted in 2008 “China Code for Sea Port Hydrology” instead of Pearson type 3;
- Poisson-Weibull CEVD was used for hurricane prediction along US Atlantic and Gulf of Mexic coasts, 2005 hurricane Katrina disaster proved that our 1982 predicted results in disaster area more reasonable than NOAA proposed SPH and PMH ;
- CEVD developed into Multivariate Compound Extreme Value Distribution (MCEVD) and used for different offshore, coastal and hydraulic engineering.
- Multi-objective triple layer probability model based on the MCEVD as follows:
    - The first layer is typhoon characteristics. They are described as maximum central pressure difference (ΔP), radius of maximum wind speed (Rmax), moving speed of typhoon center (s), minimum distance between typhoon center and target site (δ), and typhoon moving angle (θ). But the annual typhoon/ hurricane frequency (λ) is also different for certain sea area. Typhoon duration from landfall to dissipation (t) is also considered as one of

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typhoon characteristics in the prediction model. For the analysis procedure of multivariate joint probability which combines a kind of discrete distribution (λ) and six kinds of continues distributions (ΔP, Rmax, s, δ, θ, t), the stochastic simulation technique based on the theory of MCEVD is a valid way to solve such problem.

- The second layer is joint probability prediction of different combinations of typhoon characteristics triggered wave, surge, wind, rainfall, flood, current combinations by MCEVD.
- The third layer: Joint probability safety assessment for different kind defense structures with certain dominated extreme external event.

The authors' proposed MCEVD theory and Multi-objective triple layer probability model widely used for more than 40 engineering projects , such as coastal defense against typhoon attacks for Nuclear Power Plants, risk assessment for estuarine city Shanghai and hydraulic structures for Olympiad Sailing Regatta, flood prediction of Three Gorges Dam Project and design codes calibration (API, IAEA and China Design Codes) for offshore, coastal and hydraulic structures.

Chapter 2 – Resilience through use of point-of-care (POC) testing in small-world networks will change the future landscape by bringing evidence-based decision-making to sites of need globally. Point-of-care (POC) testing is performed at or near the site of care to accelerate decision-making. This chapter provides value propositions that show new POC technologies can be assimilated into challenging locations when infrastructure is compromised, and for preparedness, proposes developing professional competence and team experience in the context of existing small-world networks facilitated by geographic information systems. Environmental limitations demand that POC devices and test kits adhere to manufacture temperature and humidity specifications, which may not be robust enough for the hot, cold, and humid conditions encountered in field operations. Indeed, the effects of environmental stresses can no longer be ignored. Hence, there must be strategic alternatives for placement of POC testing in alternate care facilities. Overall, POC testing promises to transform crisis standards of care by bringing enhanced evidence-based diagnosis and treatment to victims most in need and by accelerating screening and triage critical to effective emergency and disaster care.

Chapter 3 – Children are vulnerable during a disaster due to differences in physiology, limited self–sufficiency, and increased susceptibility to hazards. It is necessary to have comprehensive plans in place in order to mitigate the events after a disaster occurs.

Many disaster plans do not effectively incorporate children into disaster management and fail to prepare for the needs of this population. Disaster drills are needed to identify roles, identify needed supplies, and understand surge capacity. Appropriate preparation will optimize response and coordination of large numbers of trauma victims in an efficient manner. Additional resources are needed for inter-hospital communication, family reunification, and vigilance against secondary injuries in this vulnerable population.

In this chapter, the authors will discuss disaster mitigation, preparation, response, and recovery strategies by healthcare personnel to limit social, psychological, and medical effects of natural disasters on children.

Chapter 4 – The authors examine the earthquake size distributions in the uppermost range of extremely rare events using a new method for statistical estimation of the tail distribution.

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The main problem in the statistical study of the extremely rare strongest earthquakes (and this applies to distributions of other rarely observable extremes) is the estimation of quantiles which are "beyond the data range", i.e., quantiles of level $q > 1 - 1/n$, where n is the sample size. The estimation of quantiles of levels $q > 1 - 1/n$ can't be obtained without additional assumptions on the behavior of the tail of the distribution. As the assumptions the authors use the two main theorems in the theory of extreme values and the derived duality between the Generalized Pareto Distribution (GPD) and the Generalized Extreme Value distribution (GEV). This approach provides a possibility to estimate the quantiles of a high level. It should be noted that for some values of parameters of GPD and GEV distributions the widely used parameter - maximum possible magnitude m_{max} and other similar parameters (i.e., peak ground acceleration, PGA) are unstable statistically. This feature is a mathematical aspect of the regularly repeating cases of occurrence of strong earthquakes in the areas believed before to be of negligible seismic activity. Note that very these unexpected strong earthquakes cause huge losses rather frequently.

To avoid this instability the authors have suggested a new parameter $Q_q(\tau)$ – the quantile of a given level q of the maximum magnitude in a future time interval τ. In contrast to m_{max}, the parameter $Q_q(\tau)$ is stable and robust. The quantiles $Q_q(\tau)$ can be very useful tools for pricing risks in the insurance business and for optimizing the allocation of resources and preparedness by governments.

The authors illustrate their theoretical conclusions applying described technique to earthquakes in Japan (1900-2010) and Fennoscandia (1900-2005). In the case of Japan the authors have found that earthquakes with magnitude M~9.0 are possible despite the fact that no such events are specified in the historical catalog of Usami (599-1884). The authors have applied this approach to a new object: peak ground acceleration (PGA) caused by earthquakes. The regular part of PGA was modeled in form of a function depending on magnitude and epicentral distance. The random errors of several types were taken into account. The resulting statistical technique was applied to 4 sites in Japan: Tokyo, Hiroshima, Osaka, Fukushima atomic power station (Fukushima Daiichi).

The estimated PGA for these sites were derived. These estimates can be useful for the seismic hazard assessment.

The authors emphasize also that the methods used here to parameterize the recurrence of major earthquakes are very general and are applicable, not only to the assessment of earthquake hazard, but also to all those cases where the recurrence of rare large events is to be estimated.

Chapter 5 – Torrential floods, as a natural disaster, which appears suddenly as a two-phase flow (maximal water discharge and high concentrated sediments) on slopes in mountain areas, cause an increased risk to human lives, their activities and material goods. In Serbia, torrential floods are the most frequent natural disaster, regarding the fact that 86.4% of the territory is affected by erosive processes and about 70% with dissected relief prone to torrential floods. In the Skrapež River watershed, located in western Serbia, erosion and flow characteristics of the main stream and its tributaries are conditions for the occurrence of torrential floods. Based on these characteristics, the classification of torrential streams in the basin was carried out. In this case it is also confirmed that the mode of their occurrence is seasonal. Large sediment production, filling of river beds, flooding and material damage point to the need for the appropriate solutions to these problems. They could be solved only by the

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logical order of removing their causes. The planning document Water Resources Management Basic Plan of Serbia (WRMBPS) implies the construction of two reservoirs for multiple usages, as a possible solution. Regarding the protection from torrential floods and the rational use of water in the watershed, it is necessary to create the conditions, which *sensu stricto* include riverbeds (technical works) and watershed regulation (biological works). On the other hand, *sensu lato* torrential flood prevention implies the existence of a geographic information system (GIS) of the Skrapež River watershed and its streams. GIS data include torrential floods hazard, vulnerability and resilience indicators of the watershed. Highlighting the indicators helps reducing risk of torrential floods and their consequences in the environmental, economic and socio-psychological sphere.

Chapter 6 – People in general have become more concerned about their physical safety, wherever they live or travel, in a more complex, interconnected world in which environmental issues clearly demonstrate that organisms and all the elements of nature, including air, land and water cannot be exploited without implications, including impacts on the image of international destinations, that can dramatically affect the tourism Industry. Disasters which occurred in Atlantic Islands (Azores, Madeira and Canary Islands) is clearly causing the drop in tourism and damaging the image and local economy. Higher perceived risk is associated with decreased visitation. Perceived risk can have a connection with the general idea that, as a result of global warming the environment will change and sea levels will rise. In Many regions, the impact of such changes are likely to arrive through changes in the frequency of the climatic extremes like, floods, droughts, volcanoes, storm surges etc..

This chapter proposes that previous destination image research has tended to underestimate the importance of safety, security and risk- It also proposes a strategic approach to destination management from proactive pre-crisis planning through to strategic implementation and finally evaluation and feedback.

Chapter 7 – For the past century, information and computing technology has continued to evolve at an accelerating pace. Its applications to medicine, particularly disaster medicine, have increased dramatically in recent years. Its progress has advanced the way in which patient data are collected and disseminated, as well as how knowledge gained from experience in dealing with mass casualty events can be rapidly disseminated, critically evaluated, and applied to future events by healthcare providers. In this chapter, the authors provide a brief history of information technology (IT) and the related field of bioinformatics in the context of their applicability to disaster planning and response. The authors describe both “real-world” and virtual approaches to the problem of optimizing the smooth, practiced, and most efficient delivery of healthcare resources in times of crisis. Real-world approaches include drills and the use of advanced audiovisual and communications technology to extend the reach of the disaster practitioner’s eyes, ears, and hands. Equally important are the *in silico* approaches including end user-friendly disaster scenario software packages, bioinformatics treatment of complex medical data sets to find and recognize patterns as early warning signs for poor patient outcomes, and queueing theory for the enhancement of delivery of limited resources to the disaster surge population. Overall, the authors will describe how these IT tools for disaster professionals can be incorporated into more conventional planning and response.

Chapter 8 – This chapter summarizes the authors previous work, in which she expand upon the existing literature on population and the economy by examining whether natural disasters affect fertility – a topic little explored but of policy importance given relevance to

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policies regarding disaster insurance, foreign aid, and the environment. The identification strategy uses historic regional data to exploit natural variation within each of two countries: one European country—Italy (1820-1962)—and one Asian country—Japan (1671-1965). The choice of study settings allows consideration of Jones' (1981) theory that preindustrial differences in income and population between Asia and Europe resulted from the fertility response to different environmental risk profiles. According to the results, short-run instability, particularly that arising from the natural environment, appears to be associated with a decrease in fertility – thereby suggesting that environmental shocks and economic volatility are associated with a decrease in investment in the population size of future generations. The results also show that, contrary to Jones' (1981) theory, differences in fertility between Italy and Japan cannot be explained away by disaster proneness alone. Research on the effects of natural disasters may enable social scientists and environmentalists alike to better predict the potential effects of the increase in natural disasters that may result from global climate change.

Chapter 9 – Disasters have multitude of effects on the victims; as the direct loss and damage during disasters and the indirect consequences continue for years. In the developing world disasters have colossal impact where the resources are scarce, disaster relief systems are inadequate and post-disaster long-term care is abysmally poor. Psychiatric morbidities are observed in a large majority of affected population and these often become chronic. It is imperative to study how the victims cope following the catastrophic disasters, the relation between various coping strategies and manifest morbidities and variations across disasters and cultures. This article reviews the available literature regarding coping following various disasters and summarizes the coping strategies employed by disaster victims around the world. Variations in coping across cultures are highlighted and areas for therapeutic intervention are suggested. These understandings in coping may help in facilitating positive coping and developing culture specific and appropriate intervention programmes.

Chapter 10 – The Tunguska disaster, which occurred at about 7 a.m. on June 30, 1908 over Eastern Siberia, has no equivalent in the Earth's recent past. The interaction of the Tunguska cosmic body with the Earth's atmosphere was witnessed by thousands of inhabitants of Eastern Siberia, who noted unique characteristics of this event. The visual size of the flying object was >2 km, which is considerably, (>10 times) greater than the real size of the Tunguska body. The body's substance was visibly breaking into pieces. The flying object resembled something aflame: both in its colour and form, i.e. the substance that separated from the object was undergoing a reaction of burning with atmospheric oxygen. The duration of the flight of the cosmic body was more than 1 min. The object became visible at heights of >500 km. The dispersion ellipse of the Tunguska cosmic body, the longer and shorter axis of which are ~4000 and ~2000 km, respectively, was determined. The southern part of the dispersion ellipse was found on the base of the form of the area covered by noctilucent clouds, which appeared as a result of the Tunguska disaster. The northern part of this ellipse corresponds to an area with an intense growth of trees, located to the north of the epicenter of the disaster. To form a similar dispersion ellipse, the object had to explode at a height of more than 1,000 km over the Earth's surface. The final destruction of the Tunguska body took place at a height of ~6 km above the ground. In spite of the liberation of energy in $5\ 10^{23}$ erg during this explosion, several hundred trees survived the disaster, located at a distance of <7 km from the epicenter. According to researchers, the explosion of the Tunguska cosmic body was of the sort of volume detonation explosion which is most

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widespread in nature. The explosive destruction of the object over the epicenter lasted several minutes and was represented by a series of strokes, which were more than 10 in number. As a result, over the explosion area there appeared an atmospheric discharge, which reached a height of 80–90 km above the Earth's surface. According to estimates, the Tunguska disaster was accompanied by the transfer of charges in ~10^5 C and the generation of magnetic fields 50–60 times greater than the Earth's magnetic field.

Chapter 11 – This project aims to clarify the mechanism which determines community cohesion alteration following natural disaster. Data were collected from residents in a flood effected community using an anonymous questionnaire survey. This project revealed that, contrary to the findings of previous hazard studies, community cohesion was not predicted by the length of residence, or any other demographic characteristics of residents.

Community cohesion was actually predicted by sense of community, community cognition, and degree of community participations. Cohesion alteration was not uniform, but varied along levels of hazard severity (i.e., flood invasion). Specifically, community cohesion increased in line with hazard severity at the initial flood stage, as residents recognized of the importance of community entity and therefore were brought closer together to cope with the losses they suffer. However, when the severity aggravated, residents transferred their focus to individual interests rather than community interests, which resulted in decreased community cohesion. The present project distinguishes itself in examining community cohesion in the wake of a natural disaster in the real world. Implication of the findings towards community reconstruction and suggestions to hazard researchers are discussed accordingly.

Chapter 12 – Landslide mapping in the Belica River basin in central Serbia revealed three landslides with surfaces larger than 0.5 km^2: Belica landslide (10.49 km^2), Bukovče landslide (0.4 km^2) and Ribnik landslide (0.59 km^2). The analysis of lithological, structural and morphological characteristics of the landslide locations showed that their formation cannot be explained by traditionally known genetic factors. This has led to the identification of earthquakes as potential stressors that could affect the formation of the studied mega-landslides. Seismic characteristics of the Belica River basin were analysed using the data from both pre-instrumental and instrumental (1909-2011) periods. The relation between earthquakes and the studied landslides was analysed through the slightly modified referent criteria. Out of six criteria, four support the seismic origin. The region where the landslides occur is a proven seismic region. Spatial distribution of landslides coincides with the strike of active faults or seismic zones. The dimensions of the case examples meet the required criterion for seismically induced mega-landslides. Geological and geomorphological settings are not sufficient to explain the positions of landslides. Further geotechnical research could show whether the slope stability indicates that the slope failures were seismically induced. The criterion of liquefaction occurrences for establishment of the role of seismic activity was not met due to insufficient evidence. Spatial distribution of lithological structures was used to determine the relative age of the landslides. Over 6 m thick alluvial sediments in the central part of the Belica River basin cover the foot of the Belica landslide. Such lithological relation of Quaternary sediments and Belica landslide points to its Pleistocene or Early Holocene age.

Chapter 13 – Learning during a natural disaster may be particularly important for older adults, as often the elderly are among the most susceptible to loss of life, health, or property. Although age and learning in the context of natural disasters has received little scholarly attention, much is known about the relationship between age and learning in other contexts, especially with regard to self-efficacy. In general, research has found that older individuals

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lack confidence in their own ability to master a new skill. Organizational studies have indicated that older individuals may be less likely than others to adopt behaviors to which they have low self-efficacy, while other studies indicate reluctance to training and redevelopment activities.

The efficacy problems of older audiences seem to revolve around reappraisals and misappraisals of their capabilities. Since self-efficacy is in part determined by comparisons to others, older individuals will likely perceive even less self-efficacy if they do not have similar behavioral models against which to compare their own; older individuals may have fewer opportunities to observe models of the same age successfully navigate a crisis. This chapter examines various means of promoting accurate appraisals of efficacy within older populations, including both behavioral practice and mediated interventions. It focuses on the development of public service announcements and warning systems featuring appropriate behavioral models, the underlying psychological mechanisms that may lead to their success, and specific obstacles faced by older audiences when processing evacuation messages.

Chapter 14 – Tropical Storm Irene tore through northern Atlantic states on August 28, 2011, leaving severe property damage in its wake. As part of its efforts to manage the post-disaster response, Connecticut officials asked insurers to waive hurricane deductibles on home insurance policies. Some insurers waived deductibles before pressure was brought to bear; others did so only after state insurance officials, the governor, and a United States Senator publicly called on them to waive the hurricane deductibles. This Chapter analyzes the ramifications of using political pressure in this manner. Although waiving the deductibles was touted as a pro-consumer action, insurers will respond to the increased contractual uncertainty by increasing prices for policies, thereby harming insureds over the long term. This response also raises fairness issues: those who paid more for better coverage in the face of hurricanes spent money for nothing, while those who neglected sufficient hurricane coverage were bailed out.

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Chapter 1

TYPHOON/HURRICANE/TROPICAL CYCLONE DISASTERS: PREDICTION, PREVENTION AND MITIGATION

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ABSTRACT

As the World Meteorological Organization estimates that about 90 percent of all natural disasters are extreme meteorological hazards like typhoon, hurricane and tropical cyclone triggered disasters. Typhoon-induced disaster is one of the most important factors influencing the economic development and more than 250 million people in China.

In view of the existing extreme statistical theory can not satisfy typhoon disaster prediction, during the past 30 years research activities we derived Compound Extreme Value Distribution (CEVD) by compounding a discrete distribution (typhoon occurrence frequency) and the extreme distribution for typhoon induced disaster events as following types:

- Poisson-Gumbel CEVD for typhoon induced extreme wave prediction was widly used for coastal structures design and accepted in 2008 "China Code for Sea Port Hydrology " instead of Pearson type 3;
- Poisson-Weibull CEVD was used for hurricane prediction along US Atlantic and Gulf of Mexic coasts, 2005 hurricane Katrina disaster proved that our 1982 predicted results in disaster area more reasonable than NOAA proposed SPH and PMH ;
- CEVD developed into Multivariate Compound Extreme Value Distribution (MCEVD) and used for different offshore, coastal and hydraulic engineering.
- Multi-objective triple layer probability model based on the MCEVD as follows:

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- The first layer is typhoon characteristics. They are described as maximum central pressure difference (ΔP), radius of maximum wind speed (Rmax), moving speed of typhoon center (s), minimum distance between typhoon center and target site (δ), and typhoon moving angle (θ). But the annual typhoon/ hurricane frequency (λ) is also different for certain sea area. Typhoon duration from landfall to dissipation (t) is also considered as one of typhoon characteristics in the prediction model. For the analysis procedure of multivariate joint probability which combines a kind of discrete distribution (λ) and six kinds of continues distributions (ΔP, Rmax, s, δ, θ, t), the stochastic simulation technique based on the theory of MCEVD is a valid way to solve such problem.
- The second layer is joint probability prediction of different combinations of typhoon characteristics triggered wave, surge, wind, rainfall, flood, current combinations by MCEVD.
- The third layer: Joint probability safety assessment for different kind defense structures with certain dominated extreme external event.

Our proposed MCEVD theory and Multi-objective triple layer probability model widely used for more than 40 engineering projects , such as coastal defense against typhoon attacks for Nuclear Power Plants, risk assessment for estuarine city Shanghai and hydraulic structures for Olympiad Sailing Regatta, flood prediction of Three Gorges Dam Project and design codes calibration (API, IAEA and China Design Codes) for offshore, coastal and hydraulic structures.

1. Introduction

The World Meteorological Organization estimates that about 90 percent of all natural disasters are extreme meteorological hazards like typhoon, hurricane and tropical cyclone triggered disasters in the Pacific, Atlantic, Indian Oceans, Caribbean , Gulf of Mexico areas. The 30 most severe tropical cyclone disasters in world history are shown in Table 1.

In 2005, hurricane Katrina and Rita attacked coastal area of the USA, which caused deaths of about 1400 people and economical loss of $400 billion in the city of New Orleans and destroyed more than 110 platforms in the Gulf of Mexico. In China, out of the total 28 provinces 10 coastal and 6 inland provinces are affected by typhoon induced disasters. In other words, more than 250 million lives are affected by typhoons, with an associated cost of approximately 60 trillion (RMB) GDP. In 2006, typhoon disasters were especially serious. Five of the most severe typhoon disasters brought about 1,600 deaths and disappearances, and affected 66.6 million people. The economic loss reached 80 billion RMB and influenced agriculture areas totaling more than 2,800 thousand hectares. Among these disasters, typhoon Saomai induced 3.76 m surges and 7 m waves, causing 240 deaths, sinking 952 ships, and damaging 1,594 others in Shacheng harbor. If the typhoon Saomai had landed 2 hours later, then the simultaneous occurrence of the typhoon surge and high spring tide with 7m wave would have inundated most areas of the Zhejiang and Fujian provinces, where located several NPP. Details of the 2006 typhoon disaster can be seen in Table 2.

Current situation of typhoon disaster prediction, prevention and mitigation in China:

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a) The lessons learned from hurricane Katrina and typhoon Saomai show that disaster prevention criteria for coastal areas, offshore structures, and estuarine cities, predicted by traditional unit-variant extrapolation from annual maxima data sampling, cannot satisfy the increasing tendency of typhoon impacts on China.
b) About half of the existing sea walls in China do not meet the design criteria. Several dams and reservoirs are dangerously vulnerable to typhoon-induced floods. There are no satisfactory design and disaster prevention criteria that include typhoon-induced secondary disasters, such as floods, mud-rock flows, and landslides.
c) More than 37 nuclear power plants along the south-east coastal areas of the China Sea are in the stages of planning, design, or construction. For these plants, the principle requirement of nuclear safety regulation'' (HAF0100) proposes the use of a probable maximum storm surge (PMSS) induced by a probable maximum tropical cyclone (PMTC) coupled with wind wave setup and a spring tide. However, although this is recommended, in actual practice, the probability of joint occurrence of typhoon- induced storm surge, wave setup, and spring tide are not taken into account.

Taking into account the historical data on typhoon disasters and the current state of prediction, prevention, and mitigation of typhoon disasters in China, with the global warming and sea level rising, the frequency and intensity of typhoons and typhoon induced disasters would increase. All the coastal, offshore and hydraulic infrastructures accepted the traditional safety regulations are menaced by possibility of future typhoon disasters. In view of the existing extreme statistical theory can not satisfy typhoon disaster prediction, in this chapter introduced our research activities during the past 30 years: our proposed Multivariate Compound Extreme Value Distribution (MCEVD), Multi-Objective Four Layers Nested Probability Model (MOFLNPM) and their applications in coastal, offshore, hydraulic engineering, landslides and debris flows disasters prediction , prevention and mitigation.

2. Theory of Multivariate Compound Extreme Value Distribution (MCEVD)

In 1972, Typhoon Rita attacked Dalian port in the North Bohai Bay of China, causing severe damage in this port. The authors found that, using traditional extrapolation (such as a Pearson type III model), it was difficult to determine the design return period for the extreme wave height induced by a typhoon. According to the randomness of annual typhoon occurrence frequency along different sea areas, it can be considered as a discrete random variable. Typhoon characteristics or typhoon-induced extreme sea events are continuous random variables. The Compound Extreme Value Distribution (CEVD) can then be derived by compounding a discrete distribution and the extreme distribution for typhoon-induced extreme events along China's coasts [18]. Then the CEVD is used to analyze long-term characteristics of hurricanes along the Gulf of Mexico and the Atlantic US coasts [19]. During the past few years, CEVD has been developed into MCEVD and applied to predict and prevent typhoon-induced disasters for coastal areas, offshore structures, and estuarine

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cities [20, 23, 24, 35]. Both CEVD and MCEVD have the following advantages: instead of traditional annual maximum data sampling, the typhoon process maximum data sampling is used and the typhoon frequency is used in the models. In view of the ‘‘summary of flood frequency analysis in the United States” concluded that “the combination of the event-based and joint probability approaches promises to yield significantly improved descriptions of the probability laws of extraordinary floods’’ [50]. MCEVD is the model that follows the development direction of the extraordinary floods prediction, as desired by Kirby and Moss. It stands to reason that MCEVD is a good model for typhoon (or hurricane) disaster prediction.

During the past years, CEVD and MCEVD have been applied to more than 40 coastal, offshore, and hydraulic projects in China and abroad. The theory of CEVD is also referenced by some foreign experts [49, 50, 51, 52, 53, 67]. Our proposed methods in [18, 19, 25, 26] are used as design criteria of wind-structure interaction experimentation for mitigating hurricane-induced U. S. coastal disasters [15].

The derivation of the MCEVD is as follows:

Let N be a random variable (representing the number of storms in a given year), with their corresponding probability

$$P\{N = k\} = p_k, \quad k = 1, 2, \cdots;$$

and

$$(\xi_{11}, \ldots, \xi_{n1}), (\xi_{12}, \ldots, \xi_{n2}) \ldots\ldots$$

be an independent sequence of independent identically distributed random vectors (representing the observed extreme sea environments in the sense defined above within the successive storms) with common density $g(\cdot)$. Then we are interested in the distribution of

$$(X_1, \ldots, X_n) = (\xi_{1i}, \ldots, \xi_{ni})$$

where ξ_{1i} is the maximum value of

$$\xi_{1j}, 1 \le j \le N, N = 1, 2, \ldots\ldots$$

This represents the maximum annual value of the principal variable, together with the simultaneously occurring values of the concomitant variables. There is a reasonable approximation in definition of $(X_1, \ldots, X_n)$, no concerning of N=0, because no extreme value of interest can occur outside the storm in case of N=0. The more detailed discussion of the model correction in case of $p(N = 0)$ can be found in reference [18].

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Table 1. Deadliest Tropical Cyclones in History

Rank	Name / Areas of Largest Loss	Year	Ocean Area	Deaths
1.	Great Bhola Cyclone, Bangladesh	1970	Bay of Bengal	500,000
2.	Hooghly River Cyclone, India and Bangladesh	1737	Bay of Bengal	300,000
3.	Haiphong Typhoon, Vietnam	1881	West Pacific	300,000
3.	Coringa, India	1839	Bay of Bengal	300,000
5.	Backerganj Cyclone, Bangladesh	1584	Bay of Bengal	200,000
6.	Great Backerganj Cyclone, Bangladesh	1876	Bay of Bengal	200,000
7.	Chittagong, Bangladesh	1897	Bay of Bengal	175,000
8.	Super Typhoon Nina, China	1975	West Pacific	171,000
9.	Cyclone 02B, Bangladesh	1991	Bay of Bengal	140,000
9.	Cyclone Nargis, Myanmar	2008	Bay of Bengal	140,000
11.	Great Bombay Cyclone, India	1882	Arabian Sea	100,000
12.	Hakata Bay Typhoon, Japan	1281	West Pacific	65,000
13.	Calcutta, India	1864	Bay of Bengal	60,000
14.	Swatlow, China	1922	West Pacific	60,000
15.	Barisal, Bangladesh	1822	Bay of Bengal	50,000
15.	Sunderbans coast, Bangladesh	1699	Bay of Bengal	50,000
15.	India	1833	Bay of Bengal	50,000
15.	India	1854	Bay of Bengal	50,000
19.	Bengal Cyclone, Calcutta, India	1942	Bay of Bengal	40,000
19.	Bangladesh	1912	Bay of Bengal	40,000
19.	Bangladesh	1919	Bay of Bengal	40,000
22.	Canton, China	1862	West Pacific	37,000
23.	Backerganj (Barisal), Bangladesh	1767	Bay of Bengal	30,000
24.	Barisal, Bangladesh	1831	Bay of Bengal	22,000
25.	Great Hurricane, Lesser Antilles Islands	1780	Atlantic	22,000
26.	Devi Taluk, SE India	1977	Bay of Bengal	20,000
26.	Great Coringa Cyclone, India	1789	Bay of Bengal	20,000
28.	Bangladesh	1965 (11 May)	Bay of Bengal	19,279
29.	Nagasaki Typhoon, Japan	1828	Western Pacific	15,000
30.	Bangladesh	1965 (31 May)	Bay of Bengal	12,000

* Death counts from large killer cyclones are highly uncertain, particular for those before 1900. The above rankings are somewhat speculative. Information sources: Banglapedia, Wikipedia.

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Table 2. Details of the 2006 typhoon disaster

Typhoon name	Maximum wind (m/s)	Affected provinces	Affected agriculture area (1,000 ha)	Affected population (million)	Death and lost population	Economic loss (RMB) (billion)
Chanchu	45	Guangdong, Fujian, Zhejiang	368.96	11.06	35	8.56
Bilis	30	Fujian, Guangdong, Hunan, Guangxi, Zhejiang, Jiangxi	1170.38	29.85	849	32.99
Kaemi	40	Fujian, Guangdong, Hunan, Guangxi, Zhejiang, Jiangxi, Anhui, Hubei	397.56	8.42	64	5.89
Prapiroon	35	Guangdong, Guangx, Hainan	569.43	11.11	75	8.23
Saomai	75.8	Fujiang, Zhejiang, Jiangxi, Hubei	223.16	5.99	570	19.49

When multivariate continuous cumulative distribution is $G(x_1,\ldots,x_n)$, then we can derive the MCEVD as:

$$F(x_1,\ldots,x_n)=\sum_{i=1}^{\infty}p_i\cdot i\cdot\int_{-\infty}^{x_n}\cdots\int_{-\infty}^{x_1}G_1^{\,i-1}(u)g(u_1,\ldots,u_n)\,du_1\ldots du_n \qquad (1)$$

where $G_1(u_1)$ is the marginal distribution of $G(x_1,\ldots,x_n)$ $g(u_1,\ldots u_n)$ is density function.

This can be proved as follows:

$$\begin{aligned}
F(x,y,z)&=P(X<x,Y<y,Z<z)\\
&=P(\bigcup_{i=0}^{\infty}\{X<x,Y<y,Z<z\}\bigcap\{n=i\})\\
&=\sum_{i=0}^{\infty}P(X<x,Y<y,Z<z\,|\,n=i)\cdot P(n=i)\\
&=\sum_{i=0}^{\infty}p_iP(X<x,Y<y,Z<z\,|\,n=i)\\
&=p_0\cdot Q(x,y,z)+\sum_{i=1}^{\infty}p_i\cdot P(X<x,Y<y,Z<z\,|\,n=i)
\end{aligned}$$

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in which

$$P(X<x,Y<y,Z<z\,|\,n=i)$$
$$=P(\bigcup_{k=1}^{i}\{X<x,Y<y,Z<z\}\bigcap\{\underset{1\le j\le i}{Max}\,\xi_j=\xi_k\}\,|\,n=i)$$

$$=\sum_{k=1}^{i}P(\{X<x,Y<y,Z<z\}\bigcap\{\underset{1\le j\le i}{Max}\,\xi_j=\xi_k\}\,|\,n=i)$$

Let $\xi_k=\xi_1$,

then

$$P(X<x,Y<y,Z<z\,|\,n=i)$$
$$=iP(\{X<x,Y<y,Z<z\}\bigcap\{\underset{1\le j\le i}{Max}\,\xi_j=\xi_k\}\,|\,n=i)$$
$$=i\cdot P(\xi_1<x,\eta_1<y,\varsigma_1<z,\xi_1>\xi_j,\ j=2,3,\cdots i\,|\,n=i)$$
$$=iE\left\{I_{\{\xi_1<x\}}(\omega)I_{\{\eta_1<y\}}(\omega)I_{\{\varsigma_1<z\}}(\omega)I_{\{\xi_1>\xi_j,\ j=2,3,\cdots i\}}(\omega)\middle|n=i\right\}$$

$$=iE\left\{\begin{array}{l}E\left\{I_{\{\xi_1<x\}}(\omega)I_{\{\eta_1<y\}}(\omega)I_{\{\varsigma_1<z\}}(\omega)I_{\{\xi_1>\xi_j,\ j=2,3,\cdots i\}}(\omega)\right\}\\ |\left(\xi_1=U,\eta_1=V,\varsigma_1=W\right)\end{array}\right\}$$

where (U,V,W) and $(\xi_1,\eta_1,\varsigma_1)$ are statistically independent, their probability distribution function is $G(x,y,z)$.

$$P(X<x,Y<y,Z<z\,|\,n=i)$$
$$=iE\left\{\begin{array}{l}I_{\{U<x\}}(\omega)I_{\{V<y\}}(\omega)I_{\{W<z\}}(\omega)E\left\{I_{\{U>\xi_j,\ j=2,3,\cdots i\}}(\omega)\right\}\\ |\left(\xi_1=U,\eta_1=V,\varsigma_1=W\right)\end{array}\right\}$$

$$=iE\left\{I_{\{U<x\}}(\omega)I_{\{V<y\}}(\omega)I_{\{W<z\}}(\omega)G_1^{\,i-1}(u)\right\}$$
$$=i\cdot\int_{-\infty}^{z}\int_{-\infty}^{y}\int_{-\infty}^{x}G_1^{\,i-1}(u)\cdot dG(u,v,w)$$
$$=i\cdot\int_{-\infty}^{z}\int_{-\infty}^{y}\int_{-\infty}^{x}G_x^{\,i-1}(u)g(u,v,w)\,dudvdw$$

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where

$$I_A = \begin{cases} 1, x \in A \\ 0, x \notin A \end{cases}$$

is the characteristic function of A

$$F(x,y,z) = p_0 Q(x,y,z) + \sum_{i=1}^{\infty} p_i \cdot i \cdot \int_{-\infty}^{z}\int_{-\infty}^{y}\int_{-\infty}^{x} G_1^{\,i-1}(u) g(u,v,w)\, dudvdw$$

$$= p_0 Q(x,y,z) + \sum_{i=1}^{\infty} p_i \cdot i \cdot \int_{-\infty}^{z}\int_{-\infty}^{y}\int_{-\infty}^{x} G_1^{\,i-1}(u) g(u,v,w)\, dudvdw + p_0 - p_0 \tag{2}$$

When the case of n=0 is ignored, Equation (2) can be approximated as formula (3)

$$F(x,y,z) = p_0 + \sum_{i=1}^{\infty} p_i \cdot i \cdot \int_{-\infty}^{z}\int_{-\infty}^{y}\int_{-\infty}^{x} G_1^{\,i-1}(u) g(u,v,w)\, dudvdw \tag{3}$$

Therefore, formula (1) is proved.

3. Poisson-Gumbel Compound Extreme Value Distribution (P-G CEVD) and Its Applications

When $G(x_1,\ldots,x_n)$ is probability distribution function of unit-variant random variable x, then formula (1) can be simplified to

$$F(x) = \sum_{i=0}^{\infty} p_i [G(x)]^i \tag{4}$$

When typhoon occurrence frequency can be fitted to Poisson distribution, typhoon induced wave or wind fitted to Gumbel distribution, as formula (5)

$$G(x) = e^{-e^{-x}} = \exp\{-\exp[-\alpha(x-\mu)]\} \tag{5}$$

where α and μ as parameters of Gumbel distribution.

Then Poisson-Gumbel Compound Extreme Value Distribution (P-G CEVD) can be derived as [18]:

$$F(x,y) = \sum_{i=0}^{\infty} p_i [G(x)]^i = \sum_{i=0}^{\infty} e^{-\lambda} \cdot \frac{\lambda^i}{i!} [G(x)]^i = e^{-\lambda[1-G(x)]} = 1 - P \tag{6}$$

Typhoon induced extreme wave (wind speed) with return period T (1/p) can be calculated by formula (7):

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$$H_P = \mu + X_P / \alpha \tag{7}$$

where

$$X_P = -\ln\{-\ln(1 + \frac{\ln(1-P)}{\lambda})\}$$

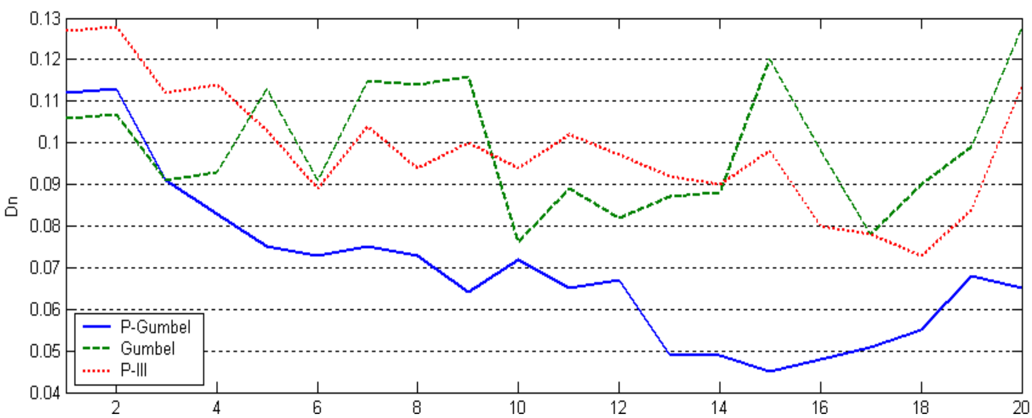
$$\lambda = \frac{n}{N}$$

is the yearly mean value of typhoon frequency

N is total number of year,
n is total typhoon number

$$\left.\begin{array}{l} \alpha = \sigma_n / S \\ \mu = \overline{H} - y_n / \alpha \end{array}\right\}$$

$\overline{H}, S$: mean value and standard deviation of typhoon induced wave, σ_n, y_n can be calculated by typhoon number.



20 yrs moving average data sampling from 50 yrs observed wave data

Figure 1. Comparison of calculated Dn between three models.

Comparison between P-G CEVD, Gumbel and PⅢ-Distributions

1953–2006 observed typhoon induced wave data in East China sea are used to statistical check for Gumbel P-Ⅲ and P-G CEVD. The Kolmogorov-Smilrnov test based on the 20 years moving average data sampling used for calculation maximum deviation between empirical and theoretical distributions as formula (8):

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$$D_n = \sup_{-\infty<x<\infty} \left| F_n(x) - F_0(x) \right| \tag{8}$$

where $F_n(x)$ ix empirical distribution, $F_0(x)$ is theoretical distribution,

Standard deviation as

$$d = \sqrt{\frac{\sum_{i=1}^{n}(pl - pj)^2}{n-1}} \tag{9}$$

where; pl and pj are theoretical and empirical value.

The estimated Dn and d for Gumbel, P-Ⅲ and P-G CEVD models are shown in Figure 1 and Figure 2.

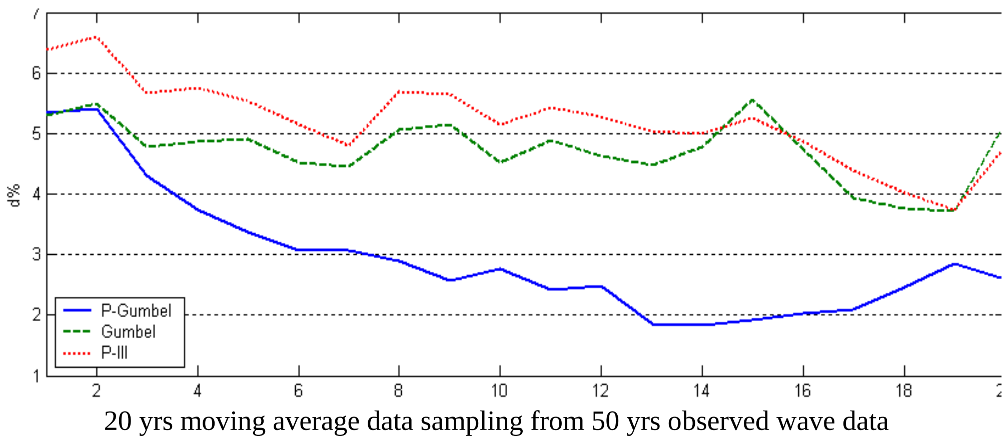

Figure 2. Comparison of calculated d between three models.

Figure 1, 2 and Table 3 show that P-G CEVD is a more reasonable model for extreme wave prediction than traditional models.

The P-G CEVD used to design wave prediction for more than 40 coastal structures of China and accepted in 2008 “China Code for Sea Port Hydrology “ as a recommended model for design wave prediction.

Table 3. Relative differences of predicted return value Δh between three models

Model	100 a	50 a	20 a
	Δh	Δh	Δh
Gumbel	26%	25%	23%
P III	26%	25%	22%
P-Gumbel	18%	17%	16%

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4. Poisson - Weibull Compound Extreme Value Distribution (P-W CEVD) and Its Application along U. S. Coasts

Long term hurricane data show that frequencies of hurricane occurrence along the U.S. Atlantic East coast and Gulf of Mexico coast agree with the Poisson distribution (Figure 3), and the hurricane central pressure, wind velocities, wave heights and storm surges agree with the Weibull distribution, a Poisson- Weibull Compound Extreme Value Distribution (P-W CEVD) is presented to predict hurricane central pressure, wind velocities, wave heights and surges [19].

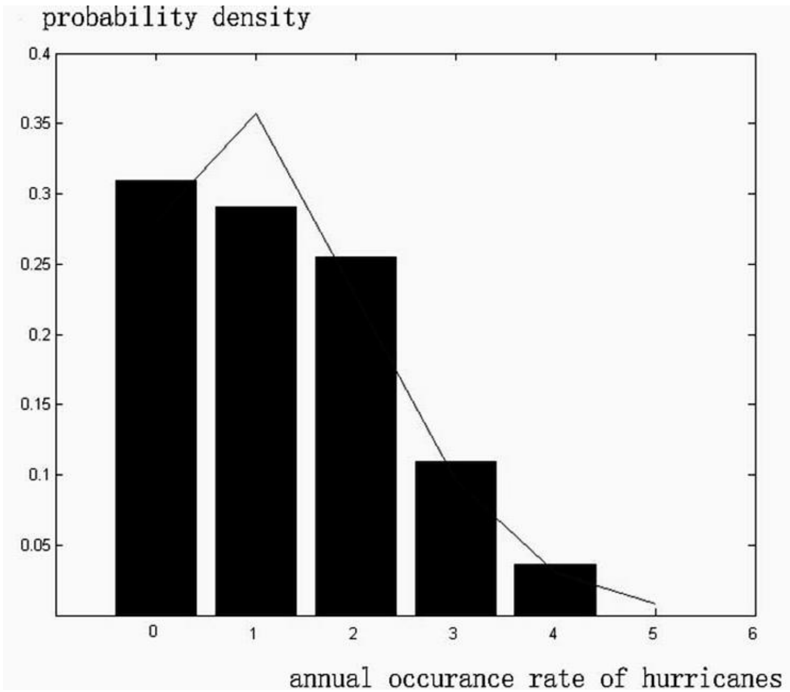

Figure 3. Curve fitting of hurricane frequency.

Weibull distribution as formula (10):

$$G(x) = 1 - \exp\left\{ -\left(\frac{x}{b}\right)^{r} \right\} \tag{10}$$

P-W CEVD can be derived as:

$$X_p = \left(-\ln\left\{ -\frac{1}{\lambda}\ln(1-p) \right\} \right)^{\frac{1}{r}} - b \tag{11}$$

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where b, r are parameters of Weibull distribution

$$\lambda = \frac{n}{N}$$

is the yearly mean value of hurricane frequency.

In 1979, American National Oceanic and Atmospheric Administration (NOAA) divided Gulf of Mexico and Atlantic coasts into 7 areas according to hurricane intensity, in which corresponding Standard Project Hurricane (SPH) and Probable Maximum Hurricane (PMH) were proposed as hurricane disaster prevention criteria [55]. Using P-W Compound Extreme Value Distribution [2], the predicted hurricane central pressures with return period of 50yr and 1000yr were close to SPH and PMH, respectively, except that for the sea area nearby New Orleans (Zone A) and East Florida (Zone1) coasts, hurricane intensities predicted using CEVD were obviously severer than NOAA proposed values. SPH and PMH are only corresponding to CEVD predicted 30~40yr and 120yr return values, respectively. In 2005, hurricane Katrina and Rita attacked coastal area of the USA, which caused deaths of about 1400 people and economical loss of $400 billion in the city of New Orleans and destroyed more than 110 platforms in the Gulf of Mexico. The disaster certified that using SPH as flood-protective standard was a main reason of the catastrophic results [9, 12, 13, 19]. Figure 4, and Table 4 indicate that P-W CEVD predicted results are more reasonable than NOAA proposed safety regulations.

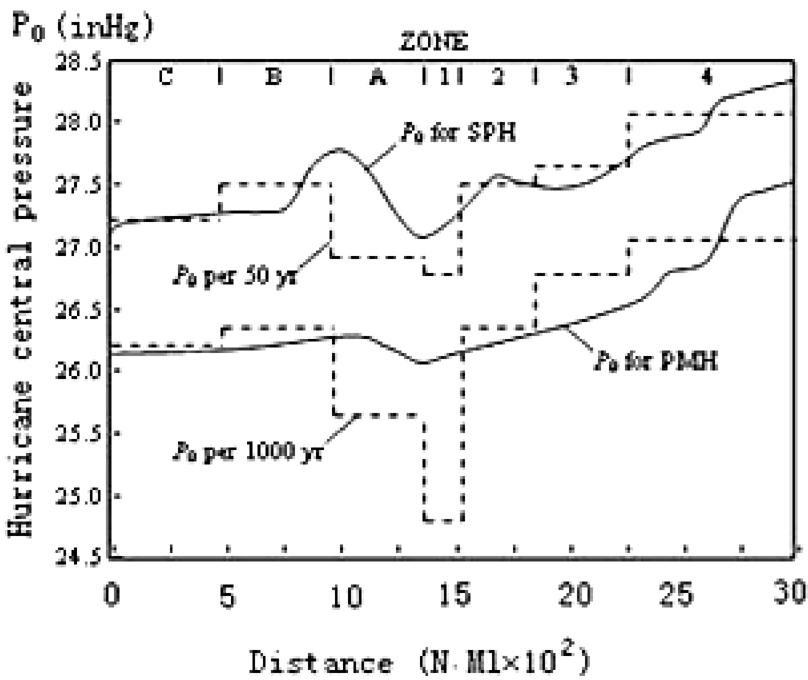

Figure 4. Comparison between the results of PWCED and NOAA (see [19], Figure (6).

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Table 4. Comparison between NOAA and CEVD predicted central pressure

Zone	NOAA In/hpa		CEVD In/hpa		Hurricane
A	SPH	27.8/941.0	50-yr	26.9/910.8	Katrina
	PMH	26.3/890.5	1000-yr	25.6/866.8	26.6/902.0
1	SPH	27.1/919.3	50-yr	26.7/904.0	Rita
	PMH	26.1/885.4	1000-yr	24.6/832.9	26.4/894.9

5. Poisson-nested Logistic Tri-variety Compound Extreme Value Distribution (PNLTCEVD) and Its Application in Hurricane Katrina Disaster

5.1. Poisson-nested Logistic Tri-variety Compound Extreme Distribution

As mentioned above, frequency of hurricane occurrence can be fitted to Poisson distribution (Figure 3), as

$$P_i = \frac{e^{-\lambda}\lambda^i}{i!}$$

And substitute nested–logistic tri-variety distribution [56] for the continuous distribution into formula (3), the PNLTCED can be obtained

Nested–logistic tri-variety distribution is expressed as

$$G(x_1,x_2,x_3)=\exp\left[-\left\{\left[\left(1+\xi_1\frac{x_1-\mu_1}{\sigma_1}\right)^{-1/(\alpha\beta\xi_1)}+\left(1+\xi_2\frac{x_2-\mu_1}{\sigma_2}\right)^{-1/(\alpha\beta\xi_2)}\right]^{\beta}+\left(1+\xi_3\frac{x_3-\mu_3}{\sigma_3}\right)^{-1/(\alpha\xi_3)}\right\}^{\alpha}\right] \tag{12}$$

in which ξ_j, μ_j, σ_j are the shape, location and scale parameters of the marginal distributions $G(x_j)$ to x_j (j=1,2,3) , respectively. And dependent parameters α, β can be obtained by moment estimation

$$\hat{\alpha} = \frac{\sqrt{1-r_{13}}+\sqrt{1-r_{23}}}{2}$$

$$\hat{\beta} = \frac{\sqrt{1-r_{12}}}{\hat{\alpha}}$$

where $r_{i,j}$ is correlation coefficient, i<j, i, j=1, 2, 3.

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Let

$$s_j = \left(1 + \xi_j \frac{x_j - \mu_j}{\sigma_j}\right)^{-1/\xi_j} \quad \text{j=1,2,3}$$

then formula (12) can be written as

$$G(x_1, x_2, x_3) = \exp\left\{-\left[(s_1^{1/(\alpha\beta)} + s_2^{1/(\alpha\beta)})^{\beta} + s_3^{1/\alpha}\right]^{\alpha}\right\} \tag{13}$$

and the corresponding probability density function is

$$\begin{aligned} g(x_1, x_2, x_3) &= \frac{\partial^3 G}{\partial x_1 \partial x_2 \partial x_3} \\ &= \frac{1}{\sigma_1 \sigma_2 \sigma_3} e^{-u} u^{1-2/\alpha} v^{1/\alpha - 2/\alpha\beta} s_1^{1/(\alpha\beta)-\xi_1} s_2^{1/(\alpha\beta)-\xi_2} s_3^{1/\alpha-\xi_3} Q \end{aligned} \tag{14}$$

in which

$$v = (s_1^{1/(\alpha\beta)} + s_2^{1/(\alpha\beta)})^{\alpha\beta}$$

$$u = \left[(s_1^{1/(\alpha\beta)} + s_2^{1/(\alpha\beta)})^{\beta} + s_3^{1/\alpha}\right] = (v^{1/\alpha} + s_3^{1/\alpha})^{\alpha}$$

$$Q = \left(\frac{v}{u}\right)^{1/\alpha} Q_3(u;\alpha) + \frac{1-\beta}{\alpha\beta} Q_2(u;\alpha)$$

$$Q_2(u;\alpha) = u + \frac{1}{\alpha} - 1$$

$$Q_3(u;\alpha) = u^2 + 3\left(\frac{1}{\alpha} - 1\right)u + \left(\frac{1}{\alpha} - 1\right)\left(\frac{2}{\alpha} - 1\right)$$

Tri-variant layer structure （α- outside, β - inside layer） shows that the correlation between x_1 and x_2 is stronger than those among x_1, x_3 and x_2, x_3.

As shown above, PNLTCED can be obtained through the estimation of parameters of the marginal distributions and their dependent parameters.

The new model has some advantages:

1) Considering the hurricane occurring frequency and combination of trivariate environmental factors induced by hurricane.
2) Considering the dissymmetry of two dependent parameters.
3) It has the simple structure, and easy to be applied in engineering applications.

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5.2. Solution of MCEVD by Stochastic Simulation Method-P-ISP

The multivariate joint probability distribution usually has a very complex mathematical form, solution of high dimensional MCEVD leads to the need of stochastic simulation method.

Based on some characteristics and hypotheses of the realistic data, simulation method is the approach of representing some procedures with the computer, for example, Monte-Carlo method. However, inevitably great computational efforts are needed to make and the large variances exist when the analyzed joint probabilities are small by use of Monte-Carlo method. Hence, different sampling methods have been developed to reduce the number of simulations and to decrease variance, among which the Importance Sampling Procedure (ISP) is an efficient method [36, 37].

The basic idea of ISP method consists of concentrating the distribution of the sampling points in the region of great importance, i.e. the part, which mainly contributes to the joint probability instead of spreading them out evenly in the whole range of definition of the involved parameters. Particularly, the multi-normal distribution centering on the design point is defined as the important sampling distribution. ISP thus requires an optimization procedure to find the design point. The joint probability can then be evaluated by weighted sampling procedure. A most significant advantage of ISP method is that it can also be used in the original space, regardless of the type of the basic random variables. The transformation of the basic variables into a vector of independent standard normal variables, which may be difficult for correlated variables, is avoid. The weighted sampling is not affected by any non-Gaussian distribution because the actual joint probability is calculated by use of original distribution.

For formula (1), we can generate N groups of $x_1, x_2, \cdots, x_n$, and record the number of groups that lead to limit state function≤0, if this number is M, the evaluation of formula (1) can be estimated by:

$$\widehat{F}(x_1, x_2, \ldots x_n) = \lim_{N \to \infty} \frac{M}{N} \tag{15}$$

Let x denote a n-dimensional random vector, its corresponding joint probability density function is $f_X(\mathbf{x})$ formula (1) can be rewritten as:

$$F(\mathbf{x}) = \iint\limits_{g(\mathbf{x}) \le 0} \cdots \int I[g(\mathbf{x}) \le 0] \frac{f_X(\mathbf{x})}{h_X(\mathbf{x})} h_X(\mathbf{x}) d\mathbf{x} \tag{16}$$

in which, x is the n- dimensional random vector, x=$x_1, x_2, \cdots, x_n$; $g(\mathbf{x}) \le 0$ is the joint probability domain decided by limit state function $g(\mathbf{x}) = 0$; $I[g(\mathbf{x}) \le 0] = \begin{cases} 1, g(\mathbf{x}) \le 0 \\ 0, g(\mathbf{x}) > 0 \end{cases}$ is the characteristic function; $h_X(\mathbf{x})$ is usually called weighting density function, from which the samples are generated in the simulation procedure.

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Then the expected value of joint probability is expressed as:

$$\hat{F}(\mathbf{x}) = \frac{1}{N}\sum_{i=1}^{N} I[g(\mathbf{x}) \le 0]\frac{f_X(\mathbf{x}_i)}{h_X(\mathbf{x}_i)} \tag{17}$$

in which, N denotes the simulation times and $\mathbf{x}_i$ is the i-th simulation vector.

As shown above, the main advantage of ISP is in that, samples are generated according to density function $h_X(\mathbf{x})$ rather the original density function $f_X(\mathbf{x})$. The efficiency of ISP is obviously higher than basic Monte-Carlo simulation.

The variance of $\hat{F}(\mathbf{x})$ is derived as follows:

$$Var(\hat{F}(\mathbf{x})) = \frac{1}{N}\left[E\left(I[g(\mathbf{x}) \le 0]\cdot\frac{f_X(\mathbf{x})}{h_X(\mathbf{x})}\right)^2 - F(\mathbf{x})^2\right] \tag{18}$$

It can be seen that if the forms of $h_X(\mathbf{x})$ and $f_X(\mathbf{x})$ are similar, the variance will be low.

The sampling procedure of MCEVD can be carried out as follows:

a. For a given λ, random number K which satisfies Poisson distribution is initially generated;
b. If K>0, K groups of $x_1, x_2, \ldots x_n$ are then generated according to multivariate joint normal density function $h_X(\mathbf{x})$. The design point $\mathbf{x}^*$ which derived by using second-moment method can be taken as sampling center;
c. From K groups of $x_1, x_2, \ldots x_n$, select $(x_1, x_2, \ldots x_n)\Big|x_1 = \underset{1\le i\le K}{Max}x_{1i}$ as the annual maximum value of the meteo-oceanic factors induced by typhoon;
d. Repeat step a to c for N times, the N year samples satisfying MCEVD are generated.

It should be noticed that, $x_1, x_2, \ldots x_n$ are correlated variables with different kinds of non-Gaussian or Gaussian distributions. This method can be used to predict long-term joint probability of typhoon characteristics and other multivariate typhoon induced environments with different kinds of marginal distributions and different correlation coefficients between variables.

These features affect disaster intensity and consequence directly. So the analysis of typhoon characteristic combinations and the corresponding disaster consequences in different areas should be the important part of typhoon disaster zoning. The typhoon characteristics are usually described by using maximum central pressure difference (ΔP), radius of maximum wind speed (Rmax), moving speed of typhoon center (s), minimum distance between typhoon center and target site (δ) and typhoon moving angle (θ). But one of the chief advantages lies in taking the annual typhoon frequency (λ) into account as a discrete random variable in the MCEVD model. What's more, considering the secondary typhoon disaster, for instance typhoon Nina 1975 in China induced the dam collapse of Banqiao reservoir that led to the tragic loss of life in numbers and Typhoon Bilis2006 made terrible loss of life in the land provinces. So that in this study the typhoon duration from landfall to dissipation (t) is also

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considered in the prediction model. For the analysis procedure of multivariate joint probability which combined by a kind of discrete distribution (λ) and six kinds of continuous distributions(ΔP, Rmax, s, δ, θ, t), stochastic simulation technique based on theory of MCEVD is a valid way to solve such a six-dimensional non-Gaussian problem.

It should be noticed that, the solution of the multi-dimensional joint probability problem is a contour surface with some probability value. In the application process, aiming at different objectives, for instance, (⊿P) reflects typhoon intensity, (Rmax) reflects area influenced by typhoon, (s) reflects intensity of typhoon induced surges and waves, (t) reflects inland areas affected intensity and should be selected as the dominated factor respectively to calculate the unique solution of joint probability for different disaster consequences. This procedure is taken as the first layer of the double-layer nested multi-objective probability model, which is offered as the basis for typhoon disaster zoning.

Table 5. Marginal distribution and parameters of typhoon characteristics

	Distributions	Mean	Standard variance	Parameters
λ	Poisson	λ =6.19		
ΔP hPa)	Gumbel	21.89	14.96	a=0.073, b=14.45
Rmax (km)	Lognormal	45.79	25.22	μ=3.71, σ =0.5
s (m/s)	Gumbel	30.19	15.95	a=0.07, b=22.4
δ (km)	Uniform	44.37	169.63	a=294.6, b=333.8
θ (°)	Normal	15	37.36	μ=15, σ =37.36
t (h)	Gumbel	12.95	5.56	a=0.20, b=10.29

In the simulation procedure P-ISP, it is needed to input mean value of typhoon frequency (λ), marginal distribution of the six kinds of typhoon characteristics (P-ISP is suitable for Normal, Uniform, Exponential, Rayleigh, Gumbel, Weibull, Log-normal, Gamma and Frechet distribution), mean value and standard deviation of each variable group, matrix correlation coefficients among the variables and the limit state equation, then the joint probability of different typhoon characteristics with some typhoon occurrence frequency can be calculated as the output (Table 5). Comparing with basic Monte Carlo Method, P-ISP performs more quickly and accurately, so it has been successfully applied to the joint probability analysis of typhoon induced extreme sea environmental loads such as wind, wave, storm surge, current, et al., for different kinds of offshore structures; risk assessment of coastal and hydraulic structures of Olympic Sailing Games and design floods [37, 40, 41, 42, 43, 44].

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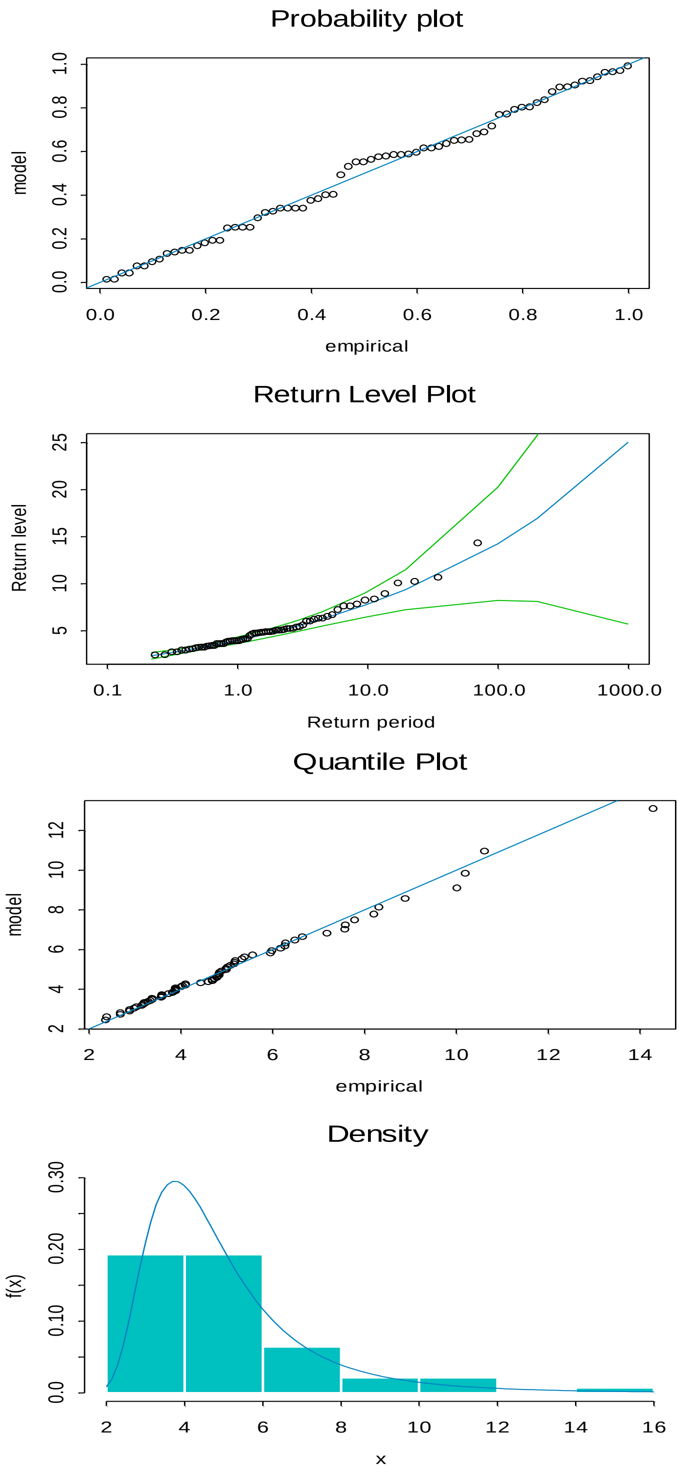

Figure 5.a. Distribution diagnostic testing of water level.

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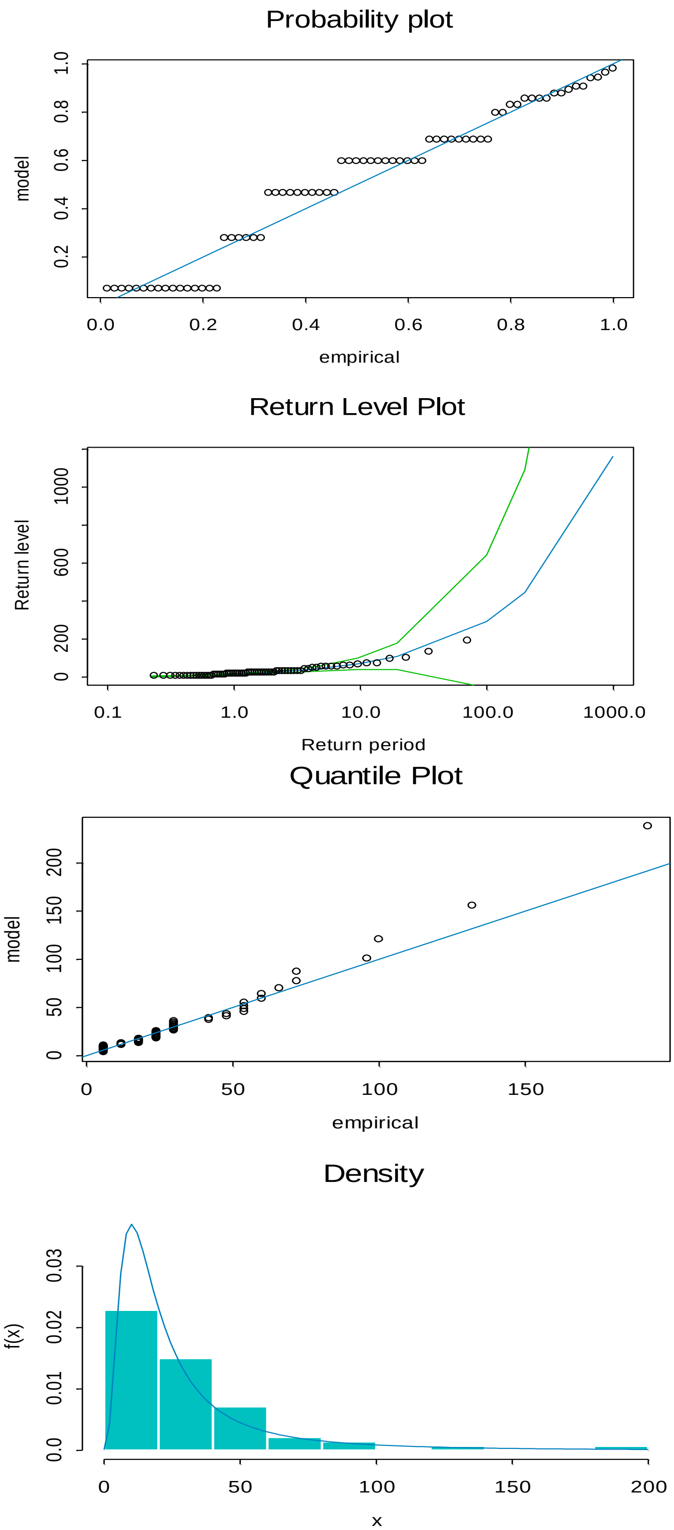

Figure 5.b. Distribution diagnostic testing of hurricane duration.

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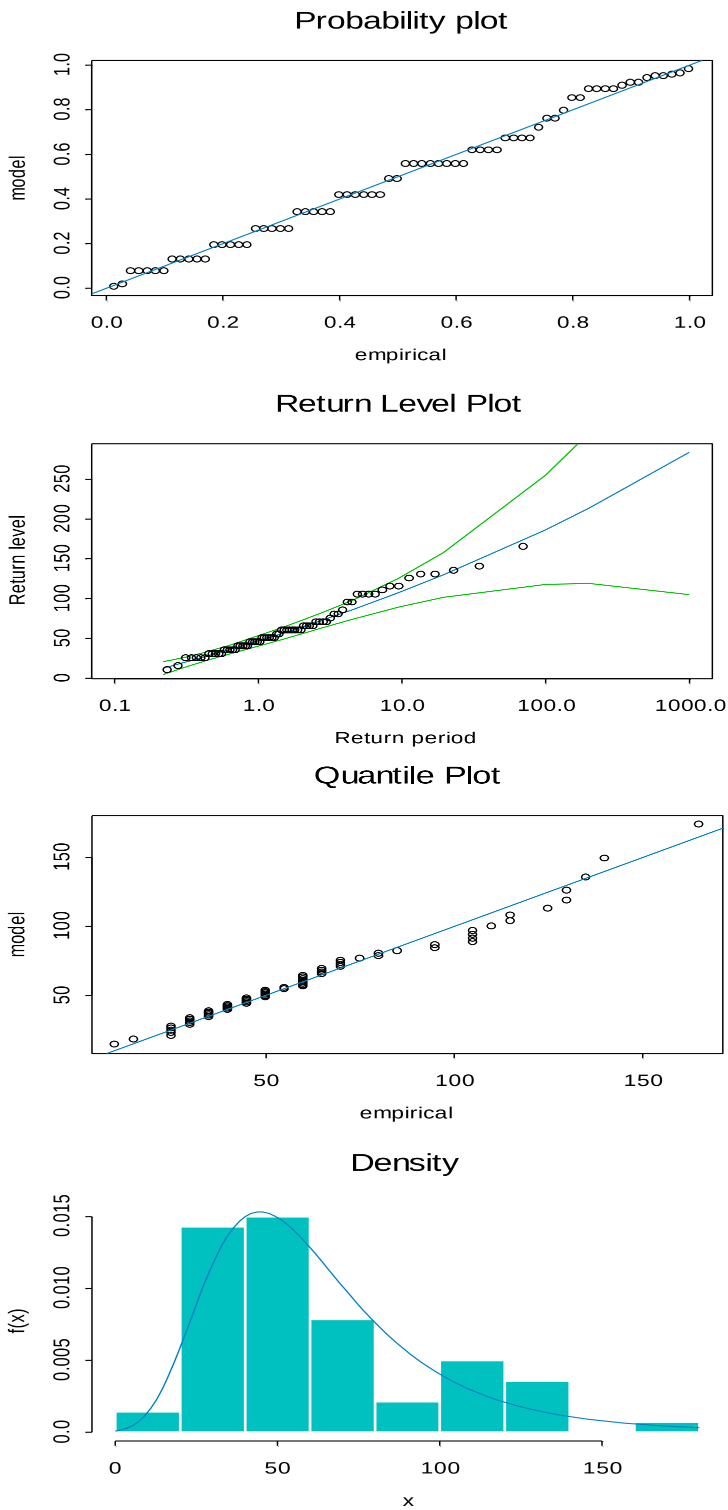

Figure 5.c. Distribution diagnostic testing of wind speed.

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5.3. The Application of PNLTCED to Hurricane Katrina Disaster of New Orleans

In this section the 55 year (1950~2004) measured data of hurricane winds, hurricane effect duration (provided by NOAA and Unisys Company) and the simultaneous Mississippi water level (provided by USACE) are used for the long term joint probability prediction of Hurricane Katrina. (The value of wind speed, water level and wind duration are taken as variable series x_1, x_2, x_3, respectively. The correlation coefficient among them are r_{12}, r_{23}, r_{13}) It should be noticed, to the extend that even sites which are as much as 500 nautical miles apart have a high probability of having high wind speeds from the same meteorological event [14, 16, 17], so we select the 70 tropical storm passed through Gulf region 3 with the range of 500 miles as data series. And for the data limit, in this paper we directly use water level data of Mississippi river to reflect the effect from storm surge and upper river flood. It can be seen in Figure 3 that the frequency of hurricane in this area fits to Poisson distribution very well. The diagnostic checks shows that all the data of the wind speed, water level, and hurricane duration well fit to the generalized extreme value distribution (see Figure 5.a, b, c). The parameters of marginal distributions are shown in Table 6.

Table 6. Parameters of marginal distribution

Parameter of marginal distribution	Peak wind speed	Water level	Hurricane duration
Location parameter μ	46.77	4.00	14.65
Scale parameter σ	24.12	1.27	11.59
Shape parameter ξ	0.096	0.22	0.59

Table 6 shows there is more strong correlation between wind speed and water level than others, so the wind speed (Ws)and water level (Wl) should be taken as inside layer variables.

Using PNLTCED one contour surface about Ws, Wd and Wl for each joint return period can be obtained. (See Figure 6) So there should be different combinations that can be resulted with same joint return period.

We proposed two cases of data sampling method for unique solution from multiple combinations of typhoon induced environments with a joint return period [36, 39, 44]:

a. Data sampling of dominated extreme wind speed with other concomitant environments to estimate the joint return values for coastal structure designing
b. Data sampling of dominated extreme water level with other concomitant environments to estimate the joint return values as the disaster prevention design criteria for the coastal and estuarine cities.

For New Orleans the hurricane induced flood is the fatal factor that lead to the seriously damage, so the results from data sampling of dominated extreme water level seems more reasonable. The calculated results comparing with the corresponding results using other methods are listed in Figure 7.

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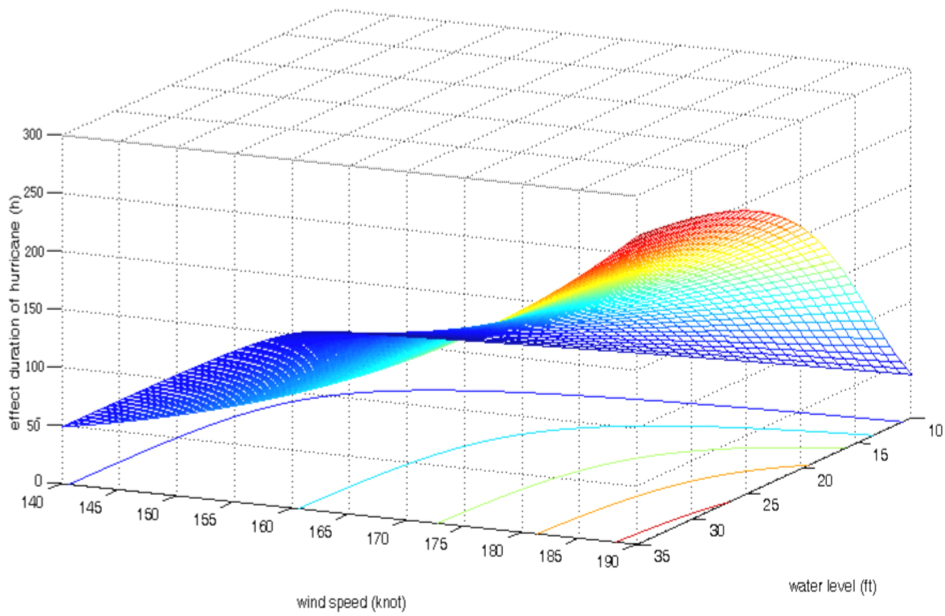

Figure 6. Contour surface with return period of 2000 years.

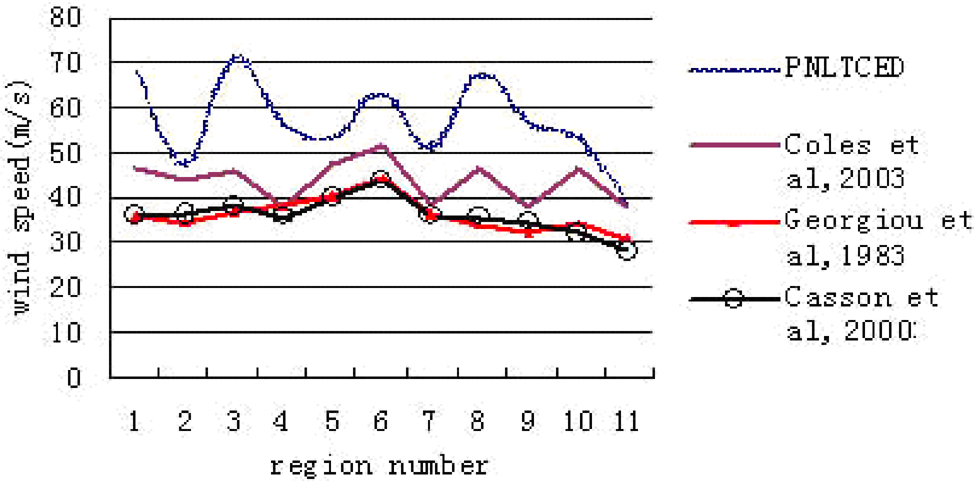

Figure 7. Comparison of 100yr—hurricane wind speed using different methods (see [26] Figure 2).

Table 7. Linear correlation coefficient and dependent parameter

Wl vs. Wd $r_{2,3}$	Ws vs. Wd $r_{1,3}$	Ws vs. Wl $r_{1,2}$	α	β
0.006	0.204	0.3	0.94	0.886

Sometimes later than Figure 3 showed NOAA proposed 7 regions , Gulf of Mexico and Atlantic coasts were divided into 11 regions according to the regional planning of hurricane. It can be seen in the Figure 6 that in Region 2,4,7,11,our results are close to those of other researchers, but our predicted hurricane intensity in Region1,3,6,8,10 are more greater,

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especially significant in New Orleans area and Florida. It is because of that the PNLTCED model is sensitive to the hurricane frequency. What's more, according our results, in New Orleans, the combination with 50yr return period is 125.5knot (64.2m/s) wind (Ws) associated 11.5ft (3.35m) water level (Wl) and the hurricane influence duration (Wd) is 96h. Its intensity is close to that of Katrina. But SPH is just about 40yr return period hurricane. So it is obviously not safe enough as prevention criteria in New Orleans (See Table 8).

Table 8. The calculated results with different joint return period of New Orleans

	1000yr	100yr	50yr	10yr
Ws (m/s)	89.4	70.6	64.2	44.1
Wl (m)	7.6	4.11	3.35	2.04
Wd (h)	149	107	96	60

5.4. The Application of PNLTCED to Disaster Prevention Design Water Level of Yangtzi River Estuarine City Shanghai

Shanghai City locates at the estuarine area of the Yangtze River in China. Historical observed data shows that the surges induced by typhoon and the flood peak run-of from Yangtze River coupled with the astronomical spring tide had caused the significant losses of lives and properties to Shanghai City. Combined effect of storm surge, upper river flood and spring tide on the coastal structures is one of the most important prime factors for the disaster prevention [27].

Based on the traditional unit-variant frequency analysis model, for the 1000 year return period, the disaster prevention design water lever for Shanghai City is 5.86 (m). But No.4 typhoon in 1981 had caused the water level as high as 5.74 (m). Obviously, the unit-variant extrapolation design water level neglects of the contribution of the random combination of typhoon frequency, storm surge, flood and astronomical spring tide. PNLTCED can be used to predict design water level more accurately.

Daton Hydrological Station locates at the upper river of Yangtze River, 642 km from Wuson Oceanologic Station near Shanghai City. The observed water levels of flood at Daton station are out of influence by typhoon surge from sea side. Data of water level collected at the Wuson Station from 1970 to 1990, and the data of flood at the Daton Station are used in this study.

The observed water level at Wuson station during typhoon season (hw) can be divided into three components

1) The hourly harmonic analyzed tide (ha) obtained from 63 harmonic constants model during 1970~1990. Because there are different uncertainties included in harmonic analysis (such as uncertainty induced by the choice of different numbers of harmonic constants, uncertainty in different duration of observations, uncertainty in analyzed harmonic constants from different period of observations and et. al), so that for following multivariate joint probability study the astronomical spring tide would be considered as random variables.

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2) The flood peak run-off from Yangtze River (h_f) can be obtained by linear regression equation $h_f = 7.67\times10^{-6} Q_D - 0.19^*$, where Q_D is observed flood peak volume (m^3/s) at station Daton in 24 hours before the typhoon occurring Shanghai sea area.
3) The typhoon induced storm surge (h_s) can be obtained by $h_s = h_w - h_f - h_a$.

It can be seen from mentioned above discussion that the typhoon occurring frequency varying from year to year is fitting to Poisson distribution , the typhoon induced storm surge, simultaneous rise of water level by flood run-off from Yangtze river and astronomical Spring tide are continuous variables. So that the PNLTCED can be used to predict disaster design water level for Shanghai city.

A total 72 groups of simultaneous h_f, h_s and h_a are used to study tri-variant joint probability.

Diagnostic check shows that h_a, h_f and h_s fit to generalized extreme value distribution (See Figure 8.a, 8.b, 8.c).

Table 9 and Table 10 show the parameters of marginal distribution and the correlation between h_a and h_f is comparatively stronger than others, therefore, h_a and h_f can be treated as inside layer variables, while h_s as outside layer variable.

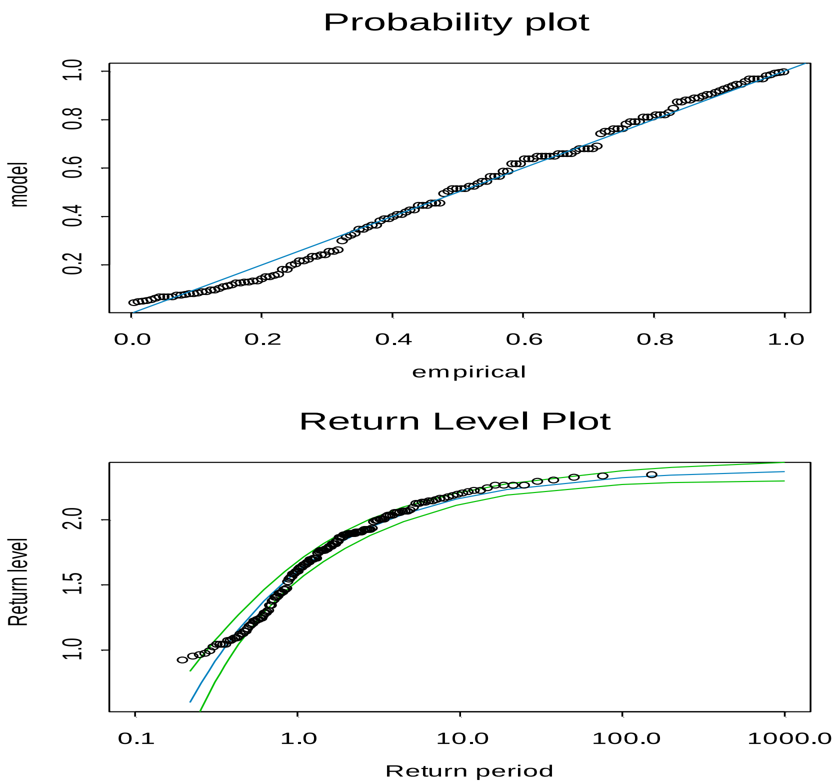

Figure 8.a. (Continued).

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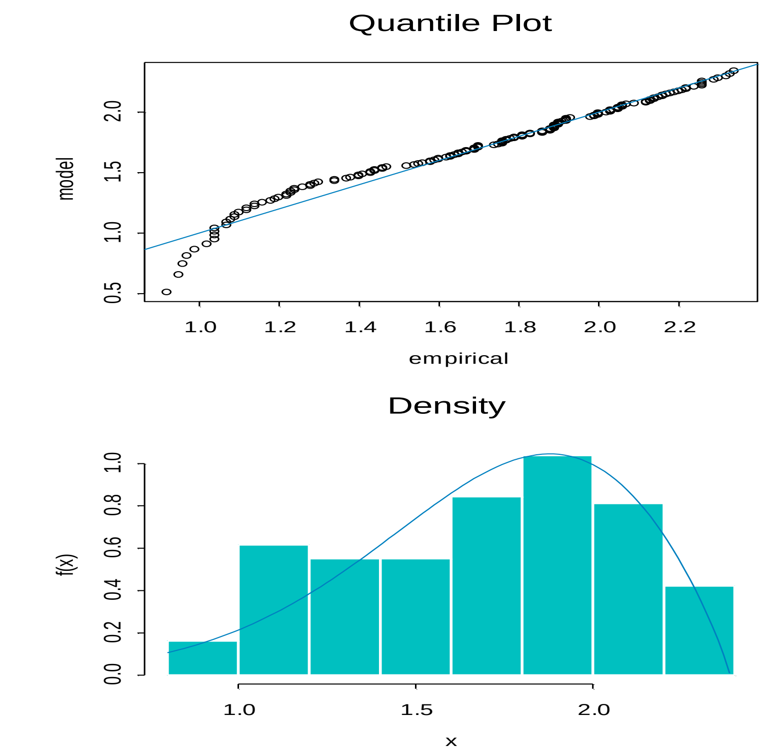

Figure 8.a. Diagnostic check of spring tide.

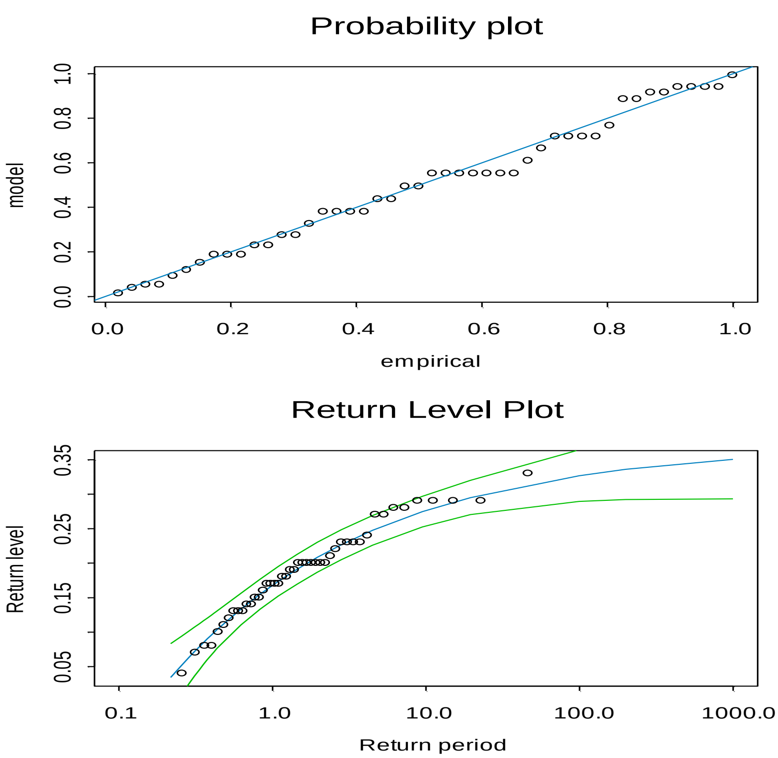

Figure 8.b. (Continued)

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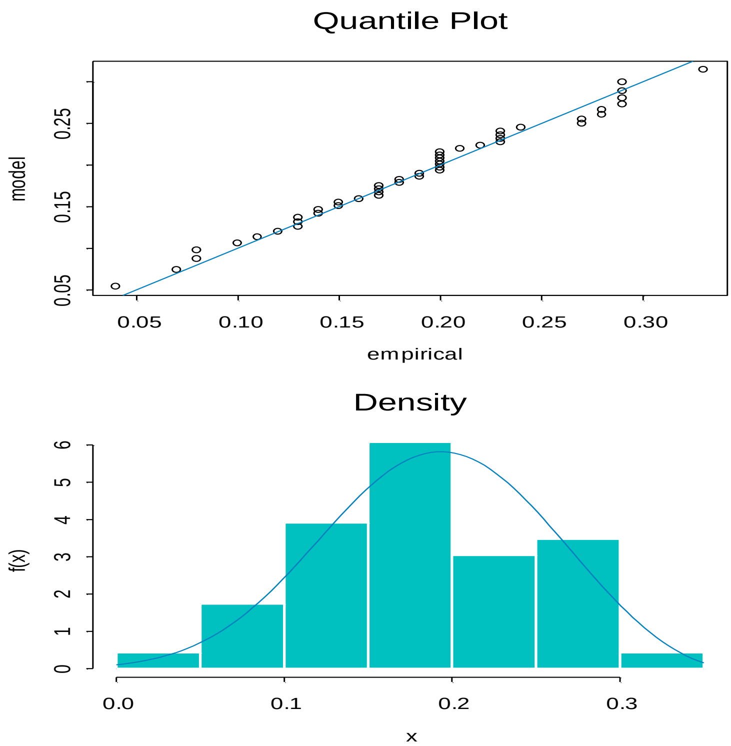

Figure 8.b. Diagnostic check of flood.

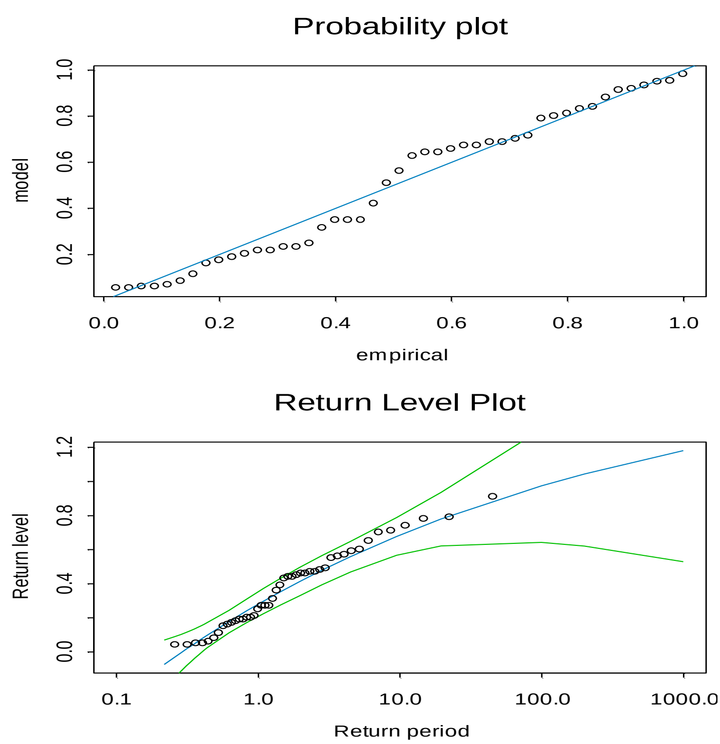

Figure 8.c. (Continued).

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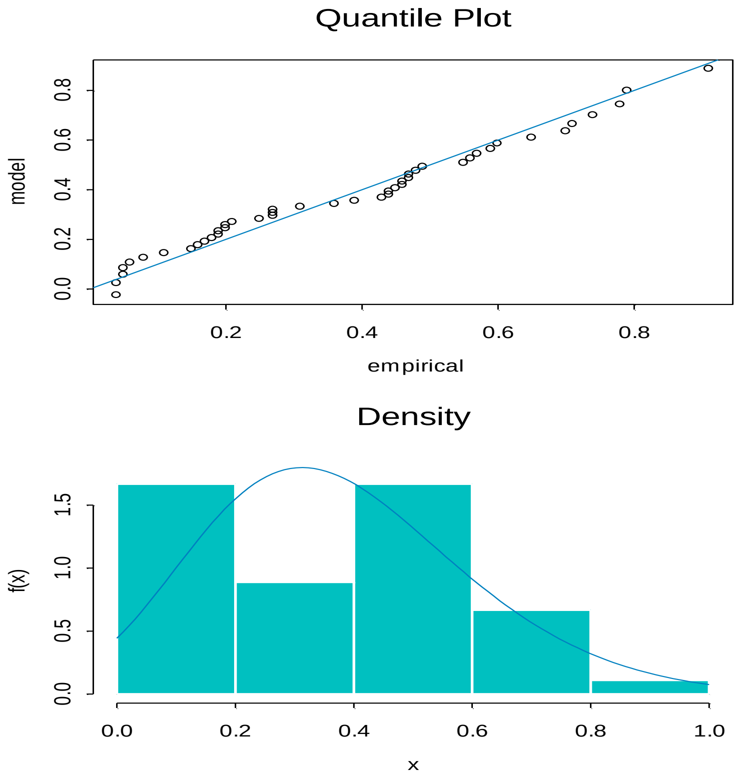

Figure 8.c. Diagnostic check of storm surge.

Table 9. Parameters of marginal distribution

Parameter of marginal distribution	h_a (m)	h_f (m)	h_s (m)
Location parameter μ	1.98	0.17	0.45
Standard deviation of μ	0.02	0.01	0.02
Scale parameter σ	0.14	0.02	0.07
Standard deviation of σ	0.02	0.01	0.02
Shape parameter ξ	-0.18	0.42	0.81
Standard deviation of ξ	0.15	0.17	0.28

Table 10. Correlation coefficients and dependent parameters

h_a vs h_f $r_{1,2}$	h_a vs h_s $r_{1,3}$	h_f vs h_s $r_{2,3}$	$\hat{\alpha}$	$\hat{\beta}$
0.29	0.075	0.10	0.95	0.84

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In this example, the design water level with one hundred years joint return period is obtained by using the data sampling dominated by the extreme storm surge with concomitant flood and tide.

Table 11 shows that the 100-yr joint return period design water level predicted by PNLTCED close to that of 1000-yr return period water level by the traditional unit-variant extrapolation method for Shanghai:

The effect of the typhoon occurrence distribution has been taken into account in the PNLTCED model, which shows the significant role of the predicted results. The new model is easy to use for prediction of typhoon or other weather process induced meteorological and hydrological disaster environmental events, and can give more reasonable results.

Table 11. Estimated disaster prevention design water level for Shanghai city

Joint return period (years)	Flood (m)	Storm surge (m)	Spring-tide (m)	Design water level (m)
100	0.43	1.32	4.14*	5.89*

* at Wuson datum plane.

6. Discussion on IAEA and China Safety Regulation for NPP Coastal Defense Infrastructures against Typhoon/Hurricane Attacks

6.1. Discussion on Design Basic Flood (DBF)

In China, three NPP have been built along coasts in 1980, and more than 37 NPP along coast of South-East China Sea are in the stages of planning, design, or construction. In the “2007 China Long Term NPP Plan” estimated that before 2020 about 70 billion USD（450 billion RMB) will be invested in 6 coastal provinces.

China has a wide continental slope to decay tsunami energy. If M9 earthquake occurs at Manila trench or Rykyu trench, the wave produced by tsunami wave at south and southeast china coast would be no more than 5-6m [64]. In. 2006 typhoon Saomai induced 3.76m surges and 7m waves, causing 240 deaths, sinking 952 ships and damaging 1594 others in Shacheng harbor. If the typhoon Saomai had landed 2 hours later, then the simultaneous occurrence of the typhoon surge and high spring tide with 7m wave would have inundated most areas of the Zhejiang and Fujian provinces, where located several NPP. The results would be comparable with 2011 Japanese nuclear disaster.

With the global warming and sea level rising, the frequency and intensity of extreme external natural hazards would increase. All the coastal areas having NPP are menaced by possibility of future typhoon disasters. So calibration of typhoon disaster prevention criteria is necessary for existed and planning NPP. In China Nuclear Safety Regulations: "HAF101, HAD101/09~11" [60, 61, 62] and IAEA Engineering Safety Section: "Extreme External Events in the Design or Assessment of NPP" [4, 5, 6, 7] there are appeared some vague definitions and they should be dissected and described with probability characteristics by using statistical analysis.

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For coastal sites, IAEA, U. S. NRC and China safety regulations recommended evaluation of DBF, which should be the combination of following three parts: Probable maximum storm surge (PMSS) induced by Probable Maximum Typhoon (PMT), spring tide and simultaneous extreme wave height. Probable wind-wave effects considered independently or in combination. IAEA recommends that deterministic and probabilistic methods for evaluating the design basis flood should be considered complementary. The estimated flood hazard should be compared to historical data to verify that the specified design basis exceeds the historical extreme by a substantial margin. For example, the characteristics of PMT and Probabilistic models for estimating design basis floods are generally based on approaches that characterize the extreme flood as a random event, describe the properties of this random phenomenon using probability distributions, and use these probability distributions to estimate extreme floods corresponding to a specified exceeded probability.

The two key components of the probabilistic models are (1) the historical flood data and (2) the probability distribution used to describe the historical flood data. Typically, the historical record of annual maximum instantaneous peak discharge at the site of interest,. Because the random variable of interest—the peak discharge—is represented as a continuous variable, a continuous probability distribution is appropriate. The design-basis flood at the site can be selected from the frequency distribution of extreme floods.

A suitable combination of flood causing events depends on the specific characteristics of the site and involves considerable engineering judgment. The following is an example of a set of combinations of events that cause floods for use in determining the design conditions for flood defense in a coastal areas: the astronomical tide, storm surge and simultaneous wave. The design basis flood associated with an established exceeded probability (e. g. 1×10^{-4}) for the combination of events should be determined.

The spring tide, maximum wave height and PMSS can be seen as non-Gaussian random variables with different correlation. The PMT and PMSS must involve the joint probability characters, and then DBF can be actually obtained by multivariate joint probability prediction. For example, the characteristics of PMT and PMSS in different sea area is related to annual occurring frequency of typhoon (λ) with six parameters.. It means that different PMT and PMSS can be derived from different combinations of typhoon characteristics. For this reason, the characteristics of PMT and PMSS inevitably involve a selection of discrete distribution (λ) and multivariate continuous distribution of other typhoon characteristic factors (ΔP, Rmax, s, δ, θ, t), which can be described by Multivariate Compound Extreme Value Distribution (MCEVD) [23]. The calculation of PMT and PMSS by a numerical simulation method can remove the uncertainties of typhoon characteristics and may be led to different results, while the PMSS obtained on basis of them may has some arbitrary and cause wrong decision making. The lesson from 2005 hurricane Katrina showed that unreasonable calculation of the Probable Maximum Hurricane (PMH) and Standard Project Hurricane (SPH) is one of the most important reasons of New Orleans catastrophe.

According to IAEA and China safety regulations, PMSS should be obtained based on PMT. So aiming at PMT with different combinations of typhoon characteristics, some sensitive factors should be selected as control factors and substituted into procedure of Global Uncertainty Analysis (GUA) and Global Sensitivity Analysis (GSA) [57]. The PMSS corresponding to PMT of different sea areas can be derived by repeated forward-feedback calculations.

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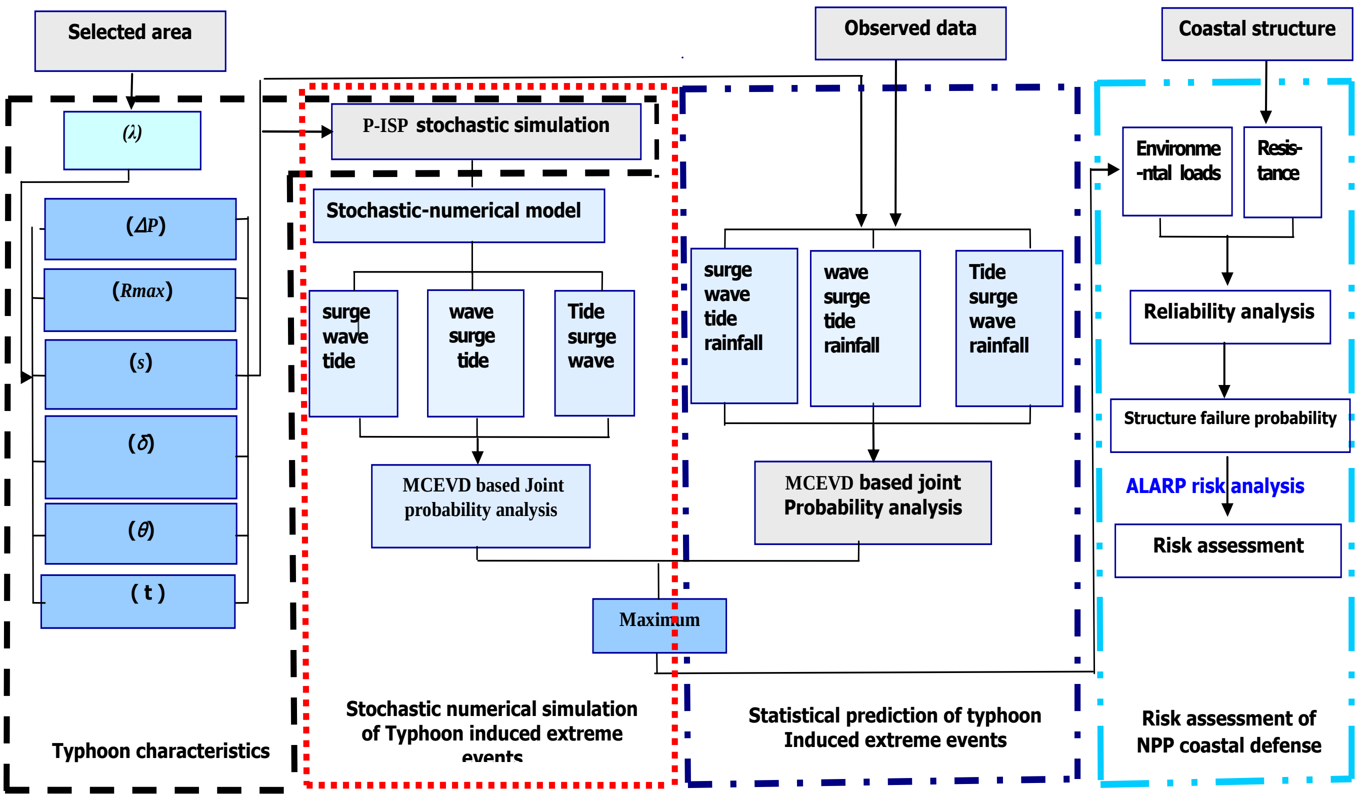

Figure 9. Application of MOFLNPM with GUA, GSA to safety regulation calibration for NPP coastal defense infrastructures.

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Based on MCEVD (analytical solution and stochastic simulation), Multi- Objective Four Layers Nested Probability Model (MOFLNPM) can be established for long term probability prediction of typhoon characteristics and corresponding disaster factors.

As shown in Figure 9, GUA and GSA are introduced into MOFLNPM. In the model, typhoon characteristics in the first layer need to be varied repeatedly, and then their sensitivities to storm surge can be calculated. The PMSS corresponding to PMT of different typhoon characteristic combinations in certain sea area can be calculated by numerical simulation of repeated forward-feedback calculations of GUA, GSA in input-output procedure. The most sensitivity combination of typhoon characteristics and their induced storm surge can be selected as PMT and PMSS. PMSS with corresponding spring tide and 100 years return period wave height with joint return period calculated by MCEVD will be determined the probabilistic definition of DBF.

Based on the numerical model of tidal wave the uncertainty - sensitivity analysis and long-term variation are taken into consideration for spring tide study.

The statistical analysis shows that harmonic constituent and sea level vary from year to year. The maximum values, minimum values and some other values of amplitudes and mean sea level are chosen as the boundary conditions of numerical model. The calculated results show that the sea level caused by semi-diurnal tide of major lunar tidal constituent M2 and major solar tidal constituent S2 (see Table 12) [21].

Table 12. Calculated maximum sea level from different inputs

Input			output
A_n (cm)	A (M_2) (cm)	A (S_2) (cm)	Maximum sea level (cm)
1*	2*	3*	
4.08	127.54	41.60	156.12
2.08	123.47	41.53	151.11
-14.92	127.05	40.14	139.62
4.08	126.41	41.39	155.32
20.8	125.22	41.25	152.45
14.92	124.69	41.39	146.41
2.08	124.44	41.22	151.64

Note 1*: Annual mean sea level; 2*: Amplitude of constituent M2; 3*: Amplitude of constituent S2.

Calculated mean value μ, variance σ and coefficient of variation Cov of the harmonic constituents and sea level are shown as follows:

For harmonic constituents:

$\mu=166.65$
$\sigma=0.88$
$Cov1=\sigma/\mu=0.0053$

For mean sea level:

$\mu=4.80$
$\sigma=3.96$
$Cov2=\sigma/\mu=0.8256$

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The resulting uncertainty for spring tide can be obtained as:

Cov = [(cov1)2+(cov2)2]1/2=0.825

The harmonic analyzed sea levels of 20 years data showed that spring tide has significant variations as examples of 1986 and 1993 year calculated sea levels (Figure 10.a and Figure 10.b).

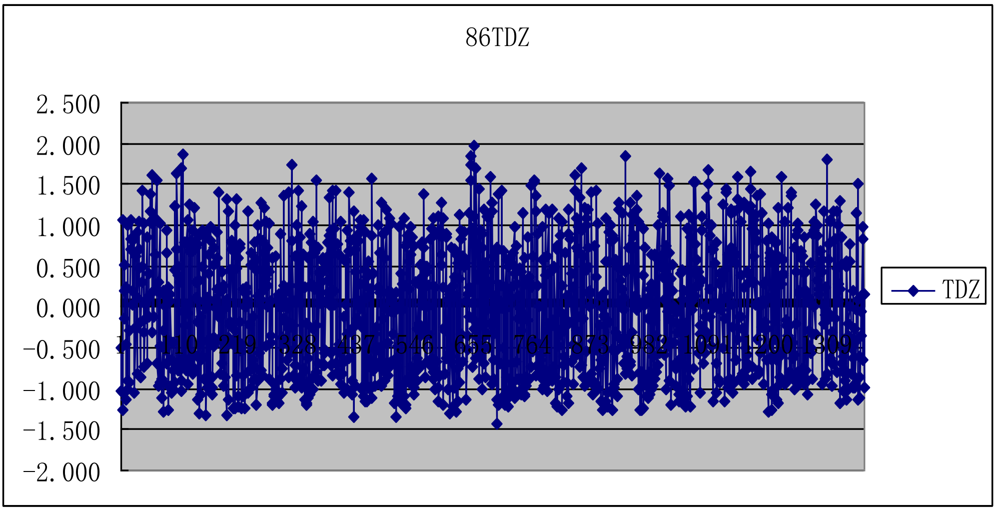

Figure 10.a. Harmonic analyzed sea levels in 1986.

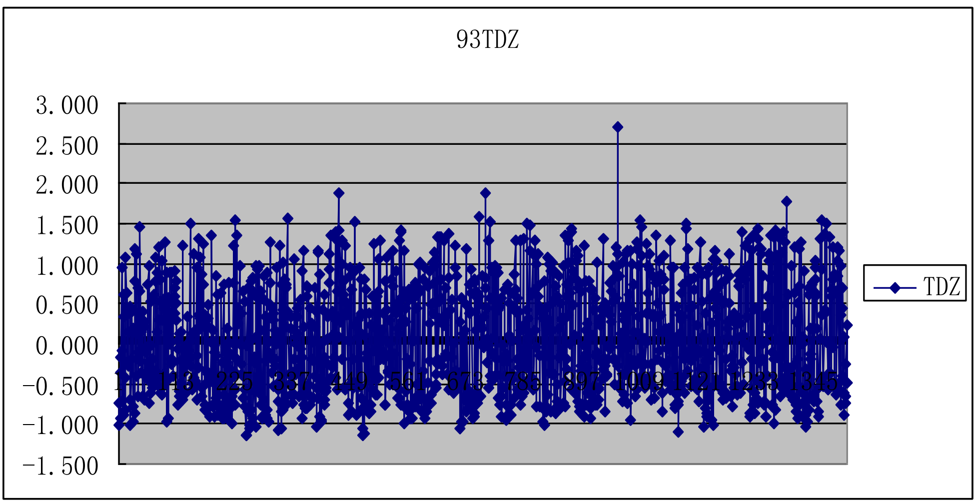

Figure 10.b. Harmonic analyzed sea levels in 1993.

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6.2. Uncertainty Analysis of Extreme Wave Prediction

There are three kinds of uncertainties influenced on extreme wave prediction:

6.2.1. Methodology-model Uncertainty

There are four different methods for predicting extreme wave heights based on a complete set of wave data for a period of time and location:

- Method Maxima: the maximum values from a consecutive period of equal length, such as annual maxima, monthly maxima, weekly maxima or daily maxima wave height.
- Peaks over Threshold Method (POT method): all wave heights above predetermined wave heights.
- Initial distribution method: all three hourly measured or hind-cast wave data.
- Process Maximum method: typhoon/tropical cyclone process induced maxima wave heights.

6.2.2. Data Sampling Uncertainty

It is clear that both measured and hind-cast wave data are associated with uncertainties.

Uncertainties associated with hind-cast wave data can be considered by comparing measured wave peaks with hind-cast wave peaks while measured wave data can be supported to be close to the true values. So long term series of wave heights can be obtained as random combinations of hind-cast wave heights and series of differences between measured and hind-cast wave data by stochastic simulation techniques.

Table 13. Uncertainty analysis of extreme wave prediction in South China Sea [22]

Uncertainty type	South China Sea
2.2.1	Cov1=0.08
2.2.2	Cov2=0.09
2.2.3	Cov3=0.10
Total uncertainty	Cov = 0.156

6.2.3. Statistical Uncertainty

Since the data sample consists of limited numbers of realizations, this phase is also associated with uncertainties.

The total uncertainty of extreme wave prediction in South China Sea can be obtained as

$$Cov = [(cov1)^2+(cov2)^2+(cov3)^2]^{1/2}$$

6.2.4. Uncertainty Analysis of PMT, PMSS and DBF

The spring tide, 100 years return period wave height and PMSS can be seen as non-Gaussian random variables with different correlation. The PMT and PMSS must involve the joint probability characters, and then DBF can be actually obtained by multivariate joint probability prediction. For example, the characteristics of PMT and PMSS in different sea

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area is related to annual occurring frequency of typhoon (λ), maximum central pressure difference (ΔP), radius of maximum wind speed (Rmax), moving speed of typhoon center (s), minimum distance between typhoon center and target site (δ), typhoon moving angle (θ) and typhoon duration (t). It means that different PMT and PMSS can be derived from different combinations of typhoon characteristics. For this reason, the characteristics of PMT and PMSS inevitably involve a selection of discrete distribution (λ) and multivariate continuous distribution of other typhoon characteristic factors (ΔP, Rmax, s, δ, θ, t), which can be described by Multivariate Compound Extreme Value Distribution (MCEVD). The calculation of PMT and PMSS by a numerical simulation method can remove the uncertainties of typhoon characteristics and may be led to different results, while the PMSS obtained on basis of them may has some arbitrary and cause wrong decision making. The lesson from 2005 hurricane Katrina showed that unreasonable calculation of the Probable Maximum Hurricane (PMH) and Standard Project Hurricane (SPH) is one of the most important reason of New Orleans catastrophe.

According to China safety regulations [60, 61], PMSS should be obtained based on PMT. So aiming at PMT with different combinations of typhoon characteristics, some sensitive factors should be selected as control factors and substituted into procedure of Global Uncertainty Analysis (GUA) and Global Sensitivity Analysis (GSA) [57]. PMSS corresponding to PMT of different sea areas can be derived by repeated forward-feedback calculations (Figure 9).

6.3. Joint Probability Safety Assessment for DYW-NPP Defense Infrastructure in South China Sea Coast

Nuclear power plant DYW is located at coast of South China Sea, where the combined extreme external events are dominated by waves. The coastal defense infrastructure design criteria is listed in Table 14.

Table 14. Present design criteria for coastal defense of DYW nuclear power plant

Design water level	Design value (m)
DBF	6.35
PMSS	5.30
Extreme Wave Height	6.6
Design low water level	-1.93

Table 15. Combined extreme external events with joint return period for DYW NPP by PNLTCED

Extreme Event Joint Probability	Spring Tide (m)	Surge (m)	Wave (m)
100	2.14	2.79	6.6
500	2.19	3.49	7.3
1000	2.75	3.85	7.9
10000	3.15	4.50	9.7

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For discussion on joint return period of wave height with storm surge and corresponding spring tide, the PNLTCED can be used for analytical solution. Different combinations of typhoon characteristics in first layer of PNLTCED can be induced different combinations of storm surge and waves. The diagnostic checks of spring tide, surge and wave in Figures 11.a, 11.b and 11.c show that PNLTCED is applicable model.

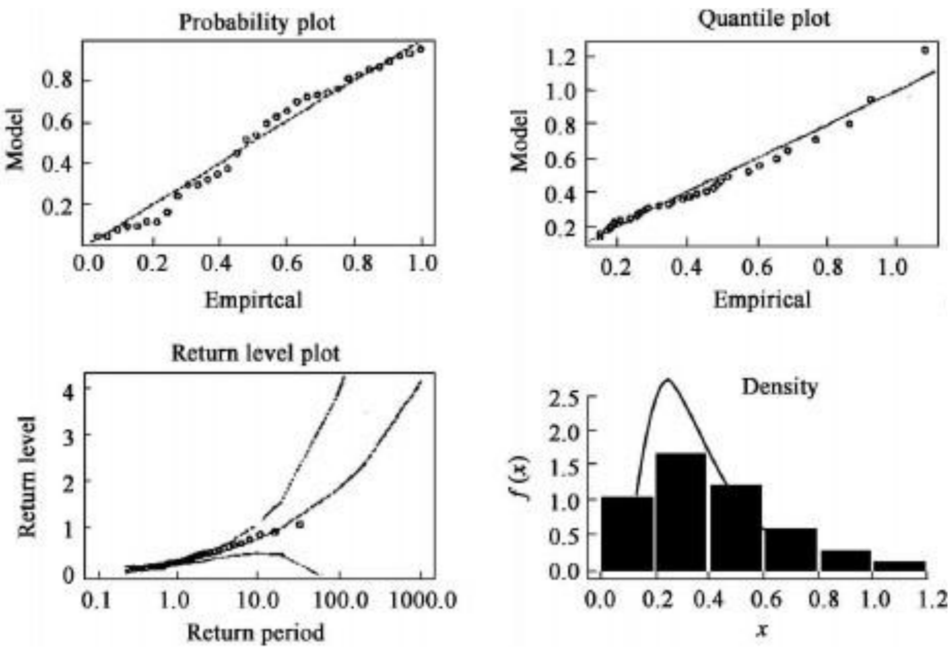

Figure 11.a. Distribution diagnostic testing of storm surge.

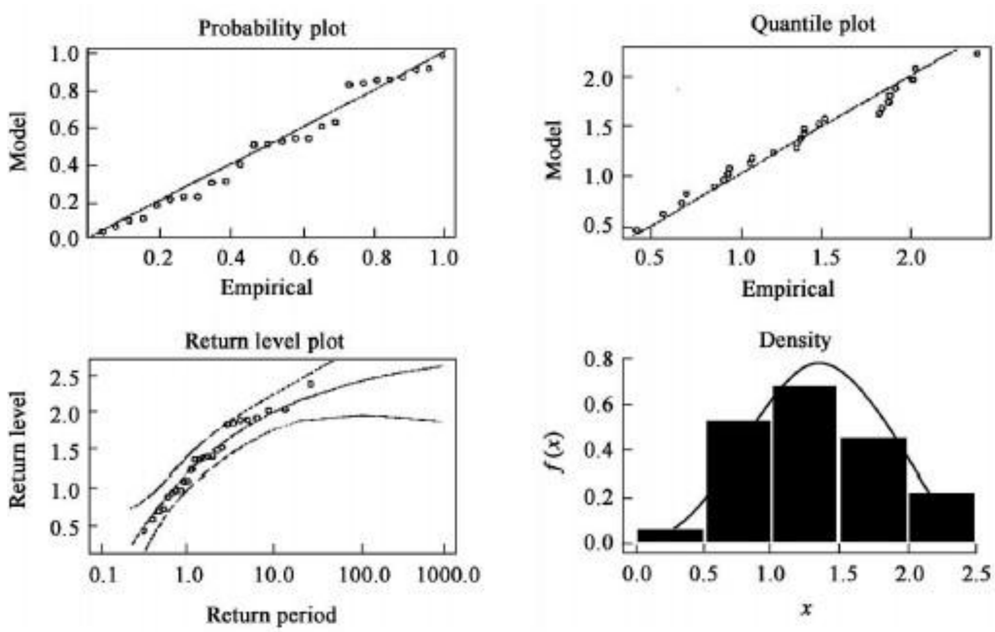

Figure 11.b. Distribution diagnostic testing of spring tide.

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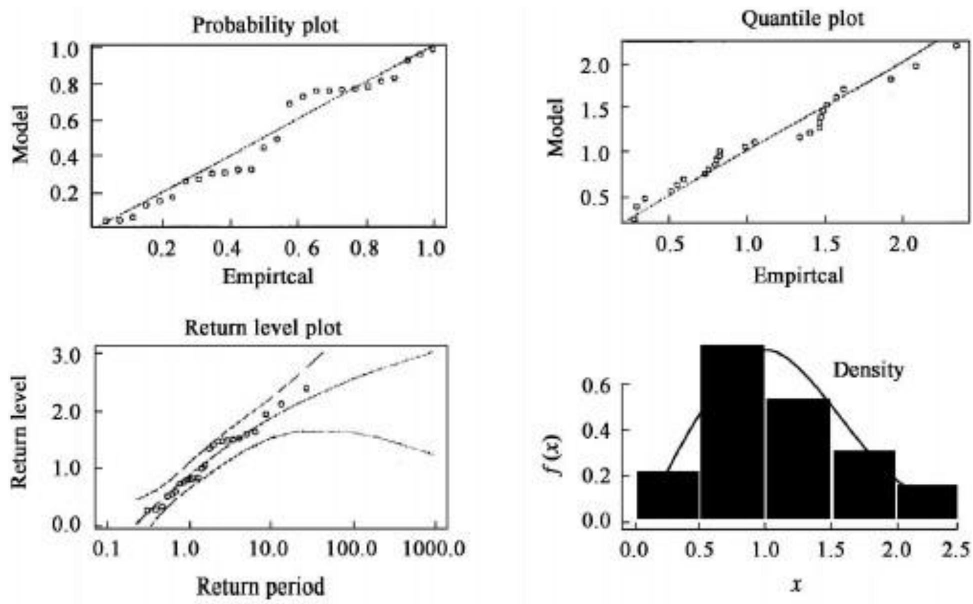

Figure 11c. Distribution diagnostic testing of wave height.

The DYW NPP constructed breakwater is 14 - 16 m height which is lower than 1000 years return period combined extreme events.

6.4. Joint Probability Safety Assessment for QS-NPP Defense Infrastructure in Qiantang River Estuarine Area, East China Sea

The combination of typhoon induced storm surge with the strongest spring tide in Qiantang river estuarine always lead to disasters. The observed maximum surge and spring tide more than 9m. The QS NPP locates in south coast of estuarine Qiantang River and face to East China Sea where always occurred the severest spring tide in China.

The height of constructed breakwater is 9.76m. So the joint probability safety assessment of combined extreme external events for coastal defense infrastructure dominated by spring tide should be taken into account.

As the severest extreme external events for QS NPP are combined effect of spring tide and surge, two dimensional joint probability model can be used to calculate corresponding joint probability density function and cumulative distribution function (Figure 12.a and Figure 12.b). Joint probability distribution of spring tide ,storm surge and corresponding extreme wave with 1000 years joint return period.can be seen in Figure 13.

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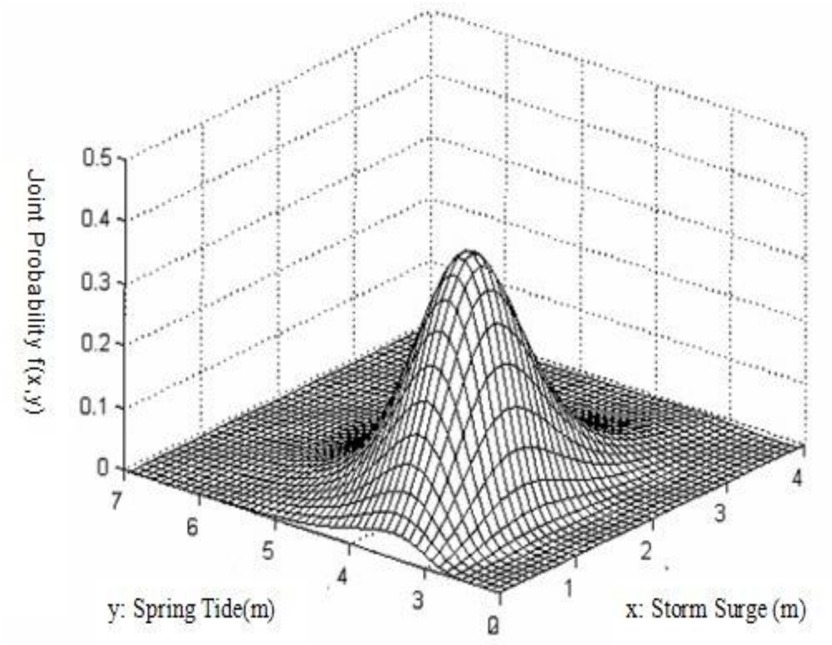

Figure 12.a. Probability density distribution of spring tide and storm surge.

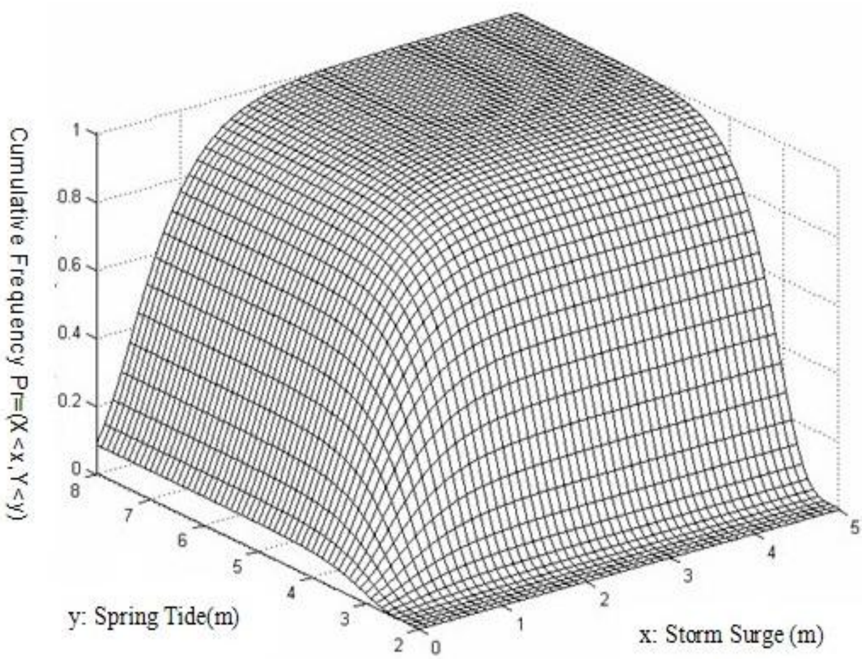

Figure 12.b. Cumulative probability distribution of spring tide and storm surge.

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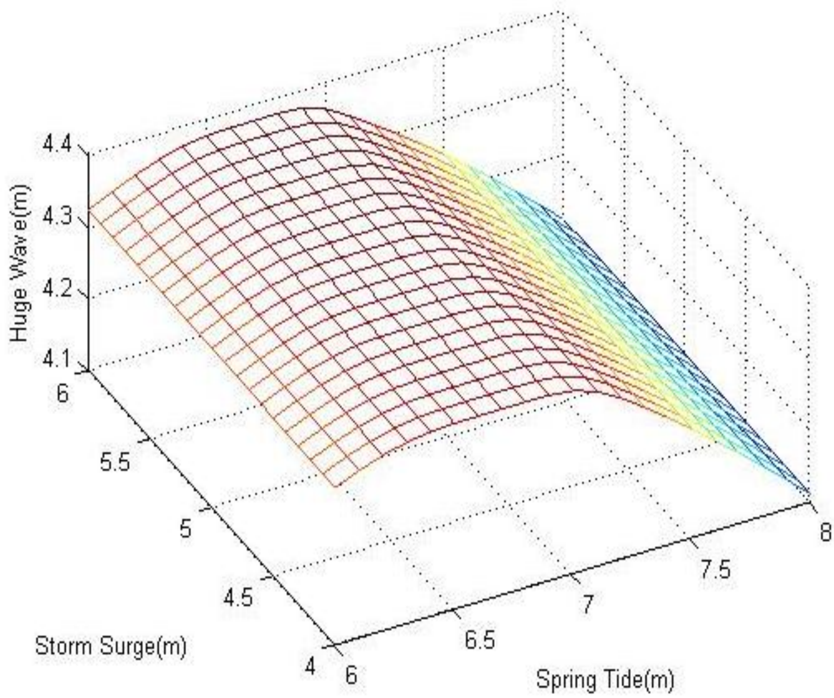

Figure 13. Joint probability distribution of spring tide ,storm surge and extreme wave with 1000 years joint return period.

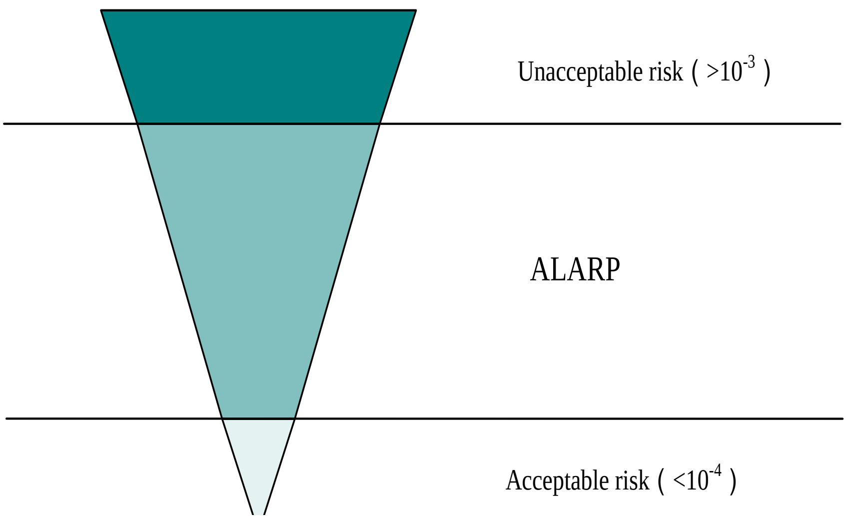

Figure 14. As Low As Reasonable Practice by Det Norsk Veritas,2001.

Joint probability risk assessment for mentioned above two constructed nuclear power plants shows that the coastal defense infrastructures of both NPP can't against 10^{-3} combined extreme external events by ALARP principle [40], that means , the risk of constructed infrastructures is unacceptable.

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Joint probability safety assessment for NPP coastal defense infrastructure against extreme external hazards shows that China and IAEA recommended safety regulations appear to have some vague definitions and different kinds of uncertainties. Both of two constructed NPP located along South China Sea and East China Sea where dominated external events are wave and spring tide, and the China and IAEA recommended safety regulation are much lower than 1000 years return period typhoon induced sea hazards predicted by DLNMPM. Face up to the frequently occurrence of typhoon hazards and disasters with 1000 years and higher return periods in the world during the past few years, we have to worry about consequence of typhoon disasters for nuclear power plant.

Table 16. Combined extreme external events with joint return period for QS NPP by PNLTCED

Extreme Event / Joint Probability	Spring Tide (m)	Surge (m)	Wave (m)
100	4.2	3.0	2.5
500	5.0	3.5	3.0
1000	5.5	4.0	3.5
10000	6.5	4.8	4.0

Risk assessment for NPP coastal defense based on the ALARP principle.

7. Risk Assessment for Offshore Platform against Typhoon/Hurricane Hazards in Global Climate Change Condition

7.1. Global Uncertainty Analysis (GUA) for Extreme External Events

Due to the complexity and randomness of natural events, statistical results often have inevitable error and uncertainties, which leads to inaccurate prediction and analysis. Therefore it's necessary to access the uncertainty of extreme load prediction by a rational method.

Input factors concerning offshore platform design mainly include wave, wind, current, sea level, bed roughness, etc. As wave height is the dominant factor, especially to fixed platform, this paper mainly takes the uncertainty of wave into account.

(1) Climate Change Uncertainty

Global climate change due to greenhouse effects has made a deep effect on human society. Sea-level rise has been observed at a rate of 1.7 mm± 0.3 mm/yr from 1870 to 2004 [10] and the duration of the most extreme events is also increasing, such as tropical cyclones [2]. So it's very necessary to consider climate change as a uncertainty factor in the process of platform design.

Nobuhito Mori and Hajime Mase have analyzed the wave change in the Pacific Ocean near southeastern Asia by General Circulation Model (GCM) and the result indicates that the

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mean waves will be increased at both the middle latitudes and also in the Antarctic ocean, on the other hand, the extreme waves due to tropical cyclones will be increased as Figure 15.

Hence it is not difficult to obtain the uncertainty of climate change: Cov1=0.21.

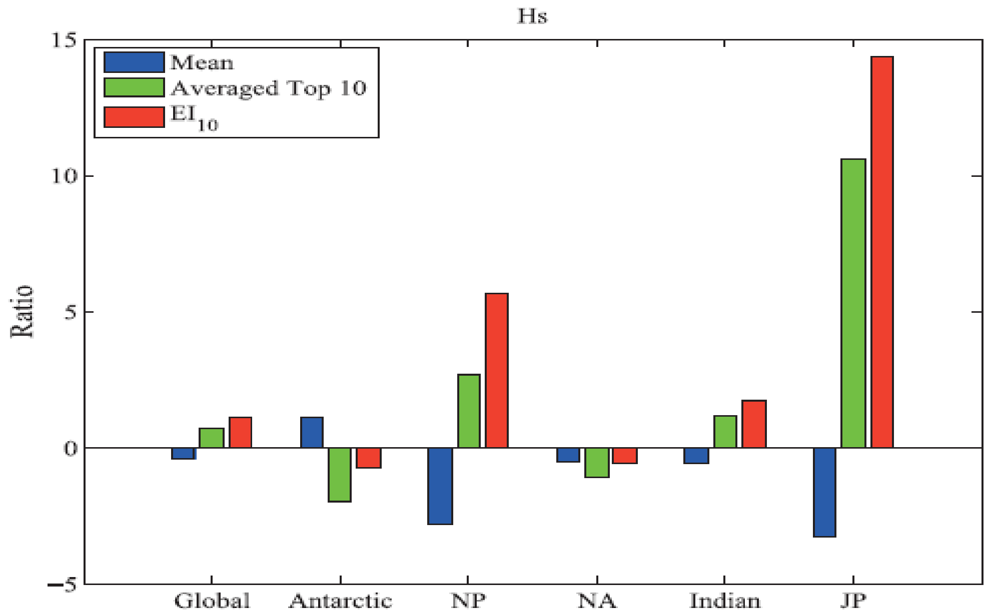

Figure 15. Spatially averaged mean, top 10 and EI of Hs (NP:Northern Pacific, NA: Northern Atlantic, JP: Pacific Ocean near Japan).

(2) Method and Model Uncertainty

Sampling with maximum method, POT method and initial distribution method, the prediction to the different return period wave height has been made, and the uncertainty is obtained: Cov2=0.08.

(3) Data Samples Uncertainty

Using statistical parameters estimated from series of differences between measured and hindcast, a long period data can be generated by Monte-Carlo simulation. For example, take one hundred 100yr return period values from 10000 simulation data, and the data samples uncertainty can be obtained: Cov3=0.09.

(4) Statistical Uncertainty

As the methodology and involved probabilistic models are selected and the corresponding sample is established, the selected models can be fitted to the data samples. Since the sample consists of the limited number of realizations, this phase will also be associated with uncertainties. Statistical uncertainty can be obtained as the maximum value: Cov4=0.10.

So resulting global uncertainty of wave height for South China Sea is:

$$Cov = \sqrt{Cov_1^2 + Cov_2^2 + Cov_3^2 + Cov_4^2} = 0.26$$

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7.2. Global Sensitivity Analysis (GSA)

The main research object of GSA focuses on the influence on failure probability and structure response from random variables and their parameters in the reliability model. It can compare horizontally the significance among random variables and their parameters.

To a output variable yi, suppose the basic random variables which have influence on the output are {x1, x2,…,xi, …,xn}, and Exi is the expectation of output variable xi , then the sensitivity vector can be defined as $\left\{ \frac{\partial y}{\partial x_1} E_{x_1}, \cdots, \frac{\partial y}{\partial x_i} E_{x_i}, \cdots, \frac{\partial y}{\partial x_n} E_{x_n} \right\}$ which could be described by sensitivity chart after normalization.

Global Sensitivity Analysis is very helpful in dealing with engineering problems. And it could play a guiding role in the area of environmental Impact prediction, simulation and assessment, and improve accuracy and reliability of prediction. Based on MCEVD, The Global Uncertainty Analysis (GUA) and Global Sensitivity Analysis (GSA) as main tools can be used for input sea environments with uncertainties and corresponding sensitivity of structure responses. Through the forward-feedback process for input-output with uncertainty-sensitivity analysis, the more reasonable responses can be obtained (See Figure 15).

7.3. Wave Theory

Wave forces is usually computed by using Airy wave theory. The linear wave theory has a simple form and easy to use. Previous studies indicated that for waves with relatively low wave heights, i.e. small amplitude waves, the spectral densities of velocity and acceleration of water particles due to wave motion can be approximately obtained by Airy wave theory. However, considering the extreme sea state, this theory is not suitable any more. Due to the fact that the nonlinear wave theory could describe the wave phenomenon better, more and more attentions are paid on it. Rules and regulations for the construction and classification of offshore platform in ABS and DNV also recommends third or fifth order Stokes wave theory for offshore structural design and strength checking.

In this paper, fifth order Stokes wave theory is proposed. Given that the amount of wave force is closely related with phase angle, when it comes to the static analysis, the most unfavorable state should be obtained. For this reason, before static analysis, phase angle φ should be checked from $0^{\circ}$to 360°in order to find out the maximum wave force coupled with current [16]. The result is showed as Figure 16.

7.4. Effects of Climate Change on Extreme Environmental Loads

This example applied 143 typhoons of Dapeng Bay in South China Sea and selects the wind velocity, wave height and current velocity of each process as samples. Based on the diagnose tests and Kolmogorov-Smiromov inspection, the sample points and the curves of general extreme value (GEV) distribution fit well. The location parameter μ, scale parameter σ and shape parameter ξ are estimated in Table 17.

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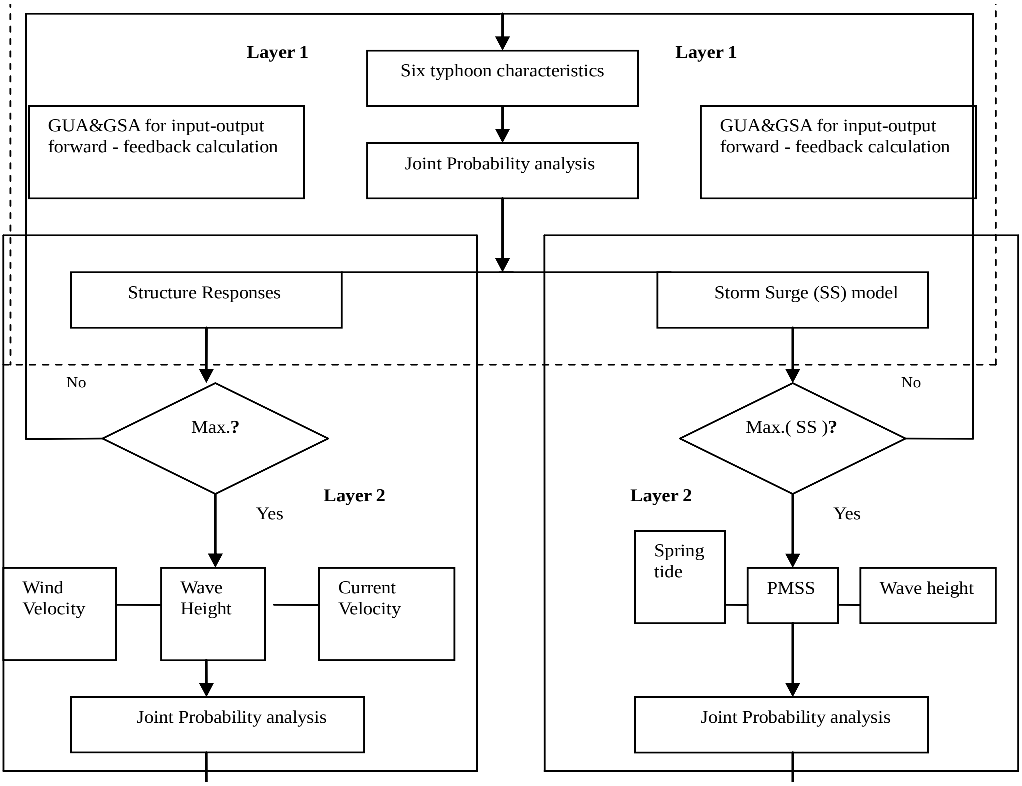

Figure 16. Application of GUA and GSA to defense code calibration.

Table 17. Parameters of variables

	Shape parameterξ	Scale parameterμ	Location parameterμ	Dn	Dn (0.05)
H （m）	0.1655	0.9630	2.1907	0.0604	0.1123
V （m/s）	-0.6084	8.2255	34.4579	0.1512	0.2941
C （m/s）	-0.3314	0.4525	1.3346	0.0918	0.2941

7.5. Application of MCEVD and Global Uncertainty Analysis (GUA)

Comparing different design loads standards, this paper gives four definitions about the design extreme loads, takes a Jacket platform with 30m design depth of water as example, and analyzes the maximum structural stress and deformation with different design standards. In the actual calculation, to clarify the issue, eliminate the influence of structural forms (such as stress concentration in tubular Joint, green water occurrence and so on) and make the result have general significance, the Jacket is just simplified to a certain extent. The result is showed in Table 17.

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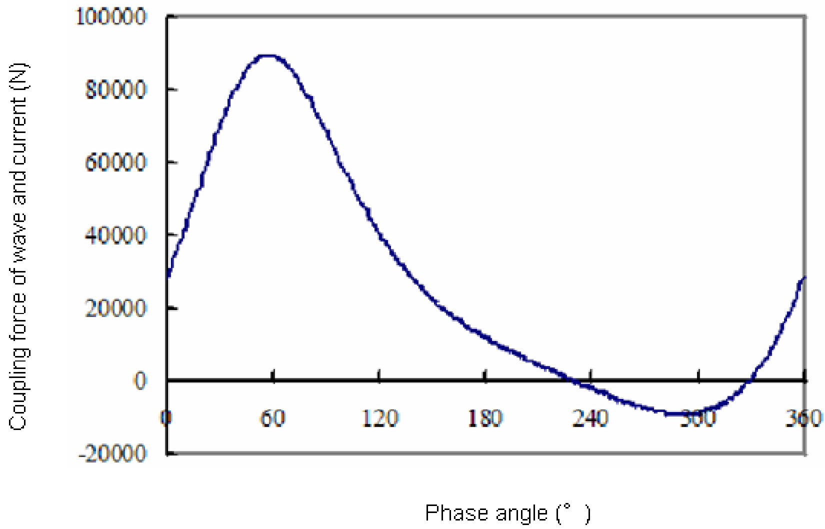

Figure 17. Relationship between coupling force and phase angle.

Traditional Design Method: 100-yr. return period wave height combined with associated wind and current. The 100-yr. return period wave height is usually calculated by fitting Pearson- curves.

Single Factor Method: 100-yr. return period wave height combined with 100-yr. return period wind speed and 100-yr. return period current speed. On the same DOF and stress conditions, the joint return period of Single Factor Method reaches 500yr. That means the conservative method is very conservative for engineering application and would cause waste of materials and funds.

MCEVD design method: MCEVD considers the correlation among the factors and takes the simultaneous wave, wind and current as design criteria, so it can give the real "100-year" sea state.

GUA design method: Based on MCEVD, 100-year sea state is defined by taking account of the influence of climate change and other uncertainty factors. After considering global uncertainties, the extreme loads (wind, wave, current) are all greater than Traditional Design Method, and the joint return period of extreme loads has reached 180yr.

In this study takes a Jacket platform with 30m design depth of water as example, and analyze the maximum structural stress and deformation with different design standards. In the actual calculation, to clarify the issue, eliminate the influence of structural forms (such as stress concentration in tubular Joint, green water occurrence and so on) and make the result have general significance, the Jacket is simplified as a conductor. The result is showed as follows:

MCEVD considers both the frequency and the correlation among the sea environment events. In the 100yr return period extreme sea state predicted by MCEVD, both wind and current speed are greater than traditional method, and on the other hand, wave height is relatively lower. However, considering the influence by the uncertainty of wave, the wave height become higher than traditional method. So it indicates that the extreme design loads by traditional method is underestimated. The global uncertainty analysis is quite necessary and climate change has made an actual effect on offshore platform design.

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Based on the finite element model of Ansys, sensitivity is analyzed considering the change of each input variable respectively, which could prevent the interaction between each other. The sensitivity vector after normalization is {0.71,0.03,0.26} (See Figure 18). According to the analysis result, wave height is the most sensitive factor to the Max. stress of platforms, current second and wind at last.

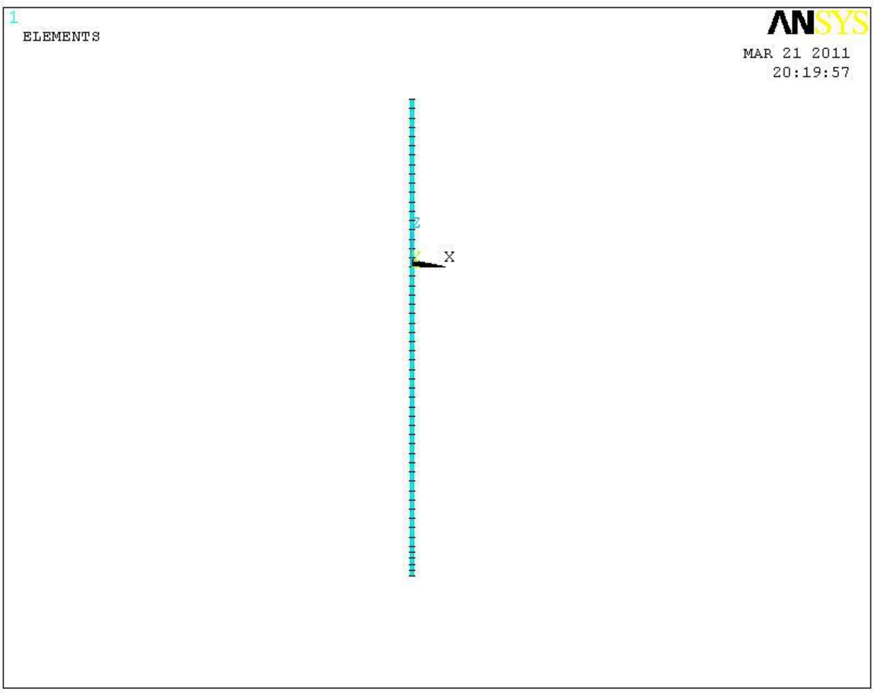

Figure 18. (Continued).

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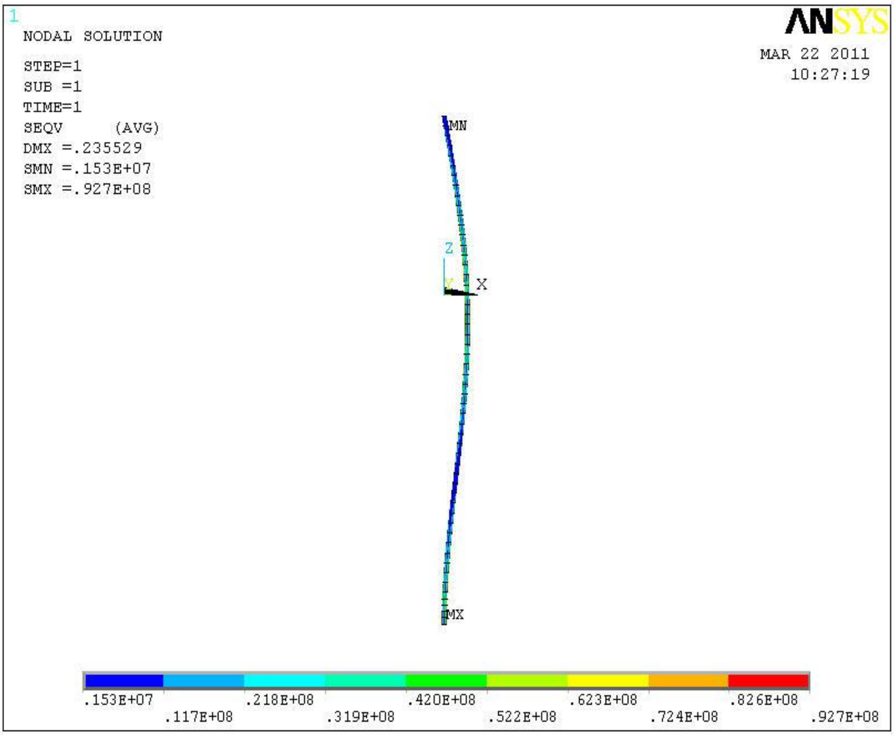

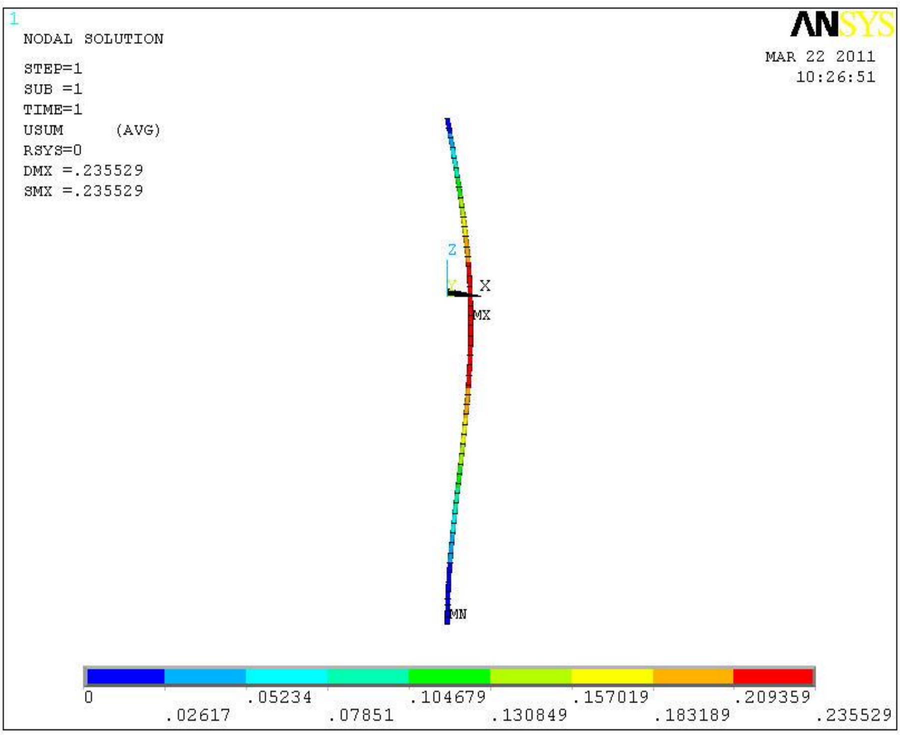

Figure 18. Stress and deformation of Jacket.

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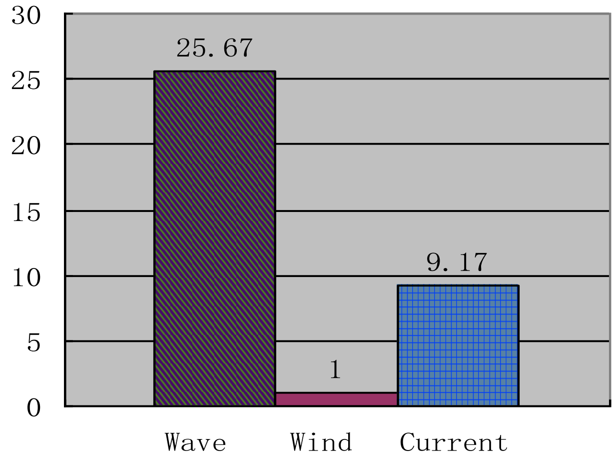
Table 18. Comparison of calculated results by different definitions

	Wave (m)	Wind (m/s)	Current (m/s)	phase angle	Max DOF (m)	Max Stress (MPa)	Joint return period (yr)
1	8.6317	39.9	1.237	58°	0.3088	0.118e9	150
2	8.6317	56.035	2.3684	58°	0.5146	0.194e9	500
3	6.9182	45.86	1.5023	58°	0.2355	0.927e8	100
4	8.7169	45.86	1.5023	58°	0.3507	0.133e9	180



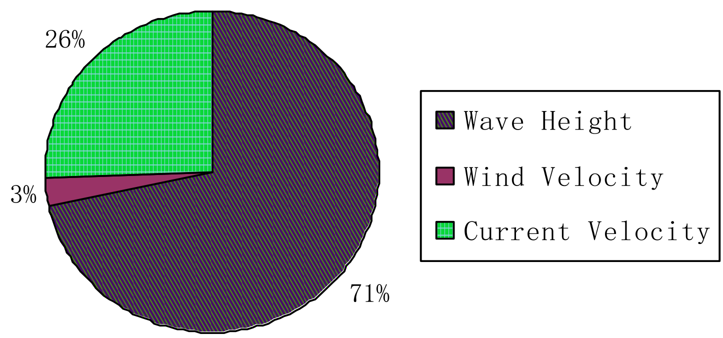


Figure 19. Max. Stress Sensitivity of Jacket.

7.6. Effects of Climate Change on Deck Elevation Design

Green water occurrence indicates that during the extreme sea state, wave associated with strong wind and high tide passes the platform deck and causes a large forces and overturning moments. It is very dangerous for offshore platform. The studies after Katrina and Rita in 2005 indicates that there were many platforms with reported wave in deck (WID) damage, attributed to the crest of the large hurricane wave hitting the platform decks and causing major damage [10, 11].

There were many platforms with reported wave in deck (WID) damage, attributed to the crest of the large hurricane wave hitting the platform decks and causing major damage. Previous study of hurricanes Andrew, Lili and Ivan all reported destruction and major damage

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due to WID [19, 11]. The catastrophic failures and damage of platforms in GOM region show the deficiencies of API recommendations.

API RP2A [1] categorizes platforms according to consequence of failure, designated as A-1 for high consequence, A-2 for medium consequence and A-3 as low consequence. The report of Forristall shows a comparison of the deck elevation for the destroyed platforms (76 cases where the deck elevation was available) at the location [68]. The circles in Figure 20 show the deck heights of individual platforms and the triangles show the crest heights predicted by Forristall. The curves A-1, A-2, and A-3 designate the deck heights recommended by API RP2A. For example, at a water depth of about 325 ft, the destroyed platform's deck height is about 42 ft and the crest height is about 60 ft. Thus the wave crests height was almost 18 ft higher than platform deck clearance. It is then no surprise that the platform was destroyed.

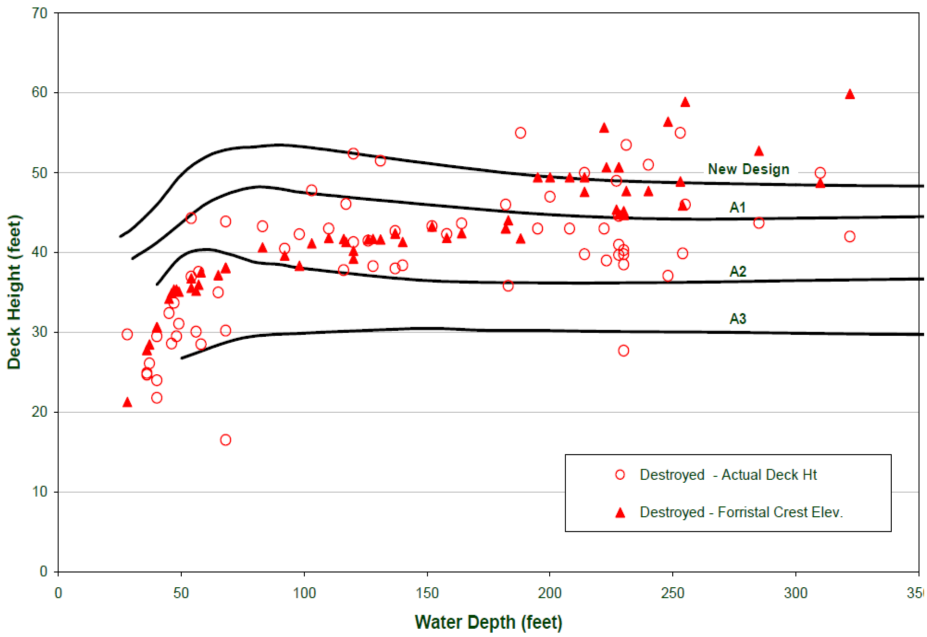

Figure 20. Platform deck height compared to predicted wave crest height.

After hurricane Katrina and Rita, API issued Bulletin 2INT-DG (2007), which provides procedures for using the hurricane conditions contained in BULL 2INT-MET (2007) for the associated type of platforms. API Bulletin 2DG updates specific recommendations for cellar deck elevation as the 'new design' that accounts for a typical 5ft air gap above the 100-year wave crest and also an additional allowance of 15% of the crest elevation to account for local wave effects.

Further, some of the primary causes of damage were wave, wind and current forces greater than 100 yrs conditions, and foundations that were unable to support the fixed platform for the additional load level experienced from the increased metocean conditions beyond the industry accepted standard for survival.

This shows there are defects and deficiencies in previous platform deck elevation design method.

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DNV [65] requires that the distance between the lower part of the deck structure in the operation position and the crest of the maximum design wave, including astronomical and storm tides, is not to be less than 10% of the combined storm tide, astronomical tide and height of the design wave above the mean low water level, or 1.2m, which is smaller. Actually, the requirement of DNV is ambiguous, it doesn't give a specific calculating formula, and the code calibration of API is not suitable for other non-us sea regions. Hence, the engineering application usually applies an empirical formula, that is the combination of 100yr return period wave crest height, 100yr return period design water level and 1.2m air gap. (See Figure 21) The calculating formula is showed as follows:

$$H = H_{SWL} + \frac{2}{3}H_s + 1.5$$

H Lowest deck elevation

H_{SWL} Still-water level including surge and corresponding tide;

H_s Significant wave height

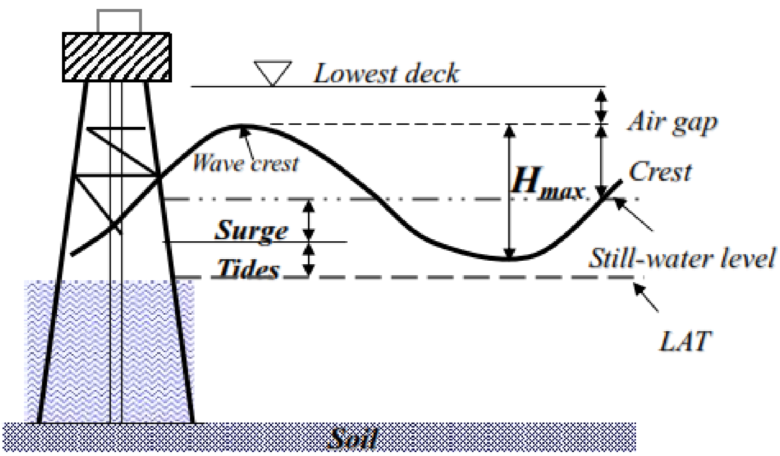

Figure 21. The definition of water levels and the lowest deck height.

This empirical formula is similar to the conservative design method of extreme loads. Although the return period is clearly marked, it neglects the joint probability and correlation among wave crest, tide and surge. As a result, it couldn't make an estimate of the joint return period of deck elevation and difficult to calculate the failure probability. And the most important defect is this formula doesn't take account of the uncertainty caused by climate change. Since climate change, subsidence and other factors may all causes uncertainty, it may results in great error between the prediction and the actual observation.

Based on MCEVD, this paper would apply the PNLTCED model with the data of the significant wave height , concomitant surge and corresponding tide in East China Sea from 1979 to 1987 (see Table 19) and compare the design deck elevation with the traditional method. It can be seen in Figure 20 that the significant wave height (Hs) ,surge and tide in

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this area fits well to general extreme value distribution. The related parameters could be estimated by maximum likelihood estimation and the calculated result is showed in Table 20.

Table 19. H_s and concomitant surge samples (1979-1987)

Typhoon No.	H_s (m)	Surge (m)	Typhoon No.	H_s (m)	Surge (m)	Typhoon No.	H_s (m)	Surge (m)
7909	4.6	0.46	8211	4.5	0.87	8508	3.2	0.24
7910	3.3	1.09	8219	3.4	0.29	8519	3.6	0.28
7915	3	0.21	8305	2.6	0.27	8607	2.1	0.35
7919	3.4	0.61	8310	3.3	0.58	8615	5.3	0.49
8001	2.1	0.18	8402	1.3	0.5	8617	2.5	0.39
8002	2.3	0.48	8403	1.6	0.15	8700	1.2	0.18
8003	5	0.26	8406	2	0.66	8701	1.5	0.26
8004	4.3	0.41	8407	2.5	0.19	8704	4.7	0.36
8101	4.5	0.93	8409	3.7	0.77	8705	2.2	0.17
8102	4.5	0.15	8504	2	0.19	8707	3.9	0.43
8209	2.2	0.52	8506	3.4	0.32	8711	2.8	0.69

Table 20. Parameters of variables

Typhoon characteristic	Marginal distribution parameters		
	Location parameterμ	Scale parameterσ	Shape parameterξ
Hs	2.70	1.07	-0.268
Surge	0.287	0.143	0.335
Tide	1.914	0.283	-0.36

The calculated results compared between empirical method and MCEVD were shown in Table 21.

Table 21. Comparison of calculated results by traditional addition method and MCEVD

<table>
<tr><td rowspan="2">Traditional addition method</td><td>Hs (m)</td><td>Crest height with 100 return period yrs (m)</td><td>Surge with 100 return period yrs (m)</td><td>Tide & Air gap (m)</td><td>Deck elevation above LAT (m)</td></tr>
<tr><td>5.56</td><td>6.78</td><td>1.23</td><td rowspan="5">2.45+1.5</td><td>11.96</td></tr>
<tr><td rowspan="3">MCEVD method</td><td colspan="3">Joint probability of 100-yera return period</td><td rowspan="2"></td></tr>
<tr><td>Hs (m)</td><td>Crest heigh（m）</td><td>Surge (m)</td></tr>
<tr><td>5.95</td><td>7.26</td><td>1.98</td><td>13.19</td></tr>
<tr><td>MCEVD With GUA</td><td>6.53</td><td>7.84</td><td>2.10</td><td>13.89</td></tr>
</table>

The design deck elevation calculated by MCEVD is not only more reasonable, but also take climate change into account. Its result is greater than the traditional empirical method. Considering the experience of Hurricane Katrina, the design method provided by this paper is more suitable for engineering application.

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8. Joint Probability Prediction Model of Rainfall Triggered Landslides and Debris Flows

8.1. The Rainfall-induced Landslides and Debris Flows Are the Major Disasters in South American, Europe as well as in China due to the Following Facts

The climate of South American, some European counties and China mainly possess the features of hurricane/ typhoon/ tropical cyclone , monsoon type and precipitation is concentrated in summer, forming stormy rainfall which is the main inducing factor for landslide and debris flow.

The resident in mountainous area mainly distributes along valleys on river terraces, deluvial fans and taluses. The land reclamation often leads to soil erosion and slope failure which threaten the safety of life and property.

Highway and railway in mountainous area are mostly arranged along river valley and gulley and often constructed by slope cutting, by which the stability condition of natural slopes is disturbed. Slope collapse, landslides and debris flows influence the traffic and threaten the life safety.

The construction of hydro-power stations, nuclear power plants and mines, new resettle regions, slope cutting, earth filling and waste piling have destroyed the primary land form; the ground water extraction and waste water infiltration change the original groundwater condition. All these changes of natural conditions can lead to the change of slope stability.

Due to the above mentioned reasons, the rainfall-induced landslides and debris flows should be investigated further.

Since the geological environment and the geotechnical characteristics are complicated and changeable, the rainfall-induced landslide and debris flow possess localized features and complicated types. In the world wide the study of slope stability is concentrated in slope classification, failure mechanism, failure mode, investigation techniques, method of stability analysis, monitoring techniques and treatment measures. During these studies the rainfall is treated as an acting factor to the slope stability. The study on regional features of slope is especially lack, which is more important for development planning, earth use planning and risk management [45, 46].

The study on rainfall-induced slope failures is more developed in a few countries, such as Italy of Europe, Hong Kong, Japan, and Australia. However the study in this countries or districts mainly is performed in combination with the study on certain slope or landslide, so the approaches vary from pure statistics to mechanical analysis. Among these studies only the landslides in Hong Kong are predicted and assessed by using the rainfall as the only indicator. With developed economy and dense population, landslide in Hong Kong may cause higher risks; therefore, the government pays great attention to the study of landslide. The geological and geo-morphological conditions and the slope failure low have been studied in detail since the territory of Hong Kong is small, and the slope movement and the rainfall are monitored by a net equipped with automatic apparatus. On this basis the correlation of slope failure with rainfall could be established.

In China, the local authorities and the large industrial or construction units pay more attention to the monitoring and treatment of certain slopes but the correlation between rainfall

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and happening of landslide or debris flow is less investigated. In the mainland of China the study on distribution of landslides in some area is well carried out. For example there is a scientific work "Landslides in Gansu Province", one of the results of which is the landslide hazard map for East Gansu based on geomorphology, geology and past landslide activity. This map has been used as basic guideline in land-use planning. However the study on correlation between the landslide and the rainfall is still very rough. Since the lack of such scientific investigation, errors in development planning or land usage planning for new constructed or extended area are frequently have made. For example, there are many building damages due to creep, deformation or tension cracks in foundation induced by the first rainfall after the completion of a new resettle point. However if this area was planned for a square or a traffic line, the loss would be less or even be avoided. Another example, there was an accident of powerhouse inundation of a hydropower station by a debris flow induced by an extra storm rainfall, since during construction the constructor has piled the solid waste in a gulley just located at the upstream of the power house. For the landslides prevention the national design code was established. As the important triggering factor for landslides and debris flow in 16 coastal and inland provinces of China typhoon induced storms and flood and its probability model was studied.

Targets of the study are focused on scheme of zoning of a certain region according to the relative homogeneity of the geological and geo-morphological conditions as well as the similarity of the failure mechanism and failure type of slopes and establish a theoretically based and practically applicable joint probability prediction model for rainfall induced landslides and debris flows.

8.2. Scheme Rainfall-induced Landslides and Debris Flows Disasters Zoning

In case that the possibility model is used for prediction and assessment of rainfall-induced landslides and debris flows in a large area, the condition of occurrence of these disasters and the similarity of their mechanism should be taken into consideration. Under different geological and geo-morphological conditions a rainfall with a same intensity, a same prolonged time and a same pre-accumulated precipitation may result in an inducing event or a non- inducing event; in case of an inducing event, disasters of landslide or debris flow with different degrees may take place. In view of these facts we must discuss the mechanism of the rainfall- induced disasters and a necessary simplified treatment should be made [66].

8.2.1. Slope Type and the Stability Situation

For the study of slope failures induced by rainfall the slopes should be classified at first into rock slopes and earth (including unconsolidated materials) slopes. The reasons are: a, The people living in mountainous and hilly regions is mainly settled along river valley on the terraces, diluvial fans and taluses, slopes in which can be distinguished as earth slopes; b, the slopes in the sites of large hydro-power stations, strip mines and along main traffic lines are mainly rock slopes.

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(1) Earth Slopes

The infiltration of rain water changes the physical situation of earth. Under the natural moisture situation earth exists in a solid or hard-plastic state. With the increasing of moisture content resulted from infiltration during rainfall earth turns into a soft-plastic state or even to a flow state. So the failure of an earth slope starts from creep to slump or to plastic flow and finally evolves to a mud flow or debris flow.

This failure mode is fit to slopes composed of earth mixed with rock fragments in natural deposits, such as slope wash, talus, residual slides in mountainous and hilly region or man-made fills, as well as to slopes composed of homogeneous soil.

(2) Rock Slope

The infiltration of rain water imparts pore-water pressure in rock mass, reduces the shear strength of the discontinuities in rock mass, especially of the weak structure planes, and induces landslide. The strength reducing is less important in wet area of heavy rainfall since the moisture content of weak structure planes in rock mass are near to saturation; the main role is increased water pressure.

Rock-slides are almost exclusively conditioned by discontinuities dipping outwards. A storm rainfall may induce rock fall in superficial highly weathered rock.

(3) Stability Situation of Slope

Since slope failure is a process of losing stability, certain stability situation of a slope should be defined in accordance with its developing stage. In Appendix A of the Design Specification for Slope of Hydropower and Water Conservancy Project of PRC slopes are classified in to stable, potentially unstable, deforming, unstable and post-failure slopes according to there stability situation. For instance, slopes in an area where landslide frequently occurs are mostly in deforming or potentially unstable situation while rock slopes in an arid area are mostly in long term stable situation [47, 48].

8.2.2. Secondary Disasters Induced by Human Activities

Human activities often break the natural balance of slopes, making the slope stability worse, decreasing the threshold value of inducing rainfall and increasing the probability of slope failure. Many landslides and debris flows are induced by construction of highway or railway and distribute along traffic lines. The factor of human activity should be considered in zoning of a region as well as in determination of rainfall threshold values. The secondary disasters brought by human activities are mainly as follows:

- Engineering cutting steepness slopes or undercuts rock slopes at their toes making the slip surface daylight at slope surface. The examples of these situations are slopes along highway or railway, slopes at rock quarries and open-pit mines.
- The waste water infiltrates into ground raising the ground water table and decreasing the stability of slope. This situation is often met in new resettlement area for reservoir immigrant or in newly constructed or extended town.
- Damage of natural vegetation leads to soil erosion, for example, along traffic lines or in construction sites.

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- Piling of waste solid obstructs the discharge channel. For example, the waste rock and earth materials are piled in gulley inducing debris flow in rainy season.
- The secondary disasters may be induced by hydraulic works. For example, water leakage from diversion tunnel, rapid drawdown of river or reservoir water level and artificial rainfall induced by flood discharge during rainy season may induce landslides along river banks.

8.2.3. Application GUA&GSA for Prediction of Rainfall Induced Landslides and Debris Flow

GUA&GSA are useful to accomplish a number of tasks and provide guidance to improve the quality of environmental assessment practices and decision support systems employed in environmental policy, ultimately improving their reliability, transparency and credibility. For instance GUA&GSA can help to understand whether the current state of knowledge on input data and related uncertainties is sufficient to enable a decision to be taken. If not, it helps identify which data or parameters require resources to be allocated for knowledge improvement, in order to achieve the desired level of confidence for the results.

For the complex input-output processes for prediction of rainfall induced landslides and debris flows the combination of uncertainty and sensitivity analysis in an iterative procedure of MOFLNPM should be taken advantage of their complementary aspects：

1) Rainfall uncertainty

Uncertainty through the calculation of threshold level for rainfall induced landslides or debris flow in beginning state; Uncertainty of rainfall characteristics; Data sampling uncertainty.

2) Geological and geotechnical parameters uncertainties
3) Uncertainties through the slope stability analysis
4) Uncertainties related to human activities.
5) Based on the predicted results by MOFLNPM in an iterative procedure the landslides and debris flow disaster prevention alarm and regionalization can be provided.

The float chart of MOFLNPM application of slide disaster research can be seen in Figure 22. In Figure 23: F-Factor of safety; W-dead weight of the sliding rock mass; β-dip angle of the slide surface; U- water pressure acting on the slide surface; V- water pressure acting on the rear edge crack; φ-friction angle of the slide surface; C-cohesion of the slide surface; l-length of the slide surface. Figure 24 is the float chart of geological hazards prevention alarm.

The targets of this study are focused on scheme of zoning of a certain region according to the relative homogeneity of the geological and geo-morphological conditions as well as the similarity of the failure mechanism and failure type of slopes and establish a theoretically based and practically applicable joint probability prediction model for rainfall induced landslides and debris flows. Based on the double layer nested multi-objective probability model, landslides and debris flows disasters prediction, prevention, alarm and regionalization system can be proposed. It has important practical value and will bring great economic and social benefits.

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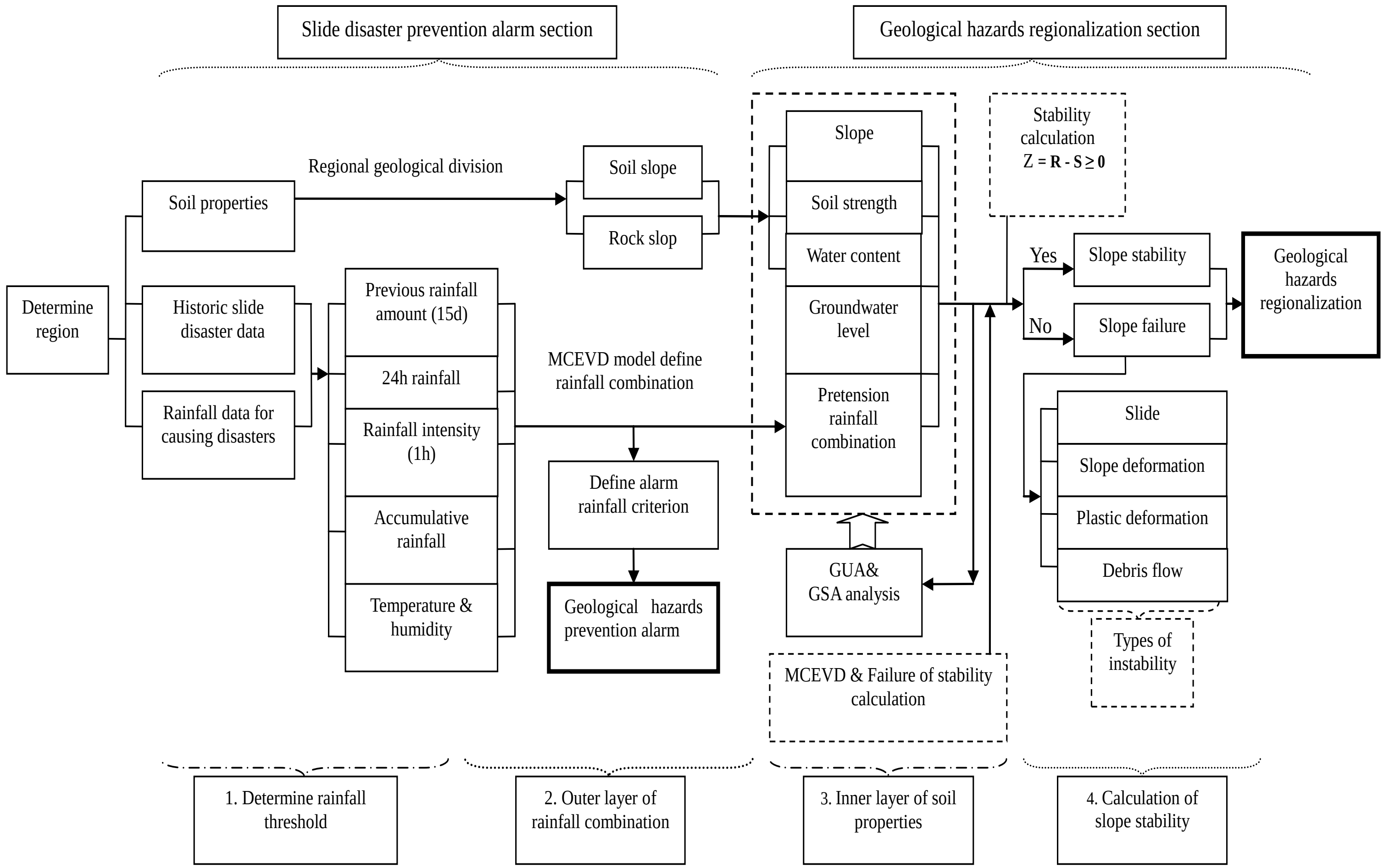

Figure 22. The float chart of DLNMCEVD application of slide disaste.

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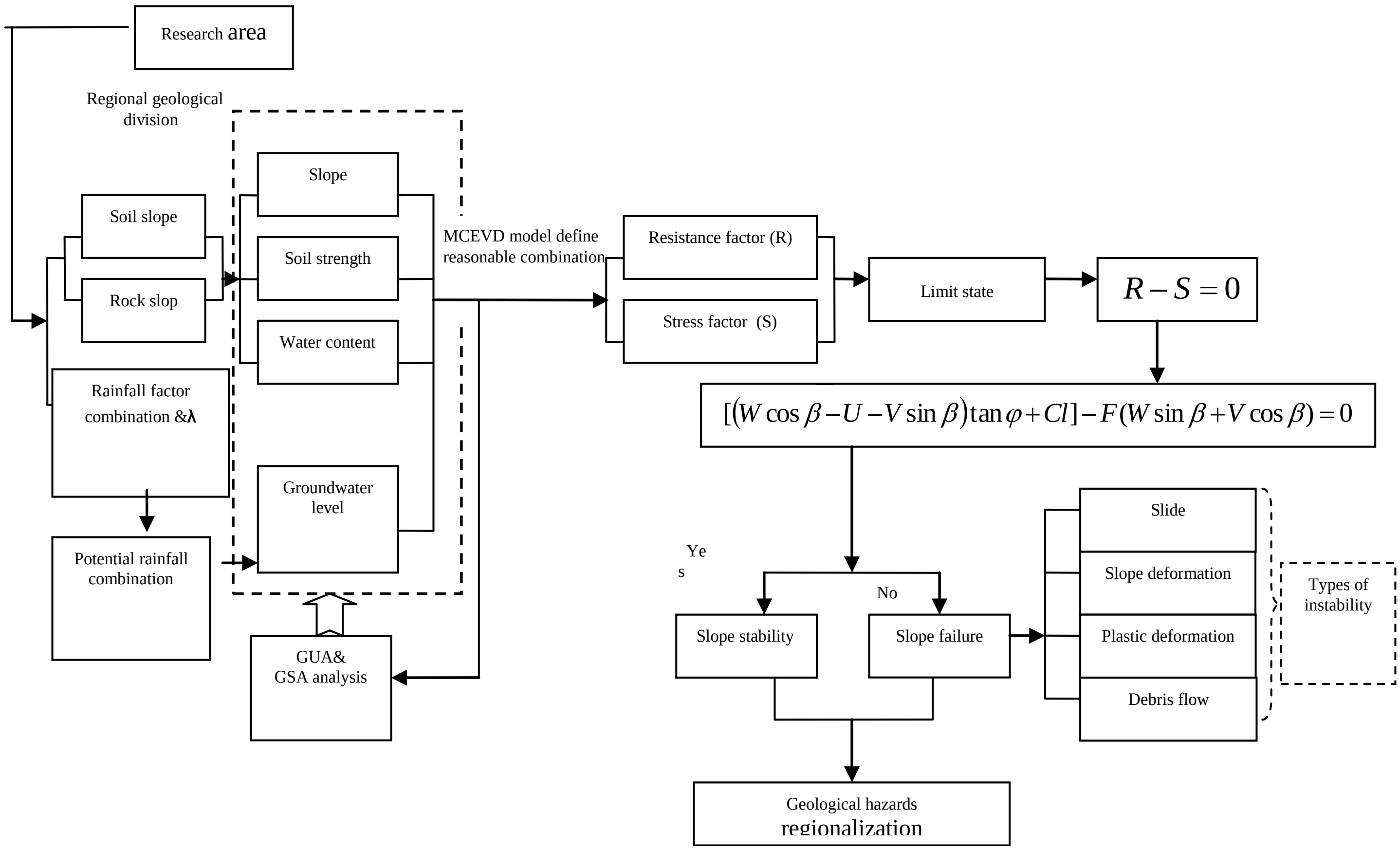

Figure 23. Joint probability assessment of geo-hazards regionalization and types of instability.

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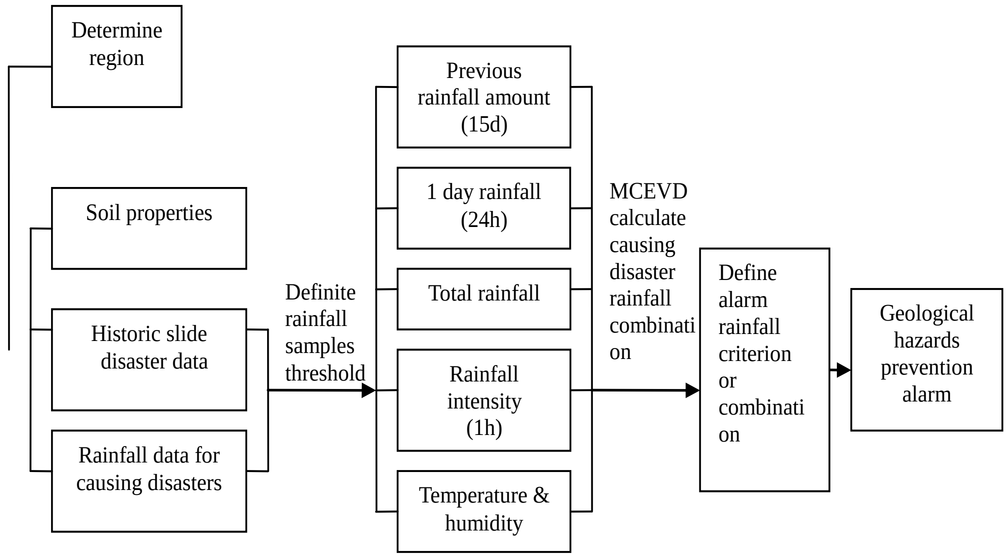

Figure 24. The float chart of geological hazards prevention alarm.

9. Application of MCEVD to Design Flood Prediction of Three Gorges Dam Project (TGP) in Yangtze River

For some large-scale hydraulic projects, such as the Three Gorges Dam Project (TGP) of Yangtze River, there is a paramount significance to predict design flood accurately.

The annual maximum series (AMS) and partial duration series (PDS) are two basic approaches in flood analysis. The AMS approach is based on annual flood series, which corresponds to fitting a distribution function to sampled values of maximum annual floods. Its most frequently used models are log-normal, Pearson Type III, Gumbel or Weibull and Generalized Extreme Value [30].

The AMS approach has been adopted by a large number of projects. According to the CHDC, the design flood volume must be predicted by Pearson Type 3 distribution model to extrapolate 100-year return period of flood volume using annual maxima data sampling method based on observations, although some projects in China have shown the method did not provide sufficient security.

9.1. Hydrological Characteristics of the Yangtze River

The Yangtze River is the largest river in China, being 6,300 km long with a basin covering nearly 2 million km2 or about one-fifth of the country's territory. It is the third longest river in the world. The spectacular TGP is located in the middle of the Xiling Gorge, in Yichang of Hubei province. The mean annual discharges exceeding 1,000 m3/s are mainly through such tributary streams as the Jinsha, Min, Jialing and Wu rivers (Figure 25). More than half a billion people or 45 percent of China's total population live in the basin, who produce about 42 percent of the country's gross domestic product.

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To simplify the analysis, we set the hydrologic station at the end of each tributary stream as the control station, which represents the flood characteristics of the whole tributary. Since the Yangtze River consists of several tributary streams, the flood volume can be calculated by the ratio between drainage area of a tributary stream and the total area of the main stream.

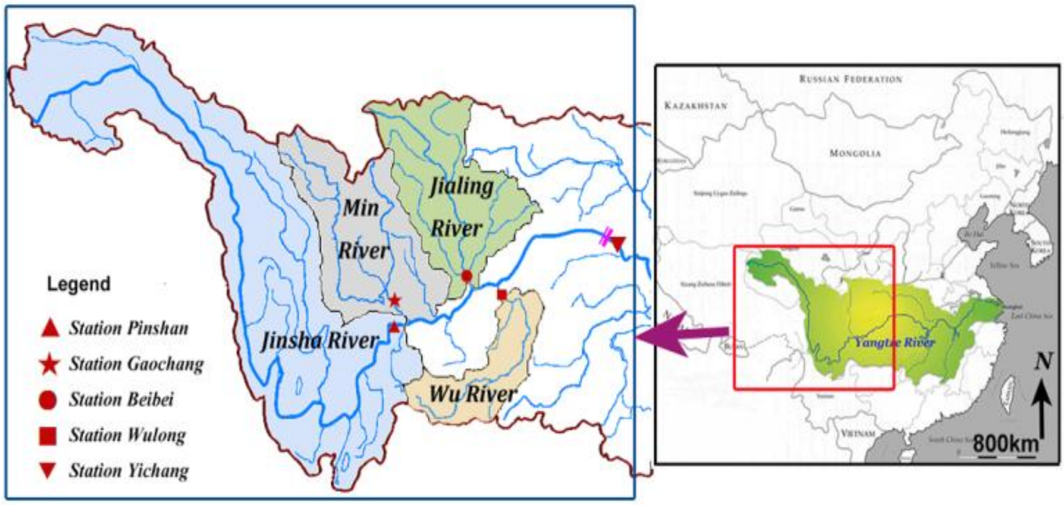

Figure 25. Illustration of the tributaries in the Yangtze River.

The flood peak's propagating time from each station upstream to Station Yichang is shown in Table 22.

Table 22. Propagating time of a flood peak from an upstream station to Station Yichang of the Yangtze River

Upstream station	Pingshan	Gaochang	Beibei	Wulong
Propagation time	90h	87h	56h	48h

The resultant discharge method is based on the water-balance equation of a semi-enclosed water body and empirical dependences. According to the resultant discharge method and the statistical characteristics between the tributary streams and the main stream as well as the flood volume and propagating time, the main stream flood volume (at Station Yichang) can be estimated. For example, 3-day flood volume between 08:00 local time (LT) on Oct. 2nd and 8:00 LT on the 5th at Station Yichang is a summation of flood volumes over 48 hours in the Wu River (at Station Wulong) between 08: 00 LT on Sept. 30th and 08:00 LT on Oct. 3rd, over 90 hours of the Jinsha River (Station Pingshan), over 87 hours of the Min River (Station Gaochang), and over 56 hours of the Jialing River (Station Beibei).

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9.2. Application of the PNLTCED to Predict 3-Day Flood Volume at Station Yichang

The 3-day flood volume of the Jinsha, Min, and Jialing rivers are taken as variables to carry out the joint probability analysis using the PNLTCED model. Twenty-six catastrophic flood volume data between 1965 and 1982 are chosen for the analysis.

The diagnostic checks show that all the data of the Jinsha River, Jialing River and Min River fit well to the generalized extreme value distribution. It can be seen in Table 23 that the frequency of flood fits Poisson distribution very well. The parameters are shown in Table 24.

Table 23. Frequency of floods during 1965 and 1982

The number of major flood in one year					Frequency λ=1.44
0	1	2	3	4	
Year of occurrence					
3	8	4	2	1	

Table 24. Parameters of marginal distributions

Parameters	Variables	Jinsha (1)	Jialing (2)	Min (3)
	Location parameter μ	2.17	3.72	2.55
	Scale parameter σ	0.92	2.44	1.19
	Shape parameter ξ	0.06	-0.12	0.34

Table 25 shows the better correlation between the Jinsha River and the Jialing River than between any other two rivers, so the Jinsha River (1) and Jialing River (2) should be taken as inside layer variables.

Table 25. Linear correlation coefficient and dependent parameter

Data	r12	r13	r23	$\hat{\alpha}$	$\hat{\beta}$
	0.365	-0.098	-0.095	1.00	0.797

Using the PNLTCED, one contour surface about the 3-day flood volume of the Jinsha, Jialing and Min rivers for each joint return period can be obtained. The resultant discharge method is based on the water-balance equation of a semi-enclosed water body and em pirical dependences. According to the resultant discharge method and the statistical characteristics.

The diagnostic checks show that all the data of the Jinsha River, Jialing River and Min River fit well to the generalized extreme value distribution. The Figure 26, 27, 28 show the distribution diagnostic testing of variables.

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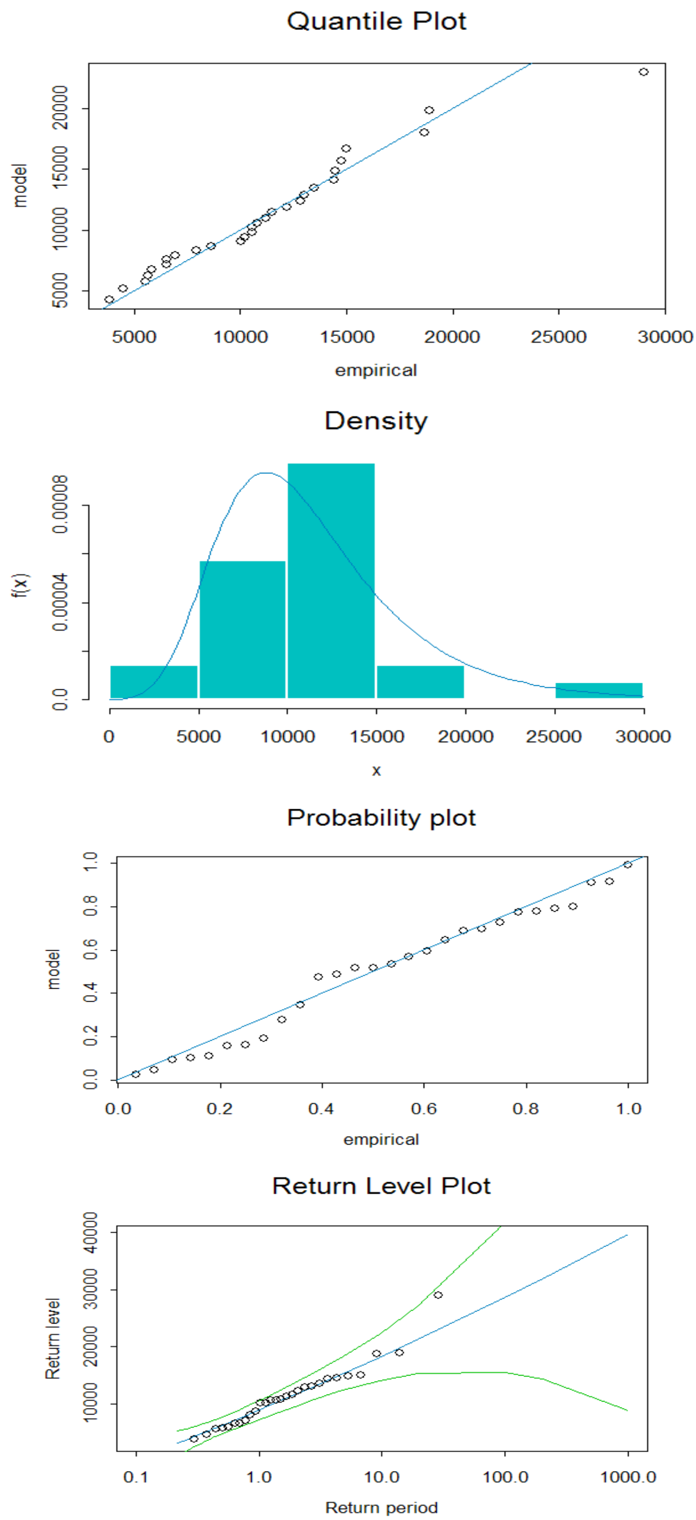

Figure 26. Distribution diagnostic testing of the Jinsha River.

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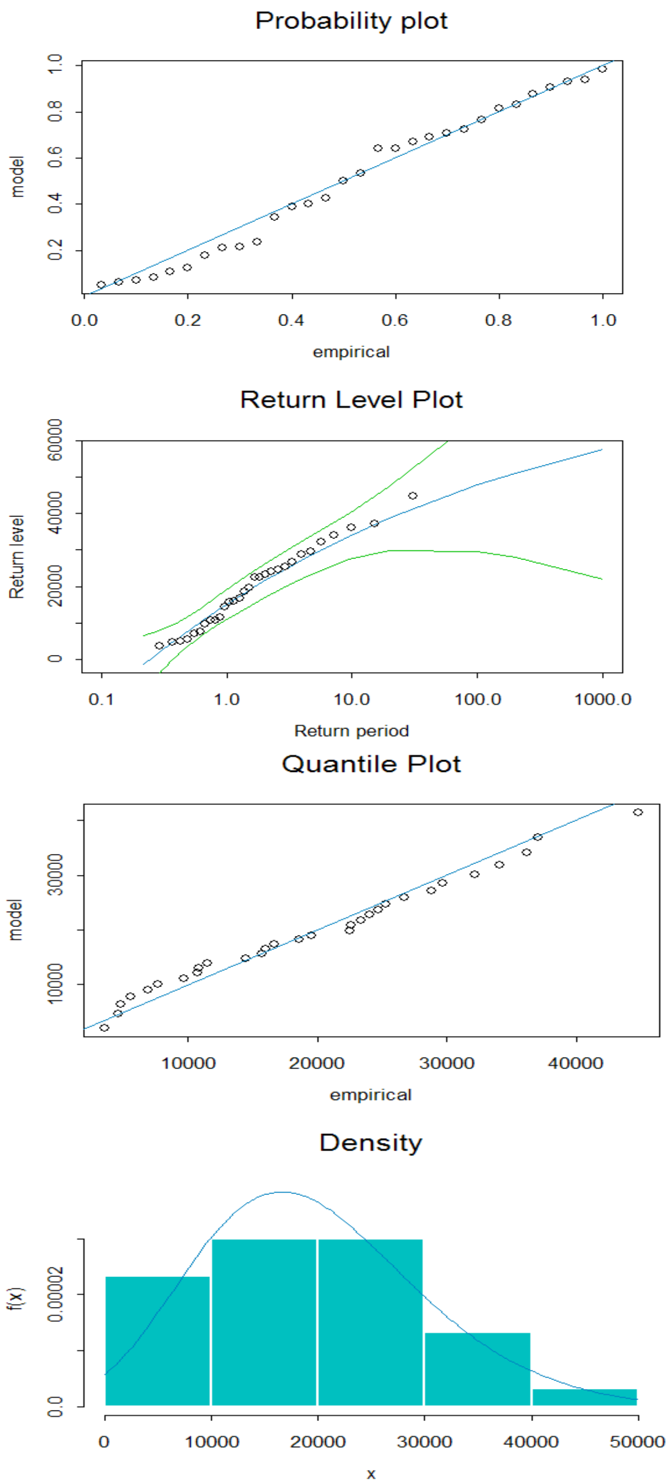

Figure 27. Distribution diagnostic testing of the Jialing River.

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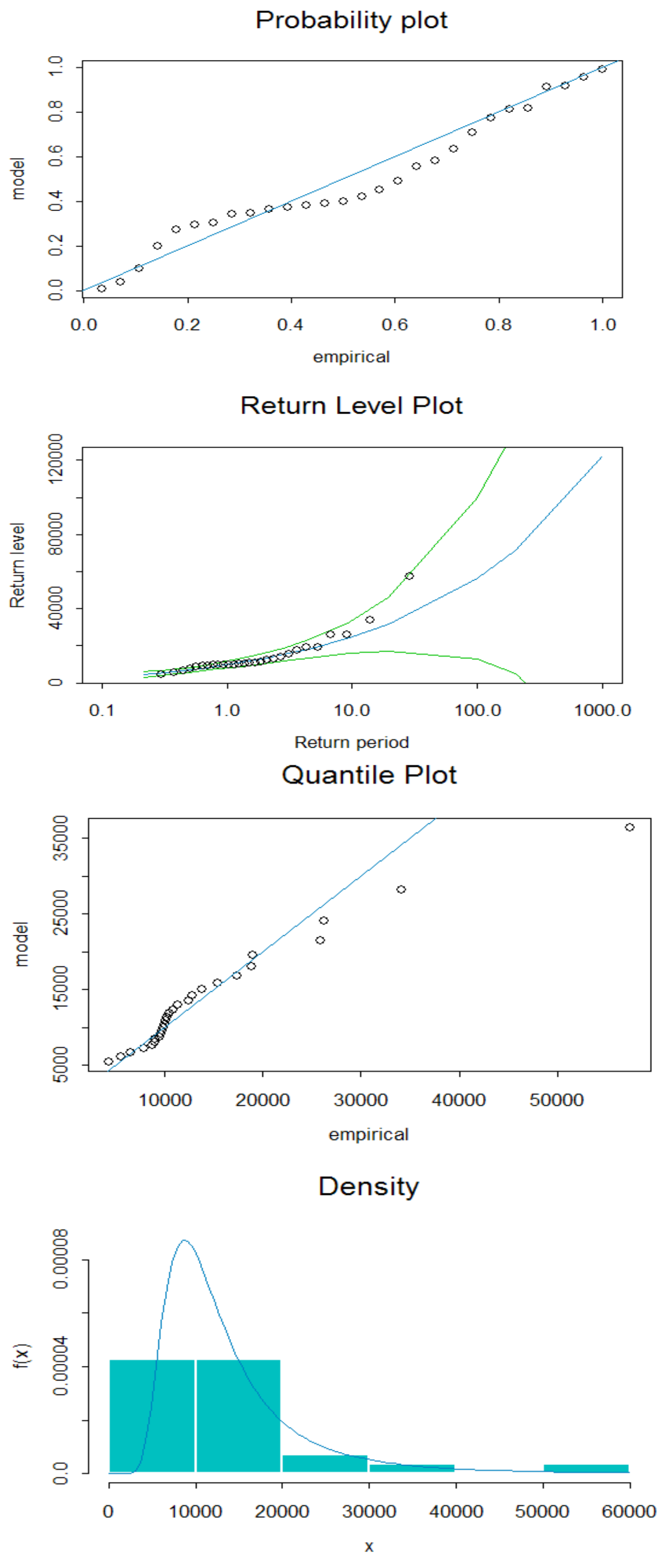

Figure 28. Distribution diagnostic testing of Min River.

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The Figure 29 shows an example of the contour surface of 3-d flood volume calculated by PNLTCED with 100-year joint return period. So there should be different combinations with same joint return period.

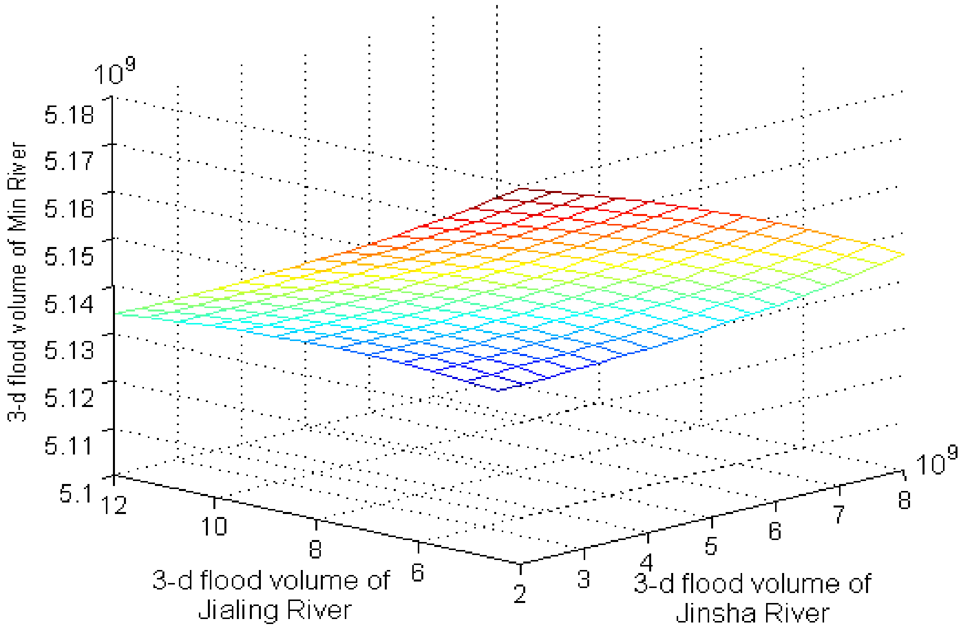

Figure 29. Contour surface of 3-d flood volume with return period of 100 year.

The results under the condition of different combinations of tributary flood volumes calculated by the PNLTCED are shown in Table 26. The predicted 100 years joint return period flood volume should be more severe than 1000 years return period design flood volume for TGDP predicted by CHDC recommended Pearson Type III model.

Table 26. The combination of the tributaries flood with100-year return period

Modes	Jinsha River		Min River		Jialing River		Wu River		Fitting data of TGV 3-d flood volume	
	T	V	T	V	T	V	T	V	T	V
Mode 1	2	43.3	25	51.2	65	92.8	2	26.8	100	260.4
Mode 2	68	70.7	26	51.4	2	52.8	2	26.8	100	245.9
TGV	T=100, V=208.0; T=500, V=235.6; T=1000, V=247.5;									

Note: T -return period (units: year); V -3-day flood volume (units: 108 m3).

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10. The Application of MOFLNPM Model to the Typhoon Disaster Prevention and Reduction System

Considering typhoon characteristics in a different area, the long term data of disaster factors can be used to predict the joint probability based on MOFLNPM system. The estimated results, combined with disaster consequences, topography, geology, society and economic characteristics, can be used as the warranty of typhoon disaster zoning.

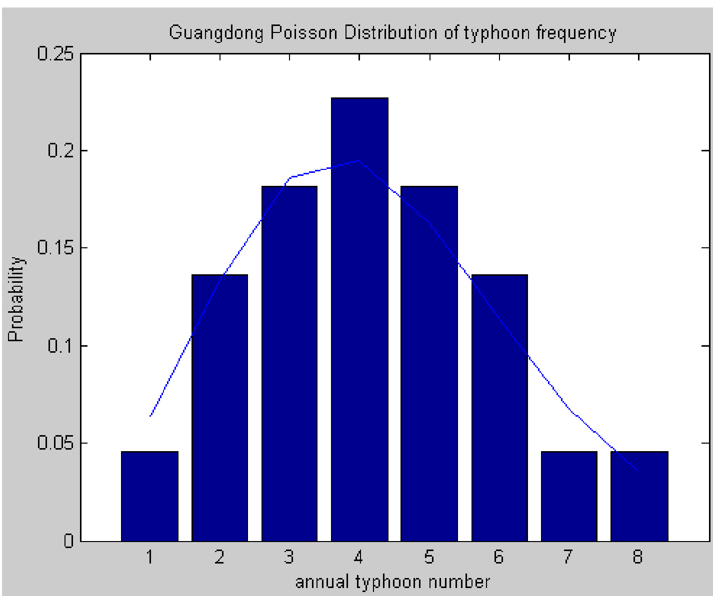
Based on joint probability prediction results of the disaster factors, different disaster prevention request and structural form of protection engineering in different area, the disaster prevention criteria can be proposed according to the typhoon disaster zoning, while for the existing protection engineering in coastal and estuarine cities, it is necessary to reassess the reliability of their original design using the proposed model.

The new theory can be applied to perform risk assessment of typhoon induced secondary disasters for residential areas, reservoirs and the areas in which mud-rock flow and slide tend to occur. The assessment results can be used as basis of scientific disaster zoning.

The proposed probability prediction system combined with weather forecast systems can offer necessary information to governments to make reasonable decision of emergency measures (such as evacuate, rescue, repair, and so on) for disaster prevention and reduction.

In the application of the new theory, it should be gradually developed by continuously repeating the optimization process for minimizing investment and maximize prevention effect, and be adopted by the state disaster prevention criterion.

In the MOFLNPM first layer – typhoon characteristics can be checked by marginal distribution as Figure 30 a-f and corresponding marginal distributions with parameters for typhoon characteristics (Table 27). Figure 31 is typhoon disaster zoning map in China.



a. annual typhoon frequency.

Figure 30. (a-f). (Continued)

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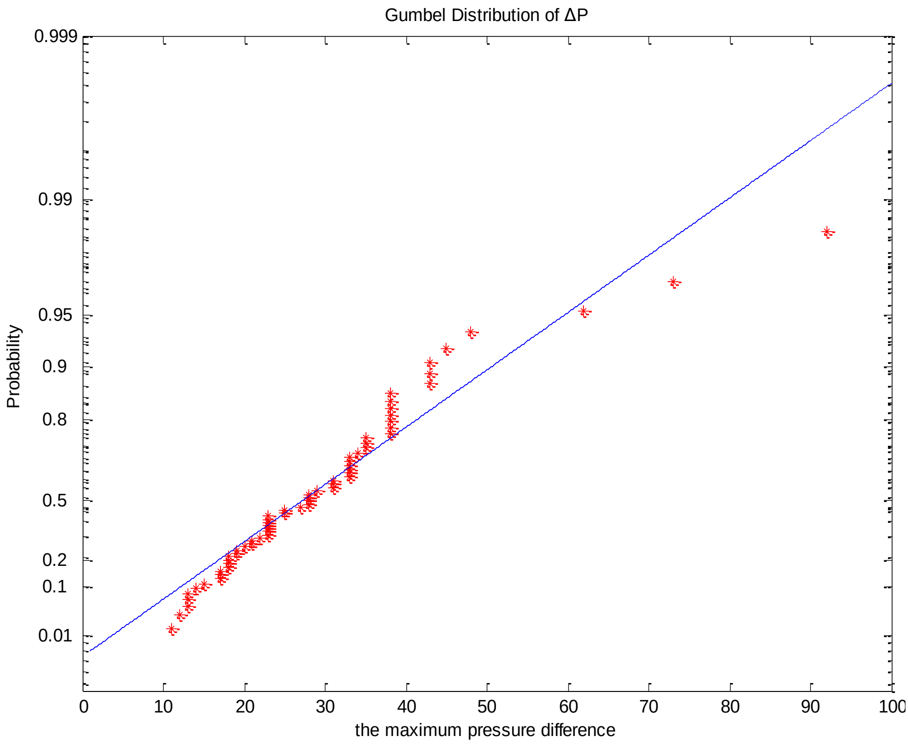
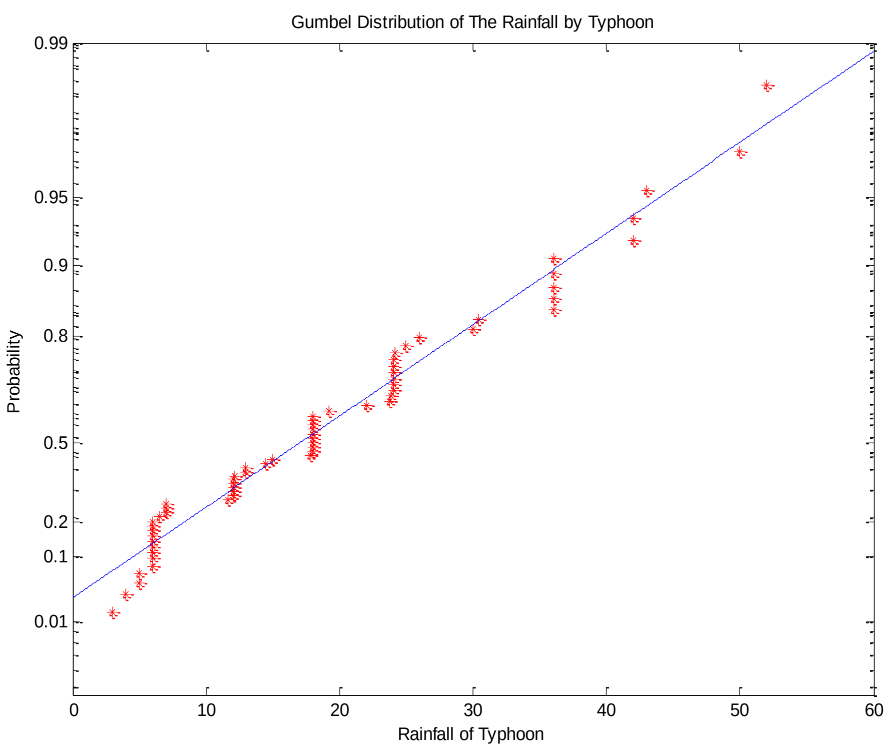


b. Curve fitting ofΔP.



c. Curve fitting of t.

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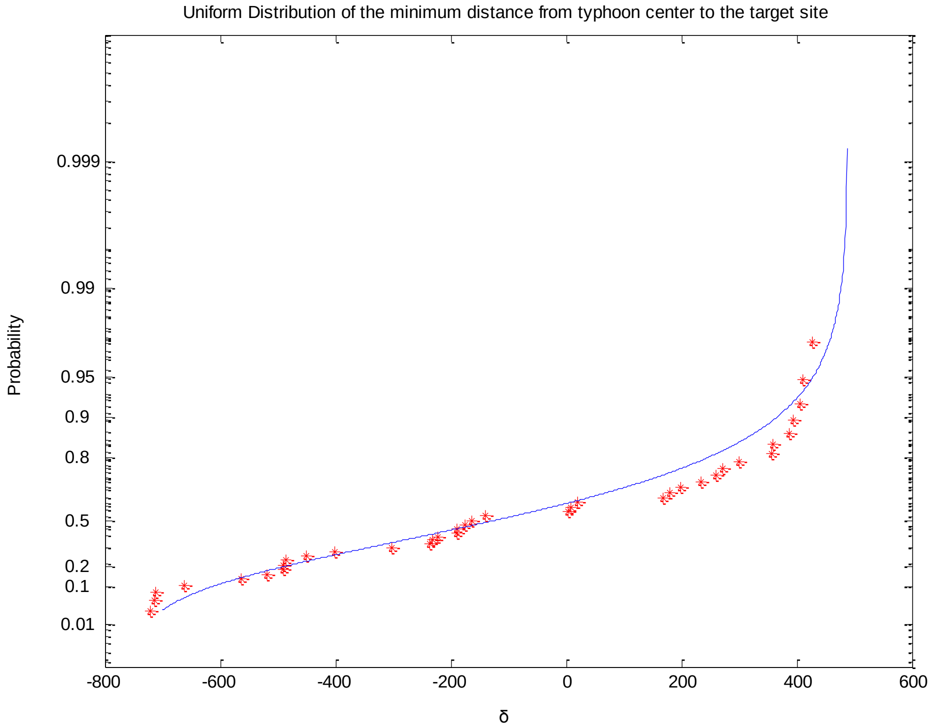
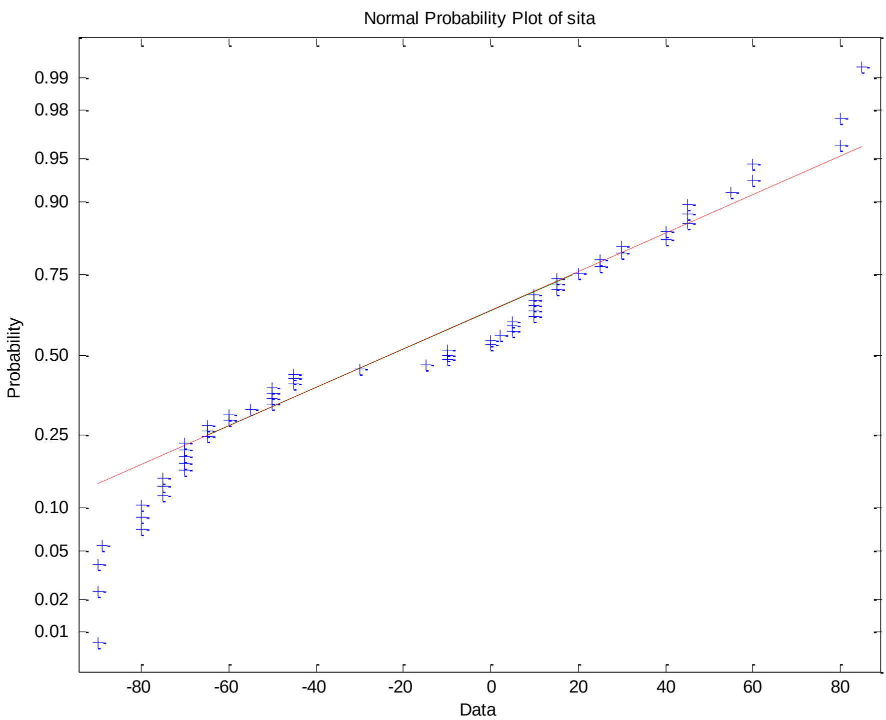


d. Curve fitting of δ.



e. Curve fitting of θ.

Figure 30. (a-f). (Continued)

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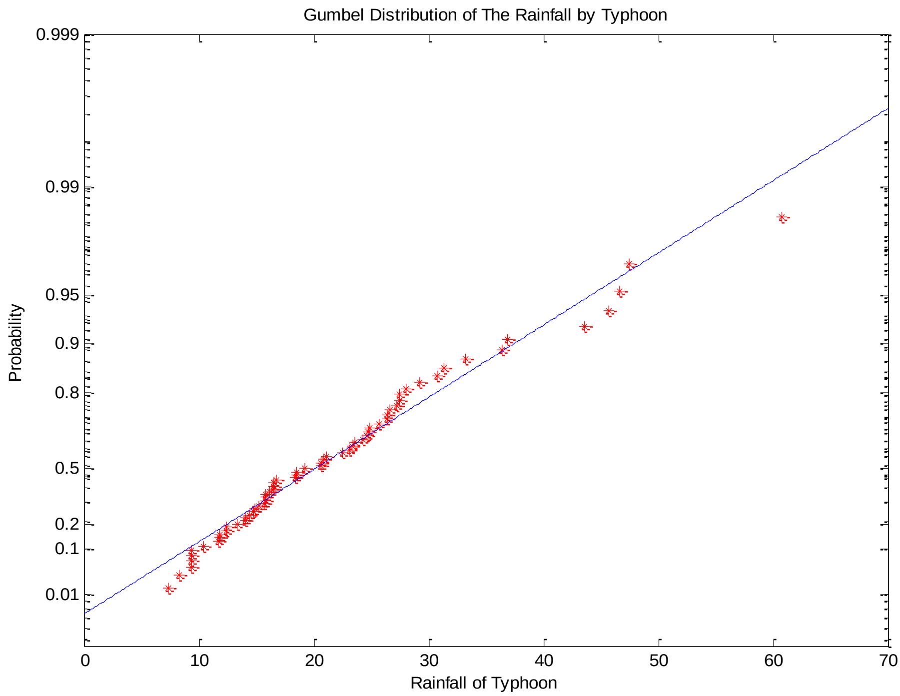

f. Curve fitting of S.

Figure 30. (a-f). Curve fitting of typhoon characteristics.

Table 27. Marginal distribution and parameters of typhoon characteristics

λ	Distributions	Mean	Standard variance	Parameters
	Poisson	λ =6.19		
ΔP（hPa)	Gumbel	21.89	14.96	a=0.073, b=14.45
Rmax (km)	Lognormal	45.79	25.22	μ=3.71, σ =0.5
s (m/s)	Gumbel	30.19	15.95	a=0.07, b=22.4
δ (km)	Uniform	44.37	169.63	a=294.6, b=333.8
θ (°)	Normal	15	37.36	μ=15, σ =37.36
t (h)	Gumbel	12.95	5.56	a=0.20, b=10.29

CONCLUSION

The theory of MCEVD is based on the combination of typhoon process maxima data sampling and joint probability analysis of typhoon-induced extreme sea environments.

MOFLNPM is a theoretically based, applicable model for the prevention of typhoon induced disasters. It can be widely used not only in coastal areas, offshore structures, and hydraulic engineering, but would also be helpful to governments as a scientific based measure in subsequent decision-making for disaster prevention and mitigation.

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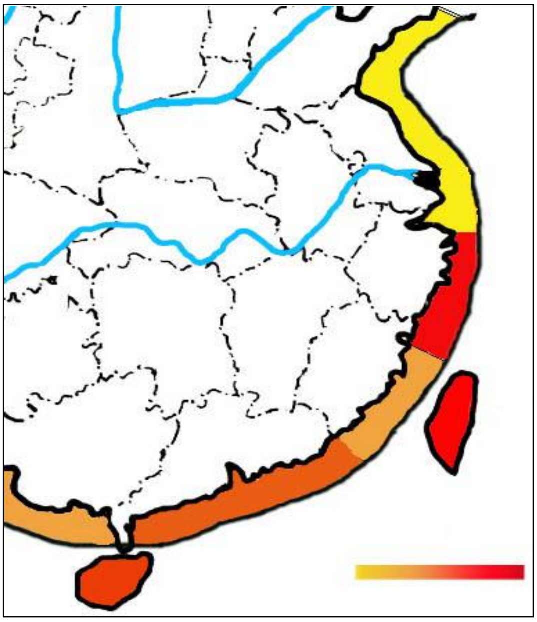

Figure 31. Typhoon disaster zoning map in China.

Design codes calibration of offshore, coastal and hydraulic infrastructures show that some traditional methods and models can not support enough safety for very important infrastructures in global climate change conditions. The disasters induced by the 1975 typhoon Nina and 2005 hurricane Katrina give an important lesson: When natural hazards combined with human hubris, the natural hazards become a catastrophic disaster sooner or latter.

Acknowledgments

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Chapter 2

THE ROLE OF POINT-OF-CARE TESTING IN COMPLEX EMERGENCY AND DISASTER RESILIENCE

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ABSTRACT

Resilience through use of point-of-care (POC) testing in small-world networks will change the future landscape by bringing evidence-based decision-making to sites of need globally. Point-of-care (POC) testing is performed at or near the site of care to accelerate decision-making. This chapter provides value propositions that show new POC technologies can be assimilated into challenging locations when infrastructure is compromised, and for preparedness, proposes developing professional competence and team experience in the context of existing small-world networks facilitated by geographic information systems. Environmental limitations demand that POC devices and test kits adhere to manufacture temperature and humidity specifications, which may not be robust enough for the hot, cold, and humid conditions encountered in field operations. Indeed, the effects of environmental stresses can no longer be ignored. Hence, there must be strategic alternatives for placement of POC testing in alternate care facilities. Overall, POC testing promises to transform crisis standards of care by bringing enhanced evidence-based diagnosis and treatment to victims most in need and by accelerating screening and triage critical to effective emergency and disaster care.

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PART 1. INTRODUCTION

Point-of-care (POC) testing (Figure 1) is testing at or near the site of care [1]. Resilience means the ability to recover readily. By increasing the value of decision-making at the site of care, one can assure resiliency, for the individual patient who might be in need of self-monitoring, for rational responses to crises, and for nations made up of more resilient individual communities. Psychologically, resiliency in an individual suggests coping with stress and adversity, then bouncing back to normalcy, perhaps in even better shape than before. "That which does not kill us makes us stronger!"—Nietzsche. Resiliency to life-

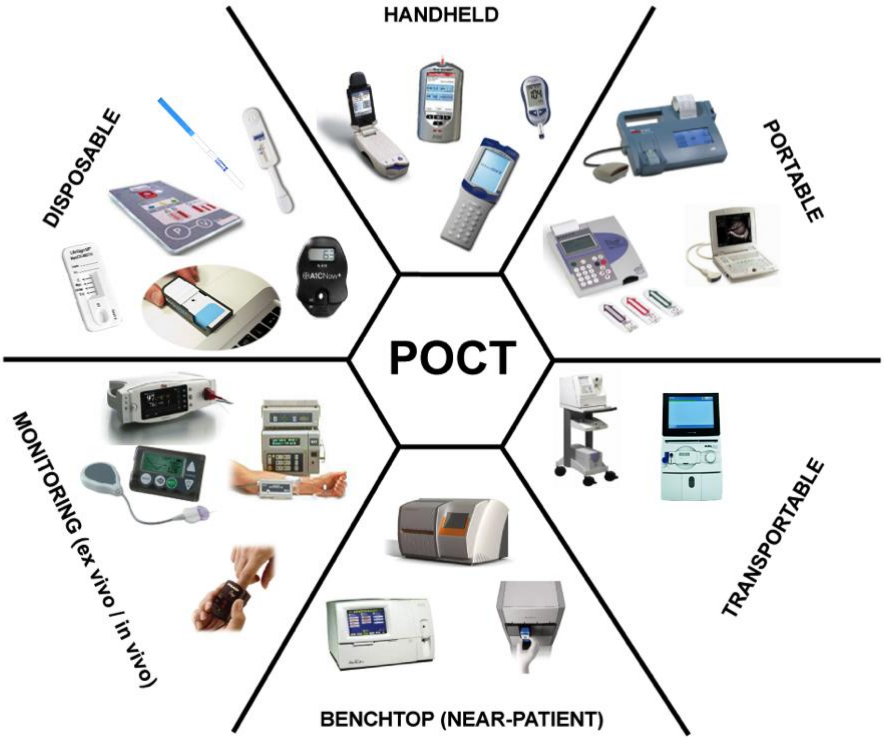

Figure 1. Point-of-Care Testing Formats. The devices illustrated are: (1) Handheld: Nova StatSensor (top), Accu-Chek Aviva Glucose Meter (right), i-STAT (wireless connectivity) (bottom), and the epoc (left). (2) Portable: iRMA System (top), a FN500 Laptop Ultrasound Scanner (right), and the Alere Triage with Cardiac Test Cards (left). (3) Transportable: Nova pHOX System (left), and the Radiometer ABL80 Flex System (right). (4) Benchtop: T2 Biosystems NMR Instrument (top), Cepheid GeneXpert IV (right), and the Nova Critical Care Xpress (left). (5) Monitoring: Masimo Radical-7 (top), VIA Blood Glucose Monitor (right), Nonin Onyx II (bottom), and the Guardian REAL-Time Continuous Glucose Monitoring System (left). (6) Disposable: IND Diagnostics HCG One Step Pregnancy Test (top), OraQuick ADVANCE® Rapid HIV-1/2 Antibody test (upper right), A1CNow+® (lower right), MinION (bottom), LifeSign MI® Myoglobin/CK-MB/Troponin I Rapid Test (lower left), and ABORhCard® (upper left). Websites: ABORhCard® (www.micronics.net); Accu-Chek (www.accu-chek.com); A1CNow+® (www.a1cnow.com); Cepheid (www.cepheid.com); epoc (www.epocal.com); FN500 (www.foinoe.com); Gaurdian (www.medtronic.com); IND (www.ind.ca); iRMA (www.itcmed.com); i-STAT (www.abbottpointofcare.com); LifeSign MI® (www.lifesignmed.com); Masimo (www.masimo.com); MinION (www.nanoporetech.com); Nonin (www.nonin.com); Nova (www.novabiomedical.com); Radiometer (www.radiometer.com); Triage (www.alere.com); T2 Biosystems (www.t2biosystems.com); VIA (www.viamedical.com).

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threatening events is not uncommon. This idea, with a caveat, is backed by scientific evidence, as Seery et al. [2] reported: "In a multiyear longitudinal study of a national sample, people with a history of some lifetime adversity reported better mental health and well-being outcomes than not only people with a high history of adversity but also than people with no history of adversity…. people with some prior lifetime adversity were the least affected by recent adverse events. These results suggest that, in moderation, whatever does not kill us may indeed make us stronger." This chapter addresses the fundamental POC principles underlying resilience, and will assemble the POC puzzle for emergency and disaster medicine (Figure 2).

Figure 2. The Fabric of Point-of-Care Resiliency: Lacking a Solution. The frame shows the incomplete puzzle pieces scattered demonstrating the chaos that comes with a lack of organization and integration of point-of-care testing.

PART 2. NEEDS ASSESSMENT

Several surveys have defined the needs of emergency and disaster responders during crises [3-7]. The most recent surveys were published in *Point of Care* in 2012 [8-10]. Survey respondents preferred disaster-ready POC devices that directly sample into a test cassette, which stores all biohazard material for easy disposal. When asked to explain the reasoning behind their choices in free response queries, respondents cited minimizing contamination when performing infectious disease testing outside of the laboratory. They also indicated that a direct sampling test cassette is more practical for use in the field or in an alternate care facility compared to sampling indirectly using a Vacutainer and then transferring the sample

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for analysis, which risks contamination. In urgent care and emergency department settings, respondents preferred coupled sample collection using a Vacutainer and analyzing a single sample for multiple pathogens. They also cited the desirability of drawing a single sample and having multiple testing options to fully evaluate each patient.

Infectious diseases can cause significant morbidity and mortality during disaster response [8,11-21]. Survey respondents indentified high priority pathogens, such as methicillin resistant *Staphylococcus aureus*, *Salmonella typhi*, *Vibrio cholerae*, *Escherichia coli*, *Staphylococcus aureus*, and *Streptococcus pneumoniae*, which commonly are encountered during disaster response [8,12-21]. Developing rapid near patient infectious disease testing for priority pathogens could improve sepsis management, a problem identified by Farfel et al. in Haiti [11].

During mass casualty events blood donation supplies will likely not meet the increased patient demand [22]. Respondents identified HIV 1/2 virus, ABO typing, and clinical sensitivity (>90%), high clinical specificity (>90%), rapid processing speed, and hepatitis B and C viruses as priority targets for a rapid POC device that can address the need for emergent blood donation screening during mass casualty events when traditional transfusion services infrastructure is destroyed. Especially in settings with high prevalence of HIV-1/2 and hepatitis, volunteers who accidentally stick themselves with needles should be able to determine their risk by testing sources. Hence, caches must include resources that will allow volunteers to perform these tests on the victims they are assisting.

Point-of-care testing has the unique ability to provide critical diagnostics during the shortages in resources and healthcare availability experienced during disasters, such as Hurricane Katrina [23]. When developing new POC devices for disasters high clinical sensitivity (>90%), high clinical specificity (>90%), rapid processing speed, and the ability to operate on battery power were all predictive of device selection by survey respondents. A high value attribute of POC testing is the ability for flexibility and adaptability. Therefore, POC tests should be easy to use and function in austere low resource environments. First line medical and disaster responders should be equipped with devices to perform critical tests at the point of need [24].

PART 3. SMALL-WORLD NETWORKS (SWN)

A small-world network (SWN) for healthcare evolves naturally from social interactions, population dynamics, the regional transportation grid, and sites of placement of health are resources. However, when crises occur, the SWN becomes constrained by interrupted transportation within the limited geographic topology. Hence, the optimization of POC testing in SWNs, while improving everyday urgent care, is also designed to enhance emergency care, disaster preparedness, and public health response at both the local province (or state) and global regional levels. New monitoring and diagnostic technologies, placed strategically at network nodes and hubs, improve workflow and accessibility of critical information for decision-making.

The physical SWN(p), when transformed into a *virtual time domain network*, *SWN(t)* (Figures 3 and 4), anticipates the dynamics of successful responses and rescues. The SWN(t) reveals why POC testing, such as fingertip oxygen saturation monitoring in ambulances and

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handheld cardiac biomarker testing in community hospitals, has high impact during complex emergencies and natural disasters. Rapid test results optimize therapeutic turnaround time (TTAT) [25], the time from test ordering to treatment locally, while accelerating overburdened care paths globally. When there is no crisis, daily use of POC testing in the SWN improves the efficiency of physicians, nurses, and patients alike. In low-resource settings, not the cost, but the integrated net value of POC testing is the most significant metric. Especially in regions of heterogeneous population clusters where people in need may not have immediate access to healthcare facilities, the POC SWN concept can be enhanced by determining provincial priorities based on demographic resource scoring [26,27] by use of geographic information systems [28], and by linking individual SWNs in a broader regional scheme for optimal resiliency.

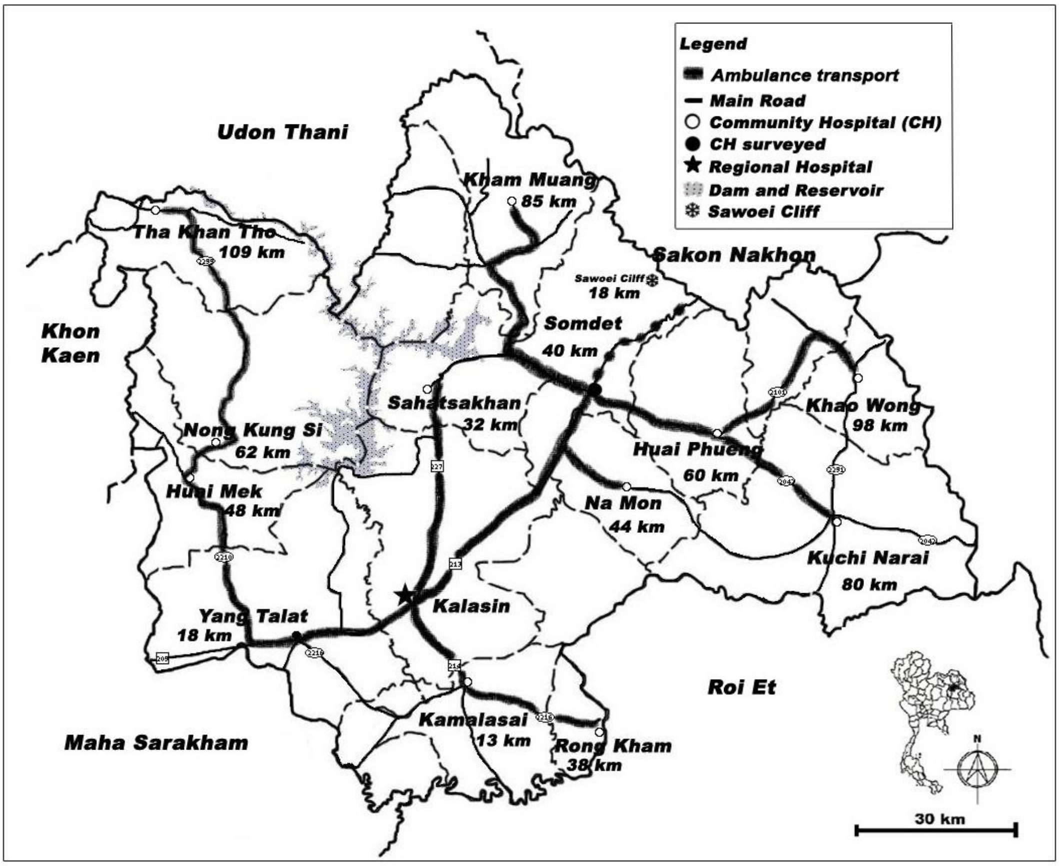

Figure 3. Small-world Network of Kalasin Province in Rural Isaan, Thailand. In Kalasin, the mean (SD) distance from community hospitals to the regional hospital is 56 (29) km (median, 53 km; range, 13-109 km). Transport time by ambulance is 60 (30) minutes (median, 60 minutes; range, 15-120 minutes), much too long for patients with acute myocardial infarction and other acute medical problems needing immediate attention, diagnosis, and triage for definitive treatment.

Table 1 summarizes principles of application of POC testing in SWNs [23,27,29-33] where key information can "jump" quickly from site to site (node to node) and take short-cuts that serve clusters of people faster, even when no helicopter rescue ordinarily is available in low-resource rural settings. Multidisciplinary decision makers can allocate resources, such as

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POC oxygen and hemoglobin monitors [34], and appropriately triage patients, who travel to regional and distant facilities that can handle more challenging medical problems beyond local capability to treat, according to accepted standards of care [35,36]. Other examples [37-39] provide SWN practice details for the Thai 2004 Tsunami province, Phang Nga and its long-term adaptations to readiness, and the Great Bangkok Flood of 2011 (discussed below).

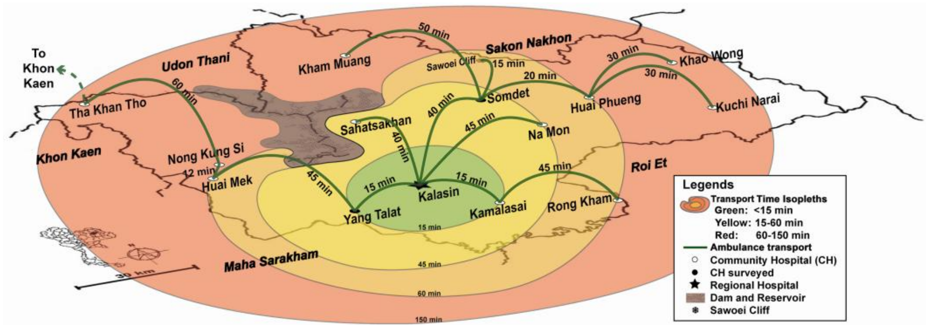

Figure 4. Transformation of the Small-World Network from the Physical (p) to Temporal (t) Domain. One can use the SWN(t) to identify nodes and hubs within prolonged time isopleths where POC testing can help to enhance standards of care best by reducing risks associated with excessively slow care paths and potential isolation in the event of a crisis.

Table 1. Small-World Network Practice Principles for Point-of-Care Testing

SWN Attribute	POCT Application	Principle
Remote nodes at the periphery of a SWN	Cardiac biomarkers (eg, Cobas h232 handheld cardiac troponin T and BNP testing)	In remote emergency departments where physicians do not want to hold acute myocardial infarction patients overnight because of the risk of death, fast diagnosis with POC testing triggers rapid transport
Primary Care Units Multiplex POC testing (PCUs) at hubs and “super” nodes		Physicians living on site in low-resource settings improve workflow when rapid test results are available directly at PCUs
Hub PCUs and their local village populations	Hemoglobin A1c performed directly in the village PCU	Knowledge of the quality of diabetes control at the village level aids the local community hospital care team to adjust therapy rapidly
Nodes subject to isolation during earthquakes, tsunamis, or floods	Emerging POC patho-gen detection using molecular diagnostics	Direct nucleic acid detection provides an efficient alternative to traditional culture methods that typically are not available in small community hospitals and, in times of disaster, may not be accessible at all
Ambulance transport	Oxygen saturation monitoring (pulse oximetry)	Continuous monitoring of the effectiveness of ventilation during prolonged transport within or outside the SWN improves outcomes
Added value for professional groups within the SWN	Preparedness and “just-in-time” educa-tion and training resources	Familiarity with performing POC testing daily lends to expertise in times of crises, such as complex emergencies, provincial disasters, or newdemics
Demographic care units determined by village popula-tion clustering	Non-invasive hemo-globin monitoring forcritically ill hospitali-zed patients	Endemic Dengue fever outbreaks with hemorrhagic fever require frequent decisions regarding need for transfusion at critical hemoglobin depletion levels
Health resource scores using	POC testing placement where needed the most objective multifactor scoring	Province scores depend on perpetually current quartile rankings for linked health care resources, poverty levels, and care paths

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To facilitate complex emergency and disaster readiness, the SWN(p) supports demographic care units, such as Primary care units (PCUs) serving discrete clusters of towns, communities, and villages, and integrates healthcare delivery components. A POC coordinator (see below) can be responsible for home monitoring, PCU screening, mobile medical units [40,41], and community hospital emergency department diagnostic services. Province- or state-level coordination helps connect regional hospitals and tertiary care centers, albeit incurring excessively long transportation times. Therefore, the behavior of the SWN(t) should be understood well and in advance of crises. In effect, added value arises for contiguous geographic regions based on micro- and macro-clustering [42] of crisis resources that extend beyond the basic framework of local infrastructures. These infrastructures can be mapped with geographic information systems when adequate input data are available, and may be measured in time saved following the transformation of SWN(p) to SWN(t). When optimized, SWN(t) should help reduce the impact of even major complex emergencies and disasters, such as occurred in Haiti (Figure 5).

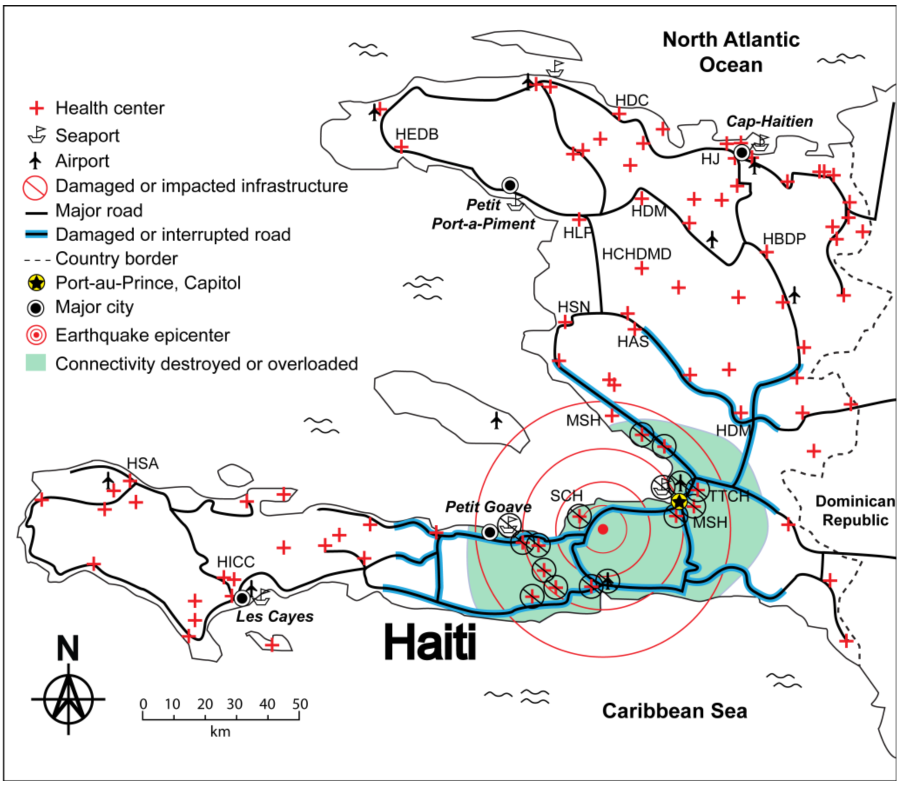

Figure 5. High impact of earthquake on health care small-world network in Haiti. Located on an island in the Caribbean Sea, Haiti borders the Dominican Republic to the East. The SWN relates the earthquake epicenter to health care infrastructure destroyed. Victim rescue routes were interrupted. Disaster responders arrived late and, in some cases, carried POC devices, which they discovered were vulnerable to environmental temperature extremes. Hospitals ("H") are as follows: HAS, Albert Schweitzer; HBDP, Bienfaisance De Pignon; HCHDMD, Claire Heureuse De Marchand Dessalines; HDC, De Carrefour; HDM, De Marmelade; HEDB, Evangelique De Bombardopolis; HICC, Immaculee Conception des Cayes; HJ, Justinien; HLP, La Providence; HSA, St. Antoine De Jeremie; MSH, Mission Saintard; HSN, St. Nicolas; MSH, Maternité Solidarité; SCH, Sainte Croix; TTCH, Trinite Trauma Center.

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PART 4. TECHNOLOGY ADVANCES THAT FACILITATE POC SWNS

4.A. Geographic Information Systems (GIS)

Appropriate management of POC testing resources can ensure that resilient communities are prepared to respond to and recover from crises quickly. A GIS reveals patterns, relationships, and trends by facilitating information analysis in relation to the location on earth. A GIS can improve efficiency, communication, and decision-making [43] in national

Table 2. Role of Geographical Information Systems (GIS) in Crisis Management

Crisis Management Stage	Goal	Country	GIS Objective(s)
Planning	Risk and hazard assessment	Vietnam	To map flood risk and identify potential vulnerable locations. [52]
		Eastern Mediterranean	To identify high-risk areas by mapping the spatial distribution and relative intensity levels of five natural hazards and layering with population distribution data. [53]
		U.S.A.	To map all injury locations after 1994 Northridge, California, earthquake in order to better anticipate which areas are at highest risk and to plan rescue efforts for future earthquakes. [54]
Mitigation	Reduction of the probability of unavoidable effects of disasters	Indonesia	To evaluate a tsunami warning system that effectively detects, monitors, forecasts, evaluates losses, and helps provide relief. [55]
Preparedness	Development of plans to save lives and improve disaster response operations	Singapore	To maximize the effectiveness of ambulance deployment through dispatch demand analysis. [56]
		U.S.A.	To use a behavioral risk factor surveillance system in South Carolina to estimate and compare the prevalence of health risks versus the availability of response resources. [57]
Response	Emergency assistance for victims	United Arab Emirates	To design a coordinated network that helps law enforcement officers identify, dispatch, and track resources for timely intervention in times of crisis. [58]
		Greece	To improve and implement location-based medical applications for quick access to information and to route instructions to patients. [59]
Recovery	Restoration of short- and long-term community stability	Indonesia	To map the spatial distribution of affected communities and estimate mortality in order to dispatch humanitarian agencies to areas of greatest need. [60]
		U.S.A.	To research and suggest use of technologies, such as barcode tracking and biometrics, that track and identify disaster victims. [61]

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defense, ecology, economics, social science, and public safety. Applications include improving the U.S. civil air defense command [44], assessing the invasive potential of the Mediterranean fruit fly in California and Italy [45], and determining the spatial distribution of regional per capita in the Beijing-Tianjin-Hebei metropolitan region [46]. A GIS was used by Zhijun et al. [47] to assess and identify levels of fire risk in the vicinity of Jiling, China, by facilitating analysis of relationships among meteorological data, social-economic data, land use/land form zonation, grassland types, and historical fires to mitigate hazards, reduce potential losses, properly allocate resources, and raise public awareness.

A GIS has been used in health care applications to monitor disease outbreaks [48], to predict early infection disease risk by analyzing regional and global climate changes [49], and to monitor HIV/AIDS epidemics in Africa and effectively allocate treatment and resources to areas most affected [50]. During crisis, the GIS allows viewing of appropriate combinations of data such as population, geography, and road networks to pinpoint potential hazards and health emergency needs [51]. Thus connectivity of POC testing should not be limited to hospitals, nor limited to discrete communications in the absence of knowledge of where the patient is located, the criticality of results, or how, if critical values in fact do appear, how the patient will be rescued, triaged, and transported efficiently to definitive treatment.

Table 2 [52-61] identifies disaster management stages and country examples of how a GIS fulfills the goals of disaster planning, mitigation, preparedness, response, and recovery. We have designed [28] an integrated approach that combines GIS and POC testing within the SWN and its nodes and hubs, which represent sites of important decision-making, triage, and treatment in most health care systems (Figure 6). The next step is to implement the GIS-POC-SWN concept with a “knowledge optimizer.” That is, at first the POC Coordinator integrates POC results, but later can be facilitated by a self-contained unit that serves as a field hub for intelligent interpretation of test results and delivery of medical instructions, whether during disasters and emergencies, or daily patient-focused care.

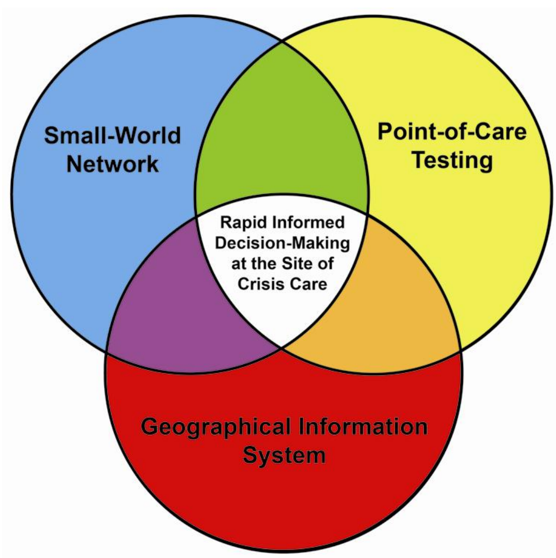

Figure 6. Knowledge-Optimized Medical Intelligence. This Venn diagram illustrates the strategic synergy of a GIS, a SWN, and POC testing when integrated to enable rapid informed decision-making at the site of crisis care.

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4.B. Demographic Deployment

Kost et al. [27] devised an integrated demography, health resources, and poverty "scorecard" system that identifies SWNs (e.g. provinces) in need of POC assets. As public health and economic conditions change, scores are updated annually to identify regions moving into the top quartile of risk, that is, the bottom quartile of combined health, economic, and personnel resource availability. The M-GIS can tie in these and other demographic data, such as census information, population distributions, and primary care records. For example, knowledge of a) people with chronic diseases (e.g. diabetes), b) birthing mothers and newborns, and c) children in the community would be invaluable when a complex emergency or natural disaster hits. Demographically targeted deployment of pediatric POC testing [62-66] in rural primary care units during power outages and crises would bring aid to vulnerable infants and children more quickly than random searching. Point-of-Care testing resources, know-how, and patient results could be tracked through rescue stages using GPS/communication devices [e.g. GeoSkeeper Aerotel Medical Systems (http://www.aerotel.com/en/)] placed on wrists or around necks of victims. Trained personnel will nearly always be scarce, and demographically tuned M-GIS approach also could be used to optimize POC coordinators and their efforts in times of dire need. Additionally, this approach would allow demarcation of high population density areas for national and regional planning, preparedness, and response.

4.C. Small-World Network Hubs

The utility of a GIS-POC-SWN during disaster response relies on a flexible network that can reliably disseminate information to and from victims, first responders, and physicians. In low-resource settings, the hub is made up of the emergency medical system (EMS) radio communications headquarters and its personnel. Typically, hubs and POC are not integrated. Therefore, hubs should integrate data for analysis and link POC test results, GPS locations, and patients with interpretive medical information.

Ensuring connectivity through improved hub functions will help track patients in real-time via cell phone tower and other infrastructure. For example, telecare technologies produced by Aerotel Medical Systems could be used to support effective medical information processing. The Aerotel GeoSkeeper®, part of the POC Coordinator "tool kit" (Figure 7), is a wireless device that uses GPS to track patients, and alerts medical providers of patient locations when they are in danger or leave geographically defined limits. The Geoskeeper also can transmit relevant medical monitoring information, such as the electrocardiogram.

Hence, hubs serve as centers of activity for medical intelligence passed to and from first responders and care teams. They will enable the organization to analyze GIS data. In Figure 8 for example, hubs could be placed in Jakarta, a mobile lab, and an alternate care facility. Computer servers in these hubs would be capable of sending and receiving results, then, intelligently interpreting POC results for responders who may not be able to triage due to lack of adequate knowledge. Thus, the GIS-POC-SWN would help initiate triage faster and allow immediate transfer of patients to sites of definitive treatment, plus provide instructions about how to reach those sites with the benefit of GPS tracking.

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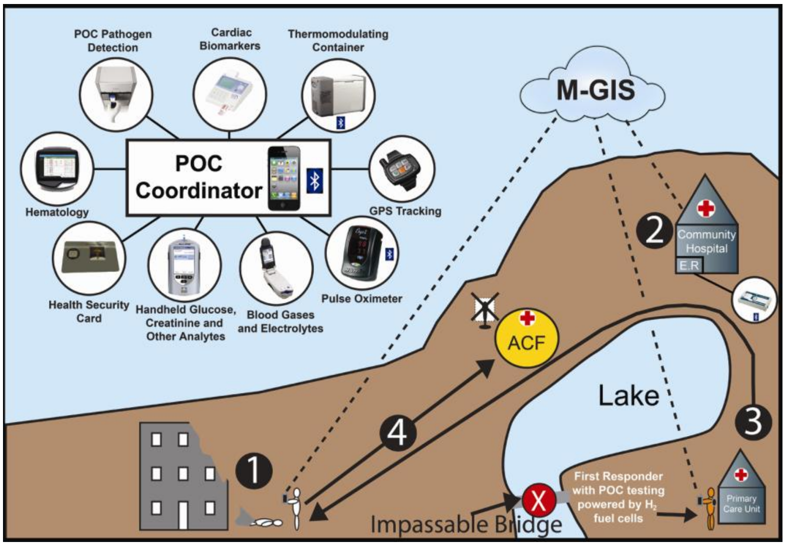

Figure 7. Crush Injury Response Facilitated by the GIS-POC-SWN Approach. The medical GIS (M-GIS) facilitates the sequence of events in stages. Stage 1: An earthquake victim is found trapped under a collapsed building following an unexpected earthquake. Stage 2: The point-of-care Coordinator who is located at a Community Hospital isolated by road damage uses a communications hub (inset circle) and analyzes the SWN by means of a M-GIS, then identifies the nearest medical responder with appropriate POC testing resources. Stage 3: The medical responder at a Primary Care Unit analyzes the quickest route using M-GIS access and bypasses hazards, such as an impassable bridge, to reach the victim. Stage 4: The victim is transported safely to an alternate care facility (ACF), triaged using M-GIS information and POC testing, and transported by helicopter to definitive treatment.

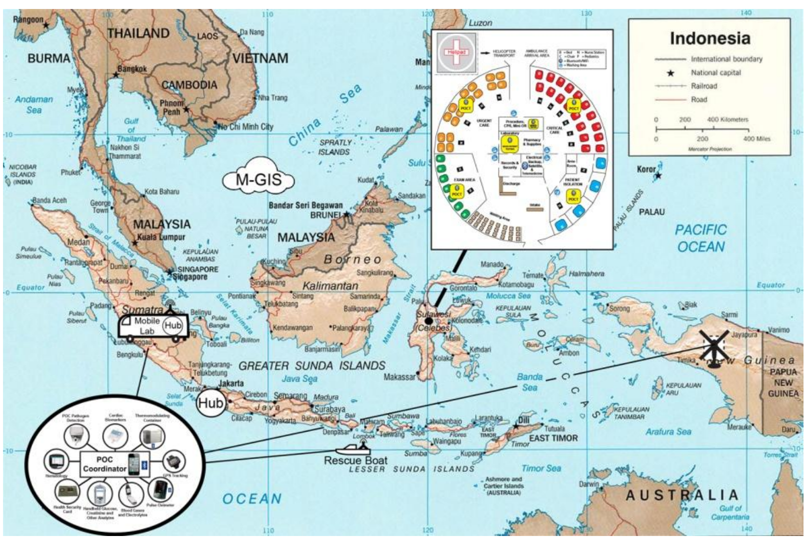

Figure 8. Medical GIS (M-GIS) for Crisis Response in Indonesia, an Island Nation. A rescue boat, helicopter, and ground-based mobile laboratory can communicate through a medical GIS (M-GIS) cloud to deliver care more effectively for the 18,000 islands of Indonesia. To the extent possible, data can be transmitted through mobile phone cell towers, the web, radio communications, and other infrastructure. Medical intelligence created within the M-GIS will help first responders diagnose and treat patients. [Map adapted from public domain courtesy of the University of Texas Libraries, at Austin (http://www.lib.texas.edu/maps/indonesia.html)]

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4.D. Environmental Protection and Stability

POC testing is deployed into environments with temperature and humidity extremes that may exceed manufacturer-specified storage and operating parameters. Recent studies show that simulated disaster conditions affect the performance of reagents rendering them unreliable for use [42, 67]. Therefore, POC resources should be stored and operated within manufacturer specifications. Novel thermomodulation technologies are being developed to protect POC testing reagents and instruments and to ensure excellent performance in austere environments [68]. Until these products become available, responders should consider placing POC resources in alternate care facilities. Figure 9 shows a conceptual design for an alternate care facility (ACF) that can be reconfigured to fit the physical dimensions of actual structures [69-72] that become available locally or are set up at or near disaster venues. Figure 10 illustrates a comparable setting in the urgent care entrance area of a typical community hospital found in low-resource countries. This type of facility is common at nodes of SWNs in rural regional healthcare systems outside the United States. Both the ACF and community hospital model will help assure environmental stability of POC testing resources.

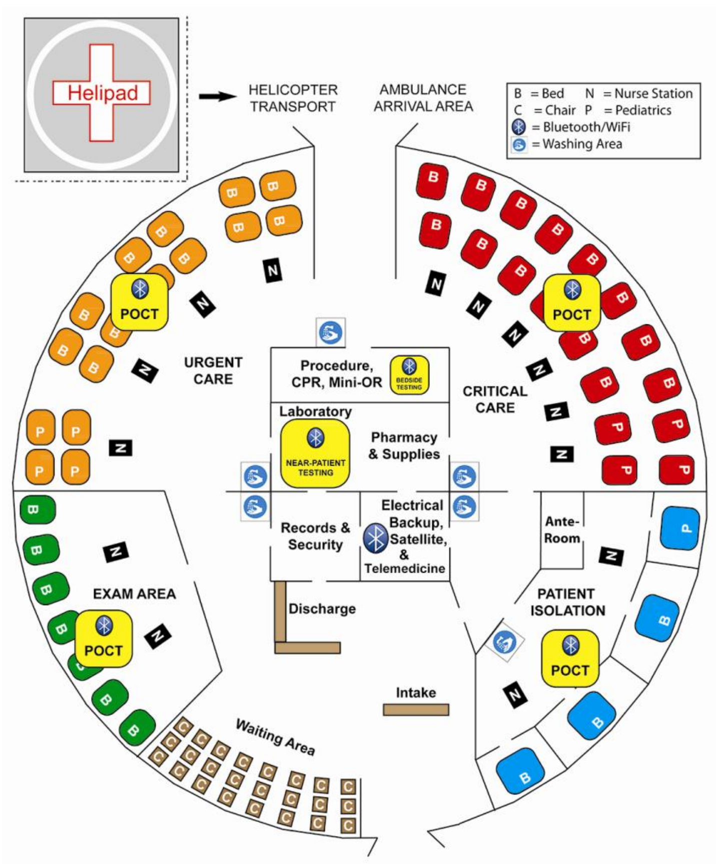

Figure 9. Alternate Care Facility with Fast Therapeutic Turnaround Time.

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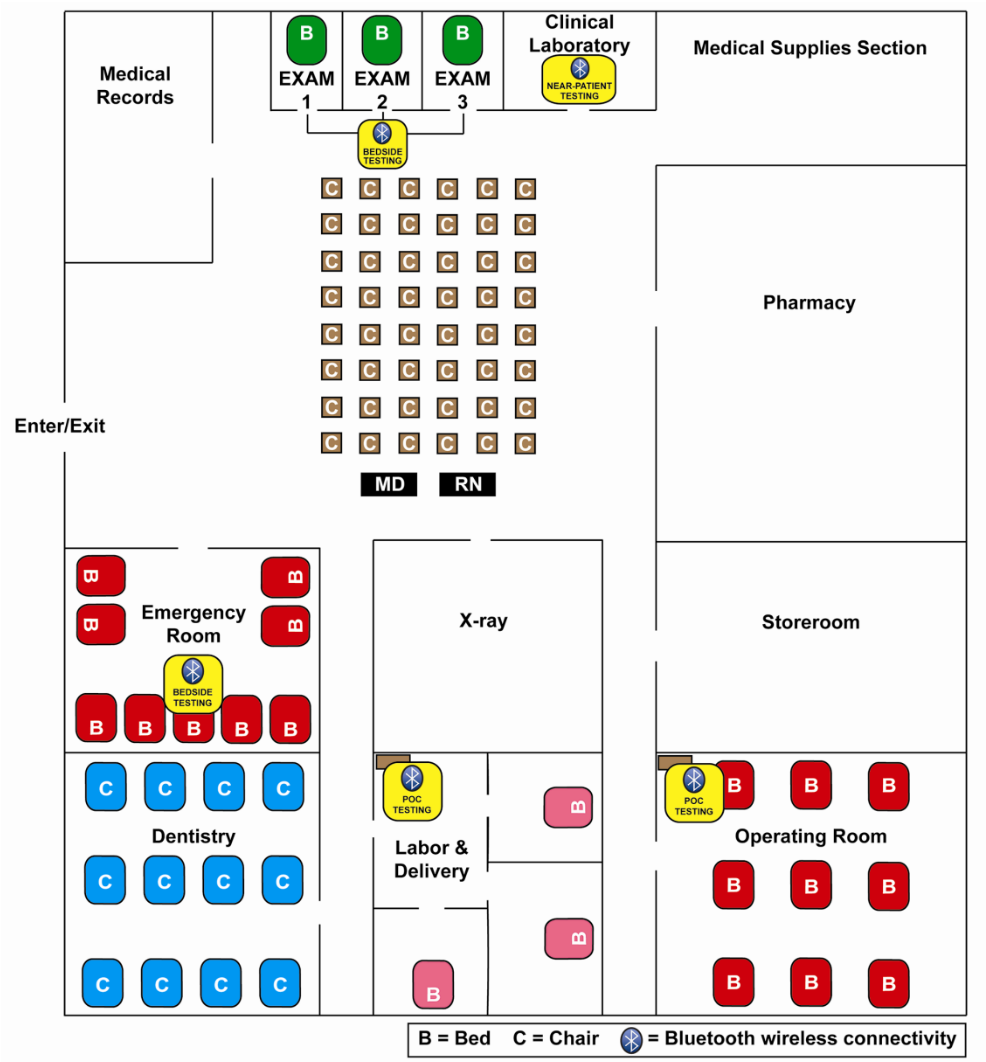

Figure 10. Low-Resource Community Hospital with Near-Patient and Point-of-Care Testing.

4.E. Complex Adaptive Systems

Robust environmental protection will assure POC performance necessary for diagnosis, monitoring, and treatment. Then, powering POC tests in field settings can be accomplished using hydrogen fuel cells (Figure 11), a reliable, portable, and environmentally-safer alternative to solar power and gas generators. A GIS can help place and manage POC technologies within the SWN. Conceptually, the combination of a GIS, SWN, and POC testing synergize to enable rapid informed decision-making at the site of crisis care (Figure 7). The resulting GIS-POC-SWN complex adaptive system will provide patient tracking and rapid response when and where needed. These concepts can be tested in field settings to demonstrate effectiveness and flexibility. Further consolidation of POC components and optimized medical intelligence at the point of need will enhance crisis standards of care [35].

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Figure 11. Hydrogen Fuel Cells Used to Power Point-of-Care Testing. Hydrogen fuel cells can power POC devices, enhance mobility, and allow diagnostic testing when the power grid is inoperable or inaccessible. The small compact design has replaceable 25 Wh, 40 Wh, and 50 Wh replaceable cartridges (inset). A 25 Wh cartridge can be used to power different POC devices, such as a handheld analyzer (top) and a blood gas electrolyte analyzer (bottom). In field settings, this approach could ensure that responders can monitor glucose levels of diabetics, electrolyte abnormalities of victims with crush injuries, and the effectiveness of oxygenation in victims with cardiopulmonary problems. The fuel cell products, shown here as conceptual illustrations, are in development.

PART 5. THE ROLE OF THE POINT-OF-CARE COORDINATOR

The POC Coordinator provides oversight for clinic and hospital POC testing and assures that the program is in compliance with accreditation requirements and with state and national law. Given the current proliferation of POC testing and devices, as well as increased demand for quality control, proficiency testing, and staff competency, most contemporary hospital POC programs cannot operate without at least one full-time POC Coordinator per two hundred beds. This person and associated staff also can provide invaluable services for preparedness, response, and recovery in the event of a complex emergency or natural disaster [41]. In fact, during such as event, it is unlikely that traditional laboratory services will be operable, in view of power outages, physical compromise of facilities, and other exigencies. POC testing often is the only resource available [73,74]!

Major functions fulfilled by the POC Coordinator include the following: assess critical needs in advance, participate in the response team, conduct drills to improve team capabilities, assure the competency of people performing field testing, maintain lists of qualified instrument operators upon whom responders can call for assistance, deal with patient information issues (e.g. identification and results tracking), standardize supplies for

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testing and quality control, provides adherence to regulations, and consider the environmental limits of both devices and reagents [75-78]. The POC Coordinator must consider the impact of any deviations in practice standards that occur under the pressure of the acute event and follow up to see that performance is improved in the future. In view of the multimodal, multidisciplinary, and bridging functions needed, as well as the level of professional complexity involved, POC Coordinator leadership is essential for resilience.

PART 6. CASE STUDY: FLOOD PREPAREDNESS

Natural disasters of monumental proportions include the Yellow River flood of 1931 in China, which killed an estimated 3.7-4.0 million people and is considered the worst natural disaster ever; the Indian Ocean Tsunami of 2004, generated by a 9.1-9.3 Richter Sumatra earthquake, the third largest ever recorded on a seismograph, that killed as many as 300,000 when huge waves struck coastal areas in several nations; and the 1815 Indonesia Mount Tambora eruption, the largest eruption in recorded history, that caused over 70,000 casualties, many from drinking ash-contaminated water, followed by blocked sunlight, 5° F lower global temperatures, and the worst famine of the 19th Century.

During these huge natural disasters and even lesser ones, significant additional hazards include outbreaks of water- and food-borne infectious diseases, and other vector-borne threats, such as diarrhea, cholera, Leptospirosis, typhoid fever, skin fungal infections, Dengue hemorrhagic fever, and malaria. These problems result when floodwaters become contaminated by sewage, feces, animal carcasses, garbage, and a multitude of pathogens that cause multimicrobial infections, which often are difficult to treat. Table 3 [12-18,20,79-122] lists infectious diseases and pathogens observed during natural disasters, including those attributable to weather crises.

In 2011, tropical rainstorms and subsequent widespread flooding in central Thailand devastated commercial and residential areas. Large number of communities, farmlands, roads, and major industrial estates were affected and accompanied by significant loss of life. As the flood waters moved south toward the Gulf of Thailand, they inundated broad areas of Bangkok (Figure 12), thereby compounding already huge economic losses. These problems arose quickly to threaten victims and residents lacking clean food, water supplies, and electricity. The Bangkok Flood weather disaster revealed need for rapid point-of-care (POC) devices, meaningful test clusters, backup instruments, specialized testing, and anticipatory planning for disaster and emergency care [10]. Table 4 summarizes strategies, emergency and disaster test clusters, and approaches to both POC testing and mobile health facilities.

The Thai government is setting up a new Center for the efficient management of water and flood information [123], and is coordinating agencies responsible for overall national water management (e.g., National Resources and Flood Policy and Water Resources and Flood Management Committees) assigned to work on flood-related policies and problems as well as implement flood-related projects in cooperation with other agencies concerned, such as the Bangkok Metropolitan Administration, and Defense, Public Health, Interior, and Social Development and Human Security and Labor ministries. When the flooding crisis reached Bangkok, the Thai Division of Medical Sciences, Ministry of Public Health, established a Working Group for Diagnostic Services.

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Table 3. Pathogens Encountered in Weather Disasters, Other Natural Disasters, and Pandemics

Scenario	Location (topic), Year	Pathogens Detected	Isolation Site/ Path of Infection	References (no.)
Drought	Florida, five epidemics since 1952	Saint Louis encephalitisvirus	Blood, Vector-borne	Shaman 2002 (79)
		West Nile virus	Blood, Vector-borne	Shaman 2002 (80)
	Indonesia, 1997	*Plasmodium* species	Blood, Vector-borne (El Nino)	Bangs 1999 (81)
Earthquake	Bangladesh, 2004	*Escherichia coli* *Vibrio cholera*	Stool/Water, Food-borne	Qadri 2005 (15)
	California, 1994	*Coccidioides immitis*	Skin, Dust cloud	Schneider 1997 (82)
	China, 2008	*Escherichia coli*	Wound, Pus/Wound	Tao 2009 (18)
		MRSA	Wound, Pus/Wound	
		MSSA	Wound, Pus/Wound	
		Streptococcus	Wound, Pus/Wound	
	Haiti, 2010	MRSA	Wound/Wound	Pape 2010(20)
		MSSA	Wound/Wound	CDC 2010 (83)
		Streptococcus	Wound/Wound	
		Vibrio cholerae	Stool, Water, Food-borne	
	India and Pakistan, 2005	*Escherichia coli*	Wound, Pus/Wound	Kiani 2009 (17)
		MRSA	Wound, Pus/Wound	
		MSSA	Wound, Pus/Wound	
		Streptococcus	Wound, Pus/Wound	
	Indonesia, 2005	*Escherichia coli*	Blood/Water-borne	Gupta 2007 (84)
	Japan, 2011	*Stenotrophomonas maltophilia* *Legionella pneumophilia* *Burkholdereia cepacia* *Pseudomonas aeruginosa*	Sputum	Inoue 2011 (85)
	Turkey, 1999	*Acinetobacter baumanii*	Wound/Wound	Bulut 2005 (13)
		Candida species	Wound/Wound	
		MRSA	Wound/Wound	

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Scenario	Location (topic), Year	Pathogens Detected	Isolation Site/ Path of Infection	References (no.)
Earthquake		MSSA	Wound/Wound	
		Pseudomonas aeruginosa	Wound/Wound	
		Acinetobacter species	Wound/Wound	Kazancioglu 2002 (12)
		Candida albicans	Wound/Wound	
		Enterobacter species	Wound/Wound	
		Klebsiella pneumoniae	Wound/Wound	
		MRSA	Wound, Blood, Urine/Wound	
		MSSA	Wound/Wound	
		Pseudomonas aeruginosa	Wound, Blood, Urine/Wound	
		Serratia marcescens	Wound/Wound	
Flooding	Bangladesh, 2004	*Escherichia coli*	Blood/Water, Food-borne	Qadri 2005 (15)
		Vibrio cholerae	Blood/Water, Stool, Food-borne	
	Global, 1980-2008	Dengue fever virus	Blood/Vector-borne	WHO 2005 (86)
		Plasmodium species	Blood/Vector-borne	CDC 2008 (87)
		West Nile virus	Blood/Vector-borne	
		Yellow fever virus	Blood/Vector-borne	
	Indonesia, 2004	*Salmonella paratyphi*	Blood/Water, Food-borne	Vollaard 2004 (88)
	Near-drowning	*Streptococcus pneumoniae*	Blood/Inhalation	Ender 1997 (89) Vernon 1990 (90)
	Thailand, 2006	Gram- negative bacilli	Skin	Vachiramaon 2008 (91)
		Web space fungal infection	“Hong Kong” foot	
	Great Bangkok Flood, 2011	*Leptospirosis, cholerae* (limited) pneumonia pathogens, others	Floodwaters	Kost (10)
Hurricanes/ Tornadoes	Georgia, 2000 species	*Enterococcus*	Wound/Wound	Millie 2000 (92)
		Pseudomonas aeruginosa	Wound/Wound	
		Serratia marcescens	Wound/Wound	
	Katrina, 2005	*Vibrio* cholerae o1	Blood/Food-borne	CDC 2005 (93) Sinigalliano 2007 (94)

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Table 3. (Continued)

Scenario	Location (topic), Year	Pathogens Detected	Isolation Site/ Path of Infection	References (no.)
Hurricanes/ Tornadoes		*Bifidobacterium*	Shoreline canal water/Water-borne	Sinigalliano 2007 (94)
		Cryptosporidium	Interior canal water/Water-borne	
		Giardia	Interior canal water/Water-borne	
		Legionella species	Lake surface water/Water-borne	
		Vibrio species	Lake surface water/Water-borne	
		Vibrio parahaemolyticus	Blood/Wound, Food-borne	CDC 2005 (95)
		Vibrio vulnificus	Blood/Wound, Food-borne	
		Escherichia coli	Shoreline canal water/Water-borne	CDC 2005 (96)
		MRSA	Wound/Wound	
		MSSA	Wound/Wound	
		Norovirus	Stool/Water-borne	CDC 2005 (97)
Pandemics/ Outbreaks	Africa, 2002	*Neisseria meningitides*	Spinal fluid, Blood / Respiratory	WHO 2011 (98)
	Africa, 2003	*Yersinia pestis*	Bubo aspirate, blood, sputum/	WHO 2005 (99)
	Africa, 2006-2007	Rift Valley Fever	Vector-borne	WHO 2007 (100)
	Angola, 2004-2005	Marburg virus	Blood, respiratory secretions/ contact with infected persons	WHO 2008 (101)
	Brazil, 2008	Dengue fever virus	Blood/Vector-borne	WHO 2008 (102)
	Congo, 2009	Ebola virus	Blood/Contact with blood or bodily fluids of infected persons	WHO 2008 (103)
	India, 2006 to 2007	Chikungunya virus	Blood/Vector-borne	Bangkok Post 2009 (104) Charrel 2007 (105) WHO 2006 (106)
	Indonesia, 2006	Influenza A (H5N1) virus	Nasal aspirate/Vector-borne	Monto 2005 (107)
				WHO 2010 (108)
	Kosovo, 2001-2002	*Francisella tularensis*	Blood and respiratory cultures/ Vector-borne	WHO 2002 (109)

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Scenario	Location (topic), Year	Pathogens Detected	Isolation Site/ Path of Infection	References (no.)
Pandemics/ Outbreaks	Malaysia, 1998-1999	Nipah virus	Blood/Contact with blood or bodily fluids of infected persons or animals	WHO 2009 (110)
	South Africa, 2008	Lujo virus	Serum and Tissue/Inhalation	Bries 2009 (111)
	Turkey, 2006	Crimean-Congo hemorrhagic fever		WHO 2006 (112)
	United States, 2007	West Nile virus	Tissue, blood, cerebrospinal fluid, or other body fluid, Vector-borne	Lindsey 2010 (113)
	United States, 2001	*Bacillus anthracis*	Blood/Direct contact, inhalation, or ingestion	Kman 2008 (114)
	United States, 1968	Influenza A (H3N2) virus	Nasal aspirate/Inhalation	Kawaoka 1989 (115)
	United States, 1957	Influenza A (H2N2) virus	Nasal aspirate/Inhalation	
	West Africa, 2008	Lassa virus	Blood/Contact with blood or bodily fluids of infected persons or animals	WHO 2005 (116)
	Worldwide (Mexico), 2009	Influenza A (H1N1) virus	Nasal aspirate/Ihalation	WHO 2009 (117)
	Worldwide, 2008	Yellow fever virus	Blood/Vector-borne	WHO 2011 (118)
	Worldwide, 2003	SARS-coronavirus	Blood/Contact with blood or bodily fluids of infected persons or animals	WHO 2003 (119)
Tsunami	Thailand, 2004	*Aeromonas*	Pus, Wound/Wound	Hiransuthikul 2005 (14)
		Escherichia coli	Stool/Water, Food-borne	
		Klebsiella pneumoniae	Pus, Wound/Wound	
		Pseudomonas aeruginosa	Pus, Wound/Wound	
		Acinetobacter baumannii	Blood/Soil, Water-born	Uckay 2008 (16)
		Aspergillus species	Blood/Inhalation, Wound	
		Burkolderia pseudomallei	Blood/Soil, Water-borne	

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Table 3. (Continued)

Scenario	Location (topic), Year	Pathogens Detected	Isolation Site/ Path of Infection	References (no.)
Tsunami		*Candida* species	Blood/Inhalation, Wound	
		MRSA	Wound/Wound	
		MSSA	Wound/Wound	
		Scedosporium species	Blood/Inhalation, Wound	
		Staphylococcus aureus	Wound/Wound	
		Stenotrophomonas	Blood/Soil, Water-borne	
		Salmonella species	Well water/Water-borne	Rajendran 2006 (120)
		Aeromonas species	Wound/Water-borne	Ivers 2006 (121)
		Clostridium species	Wound/Soil	

Abbreviations: MRSA, methicillin resistant *Staphylococcus aureus*; and MSSA, methicillin sensitive *Staphylococcus aureus.*

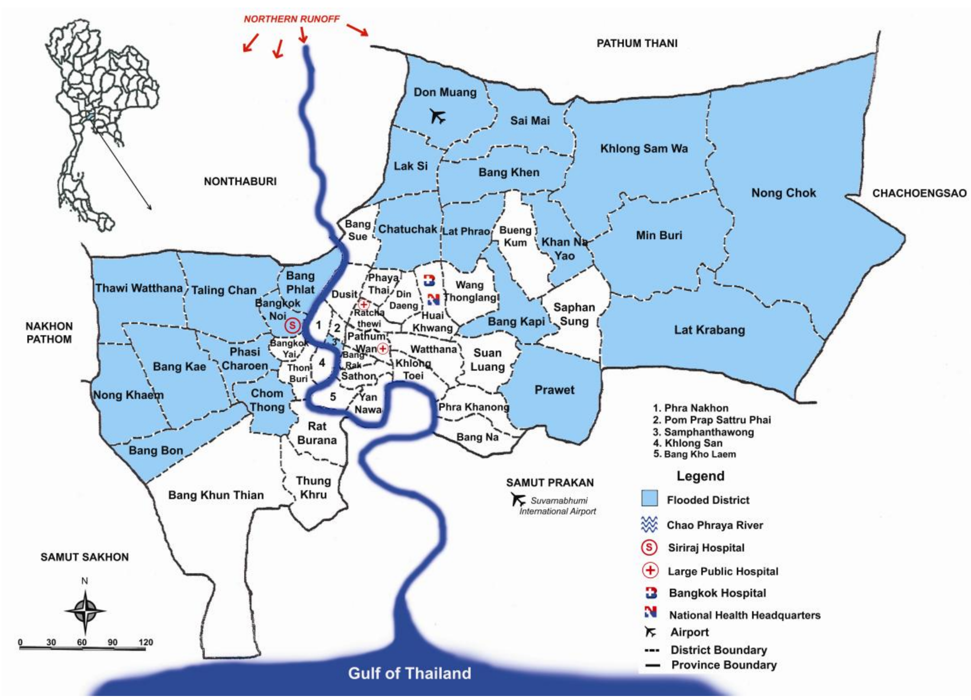

Figure 12. The Great Bangkok Flood and Its Impact. This map shows twenty-three flooded districts (blue) out of a total of fifty districts in metropolitan Bangkok. Districts identified as flooded had ≥10,000 households. Thai Cabinet resolutions declared that these districts must be supported and households compensated with government funding. While prepared for flooding, central hospitals east of the Chao Phraya River (dark blue) remained dry. Siriraj Hospital, a large referral hospital with up to 3,000 beds located immediately next to the river, experienced only minor flooding in the vicinity.

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The National Health System (NHS) group affiliated with Bangkok Hospital served as the leadership agency for the Working Group and disaster laboratory medicine in order to respond and to anticipate future potential devastating floods. Table 5 presents the outcome of the Working Group, which defined goals, objectives, risk areas, and directorates to deal with the current and also future flooding. The alerting sequence is shown at to bottom of Table 5. The NHS established a back-up laboratory on an urgent basis, placed flood-related special tests in service, called on assistance to plan POC testing, and networked with commercial laboratories and hospitals for current and future solutions. Leadership philosophy and planning issues were created (Table 6), discussed, and organized by the NHS, one of the Thai medical agencies that performed a vital role by responding to the Bangkok Flood.

Table 4. Strategic Planning, Diagnostic Testing, and Their Applications

Strategy	**Description**	**Applications**
Establish a preparedness working group	Best proactively to conduct needs assessments before flooding	General
Select emergency test clusters for mobile applications	*Mobile:* Blood glucose, pulse oximeter, troponin T, and complete blood count *Chemistry:* blood glucose, creatinine, urea nitrogen, lipid profile, electrolytes, and blood gases *Special Chemistry:* hemoglobinA1c, cardiac biomarkers, and liver function tests *Microscopy:* urinalysis, stool examination, fecal occult blood, malaria, Gram's stain, and KOH preparation *Rapid screening tests:* Influenza type A/B, H1N1, Dengue NS1Ag, Leptospirosis, and rapid anti-HIV	Great Bangkok Flood, 2011—working group selections for responsiveness
Place POC testing in ambulance and air transport	Pulse oximeters, glucose meters, and basic chemistry/hematology instruments	Temperature and humidity may exceed instrument limits (caution)
Set up a back-up laboratory	Perform mock trials and operationsvalidation, including informatics at leastone week in advance	Bangkok Medical Center(BMC) including heart, cancer, & neuro-medicine/spine
Prepare for flood-related testing	Add special focused methods (e.g., PCR for Leptospirosis) and rapid test kits	Implemented in core lab of NHS
Assay for toxic contamination of drinking water	GCMS (already in place), ICPMS (heavy metal contamination)	Rule out contamination associated with floods
Network with Commercial laboratories and other hospitals	Bidirectional support systems with new ad hoc task groups	BPL, BRIA, PCT, and Bumrungrad Hospital

Abbreviations: BPL, Bio Products Laboratory Limited; BRIA, BRIA group of companies; GCMS, gas chromatography-mass spectrometry; ICPMS, inductively coupled plasma mass spectrometry; NHS, National Health System Laboratory; PCT, PCT Technology Company Limited; and PCR, polymerase chain reaction.

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Table 5. Weather Disaster Plan of the National Health System (NHS) Laboratory

GOALS
• To prepare for future potential flooding in Bangkok
• To set up rapid and effective flood prevention plans
• To mitigate the potential impact and damage of such disasters
OBJECTIVES
• To monitor and keep a close watch for future potential flooding
• To prepare flood-related tools, equipment, instruments, and other accessories
• To set up flood-related missions and functions for personnel and staff in different divisions
• To provide healthcare services for patients and customers in case of the flooding
• To facilitate flood-related staff and/or personnel in providing healthcare services for emerging patients
• To effectively facilitate internal and external communications of the NHS
RISK AREAS
1. Headquarters, Dental Center, and Bangkok General Hospital
2. Samitivej Hospital, Sukhumvit branch
3. Samitivej Hospital, Sri Nakharin branch
4. BNH Hospital, Convent road, Bang Rak district
5. Bangkok Hospital, Phrapradaeng branch
DIRECTORATES
1. Committee Directors (n = 2) supervise the roles of Operations Committee
2. Operations Committee (n = 17) coordinates NHS divisions and implements flood disaster management

Disaster Code 2 Alert

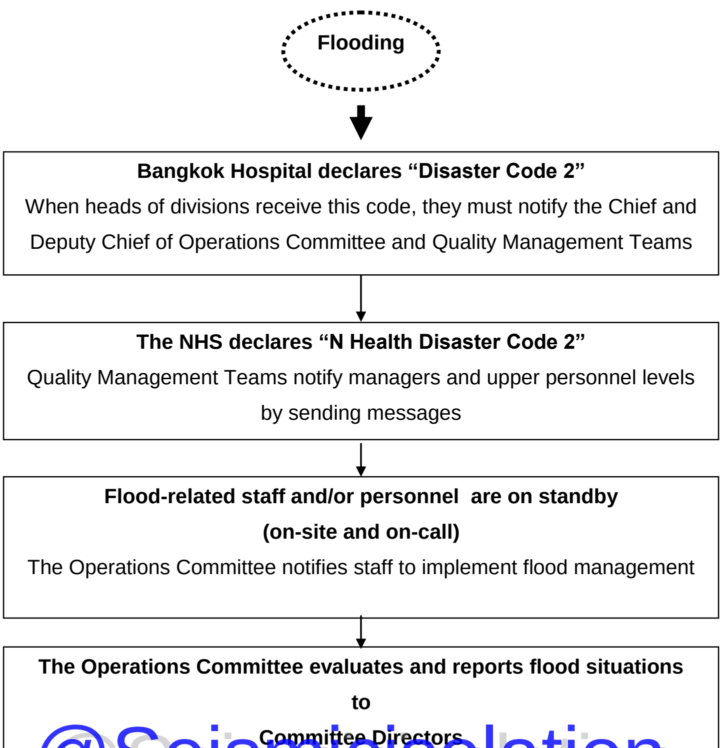

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Table 6. Philosophy, Leadership, and Implementation

Strategy	Description	Implementation
Optimize disaster thinking	"Be alert! Anything could happen and we should prepare for the worst situation."—Dr. Chuchart	Leadership model in place during the Bangkok Flood
Prepare a written disaster plan that includes floods	Required by The Joint Commission and other agencies and part of the working policies of several hospitals	Accredited hospitals and health network
Engage leadership shift for support	Management team takes on extended working hours and other challenges	National Health System (NHS) Laboratories
Secure on-site shelter for staff (MD, RN, MT)	Short-term rental facilities in vicinity	Around core facilities
Assure personnel and testing support and education	Short-term medicine, water, and food stockpile; new competency skills and training, including POC testing; perpetual quality assurance	Laboratory and hospital
Protect infrastructure	1.5 m high sandbag wall encircling 11 buildings in the Bangkok General Hospital complex	Petchaburi district
Adopt boat, 4-wheel drive, and 6-wheel truck transport; protect teams; and use helicopter patient rescue (if available)	Depth < 60 cm – 4 wheel drive, depth <1 m – 6 wheel truck, and depth >1 m – boats	Response-rescue personnel (5-6 mobile units) at Bangkok General Hospital
Maintain supply chain and customer service	Hospital and laboratory operated at full capacity continuously (policy decision)	Bangkok General Hospital and the NHS Labs
Building design must compatible with local environment	Structures with open and elevated ground floors (traditional Thai concept) are suitable for the Thai climate and mitigate the risks of flooding	Local residences be in tropical areas and modern in-fill structures
Prediction	Simulate 100-year flood with use of Geographic Information Systems (GIS) and integrated small-world networks with POC testing embedded	Region wide

Part 7. Point-of-Care Test Clusters and *In Vivo* Monitoring

In low-resource communities, demands for POC testing often appear relatively straightforward. In coastal Phang Nga Province, Thailand, where the Tsunami in 2004 had devastating impact [38], we surveyed medical professionals (N = 24) working in critical, emergency, and disaster care services from different geographic regions and medical organizations, namely seven Community Hospitals, one Regional Hospital, and the Naval Base Hospital, and the Offices of Provincial Public Health and Disaster Prevention and Mitigation. We determined locations of organizations surveyed (N = 11) and geographic relationships in the Phang Nga SWN (Figure 13). The distance [mean (SD), range, median, and maximum] from 53 Primary Care Units (PCUs) to 7 Community Hospitals was 19 (12),

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3-60, 15, and 60 kms, and from 7 Community Hospitals to 2 Regional Hospitals, 39 (20), 7-65, 40, and 65 kms, respectively, while the time needed for ambulances to travel from PCUs to Community Hospitals was 25 (22), 4-120, 20, and 120 mins, and from Community to Regional Hospitals, 43 (21), 20-80, 30, and 80 [3,37,122].

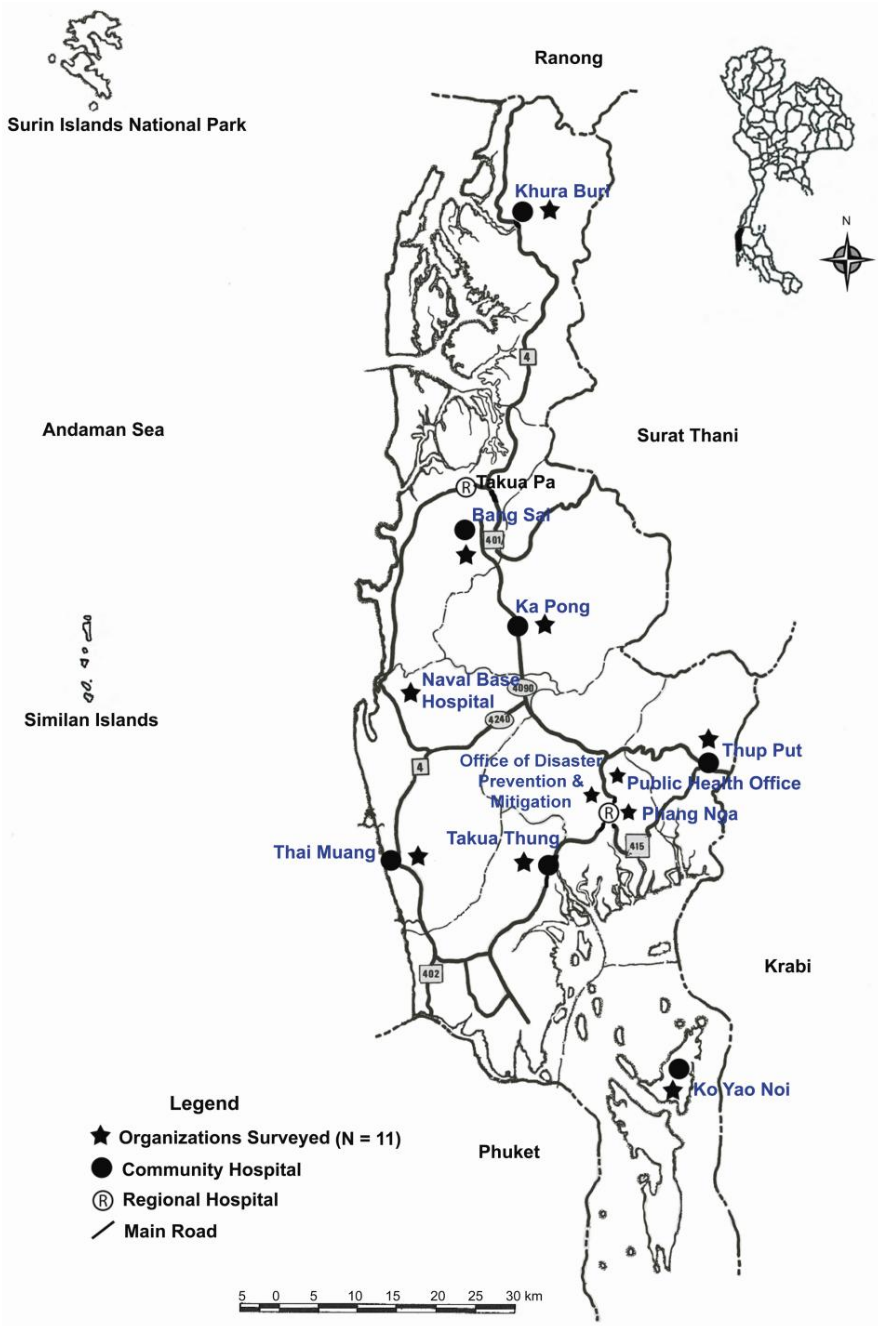

Figure 13. Phang Nga Province Small-World Network. The map shows geographic areas, transportation routes, and locations of medical organizations surveyed—community, regional, and Naval Base Hospitals, the Office of Provincial Public Health, and the Office of Prevention and Mitigation.

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Figure 14 illustrates weighted scores of the top twenty tests that respondents selected for emergencies and disasters. Complete blood count, electrolytes/chemistry, blood bank (blood group), oxygen saturation (by pulse oximeter), and hematocrit were selected as the top five POC tests to have in Phang Nga Province. Within an alternate care facility, survey respondents selected pulse oximetry (score 80), chemistry/electrolytes (58), blood bank/transfusion (43), and cardiac biomarkers (36) as first through fourth choices for near-patient testing (Table 7), while for bedside testing, they choose blood gases (63), pulse oximetry (57), chemistry/electrolytes (52), and cardiac biomarkers (29). Figure 15 illustrates eight environment conditions that respondents considered important. Temperature, vibration, humidity, and impact shock were the four most important ones when designing POC devices used during extreme conditions in local environments.

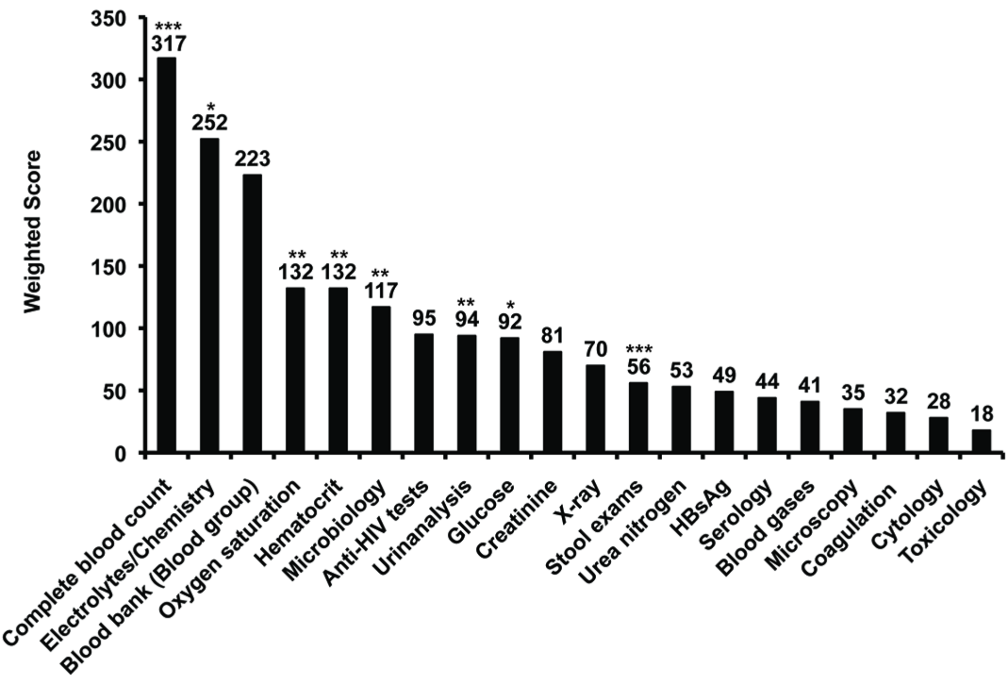

Figure 14. Priorities for Diagnostic Tests During Disasters. Respondents selected complete blood cell count, electrolytes/chemistry, blood bank (blood group), oxygen saturation (by pulse oximeter), and hematocrit as the 5 most important POC test categories to have in the Phang Nga Province SWN. These tests differed significantly from 1 or more of the 3 other asterisked tests (urinalysis, glucose, and stool exams) shown in the bar graph. [***P < 0.001, **P < 0.01, *P < 0.05]

In these settings, POC non-invasive continuous monitoring [34] has increased substantially, typically because of the small size of devices, their reliability, reagent-free operation, battery-powered operation, lack of maintenance, ease of use, and valuable "cross-over" applications during daily urgent and critical care in the emergency room, operating room, and if available, intensive care unit. A previous extensive field study [3] in Phang Nga Province also found extensive use of oxygen saturation monitoring. Pulse oximeters to monitor oxygenation status during ambulance transfer, ED evaluation, and ventilation have become available widely, and in the future, should be matched by adequate blood gas

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analyzers for timely O_2 saturation validations, plus critical arterial pO_2, pCO_2, and pH measurements, as well as new monitoring devices for hemoglobin [34]; transcutaneous bilirubin, pO_2, and pCO_2 in newborns; skin glycated proteins or POC HbA1c [32] for diabetes care; and other parameters. These measurements can support both the acute and chronic phases of care, and address issues common with vulnerable populations who become entrapped in rescue and recovery.

Table 7. Top Ranked Diagnostic Test Groups for Near-Patient and Bedside Testing Within an Alternate Care Facility

For Near-Patient Testing	Weighted Scores	Rank	Weighted Scores	For Bedside Testin
Pulse oximetry	80	1	63	Blood gases
Chemistry/electrolytes	58	2	57	Pulse oximetry
Blood bank/transfusion	43	3	52	Chemistry/electrolytes
Cardiac biomarkers	36	4	29	Cardiac biomarkers
Blood gases	35	5	28	Hematology
Hematology	17	6	26	Rapid microbiology tests
Rapid microbiology tests	10	7	24	Coagulation
Coagulation	8	8	9	Blood bank/transfusion

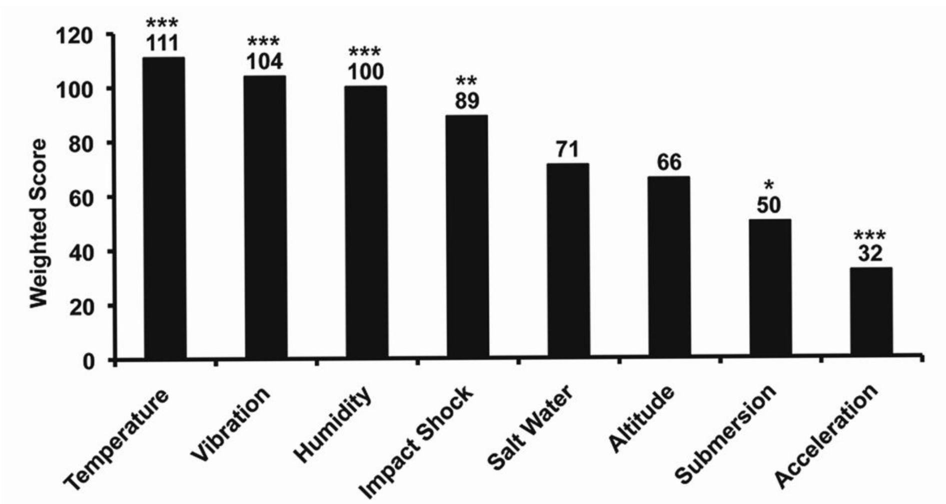

Figure 15. Environment Considerations for Future Point-of-Care Devices During Extreme Environmental Conditions. Respondents chose temperature, vibration, humidity, and impact shock as the four most important environmental conditions to consider when designing POC devices for high-risk settings, all four of which differed significantly from one or both of the other asterisked conditions (submersion and acceleration). [***$P < 0.001$, **$P < 0.01$, *$P < 0.05$]

PART 8. "POINT-OF-CARE CULTURE"

Point-of-care culture is the empowerment and transition of medical care to the individual and family nucleus integrated with norms, beliefs, expectations, and outcomes. This process

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of understanding cultural and social norms when implementing POC devices, and then, matching health care solutions with local customs and traditions represents the *final frontier* in a rapidly expanding field [124]. For example, care paths for patients with diabetes should be developed within the context of the rural province where people live, POC testing resources and training available there, and tests for confounding factors, such as urine albumin to creatinine ratio to detect renal problems, cardiac biomarkers to work up acute coronary syndromes, and retinal exams to avoid incapacitating blindness [27]. It is all too easy to forget those with chronic diseases as soon as the acute phase of a disaster passes. Low-resource regional hospitals on tight budgets cannot afford dialysis and the specialists to perform it, so medical economics figures strongly into the overall value proposition for early POC testing, and hence, resiliency.

Development of care paths in local languages facilitates cultural acceptance of POC testing. Generally, there should be a philosophy of promoting self-care behavior to improve outcomes, both personal and public health, and conversely one must know how patient behavior affects POC results (e.g. self-monitoring of blood glucose). In rural communities, major challenges arise when linking self-testing with treatment in a manner whereby the patient, primary care nurse, physician, and pharmacologist all agree and then see to it that there is persistence, continuity, oversight, and detection of non-adherence. Some POC results, such as evidence of HIV-1/2 and Hepatitis B (or C) infection, which could be discovered during triage or the acute phase, may have devastating immediate impact on patients and their families, and therefore need to be presaged by outreach, education, and public health initiatives, as elements of engraining resiliency before disasters strike.

PART 9. RESILIENCY IN CONTEXT

It is the moderation of adverse effects of crises where point-of-care (POC) testing can contribute significantly, not only to individual well-being and medical outcomes, but also to process enhancement. Characteristics of resilient processes include planning, resourcefulness, protection, coordination, continuity, networking, risk reduction, access to adequate resources, and effective communications, along with training and education of doctors, nurses, technicians, medical staff, and responders. “To build collective resilience, communities must reduce risk and resource inequities, engage local people in mitigation, create organizational linkages, boost and protect social supports, and plan for not having a plan, which requires flexibility, decision-making skills, and trusted sources of information that function in the face of unknowns.” [125] Point of care provides impactful information that reduces the unknowns. Reducing unknowns mitigates risk.

Albanese et al. [126] devised a framework for safe and resilient hospitals within integrated community disaster responses. Bosher and Dainty [127] proposed risk reduction through a parallel scheme for literally building in resilience in the constructed environment. Geelen-Baass and Johnstone [128] make the case for business continuity management, Sheth et al. [129] provide a practical dashboard for measuring capability, and Hill et al. [130] suggest ameliorating adversity through alternative resiliency investments, which should not exclude new POC approaches and technologies, especially in view of the favorable precedent set by POC instruments introduced broadly during Hurricane Katrina. [23,131] Following

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Katrina, Kost coined the term, "newdemics," [33] for modern crises, since the unexpected can wreak havoc rapidly in demographically saturated regions, and with international colleagues, innovated POC testing embedded in small-world networks [27,29,31,32,37-39] for resiliency, preparedness, and enhanced crisis standards of care [35]. Extreme weather events and other emerging exigencies motivate us all to build human resilience [132].

Multivariate analyses indicate that the prevalence of resilience is uniquely predicted by gender, age, race/ethnicity, education, level of trauma exposure, income change, social support, frequency of chronic disease, and recent and past life stressors [133]. Pre-existing relationships that ease communication challenges, continuation of organizational patterns of response integration, and known role assignments contribute to resilience [134]. Hence, the emergency management and homeland security sectors must collaborate to engage the community better [135,136]. Therefore, in support of human resilience, it is logical to assemble the building blocks of process, per se, using a heretofore somewhat neglected element, namely, adaptive and connected POC testing in small-world networks where it is needed the most by people who use it every day, and then can also respond more effectively to complex emergencies, disasters, and public health crises in small community hospitals, in alternate care facilities, or directly at points of need.

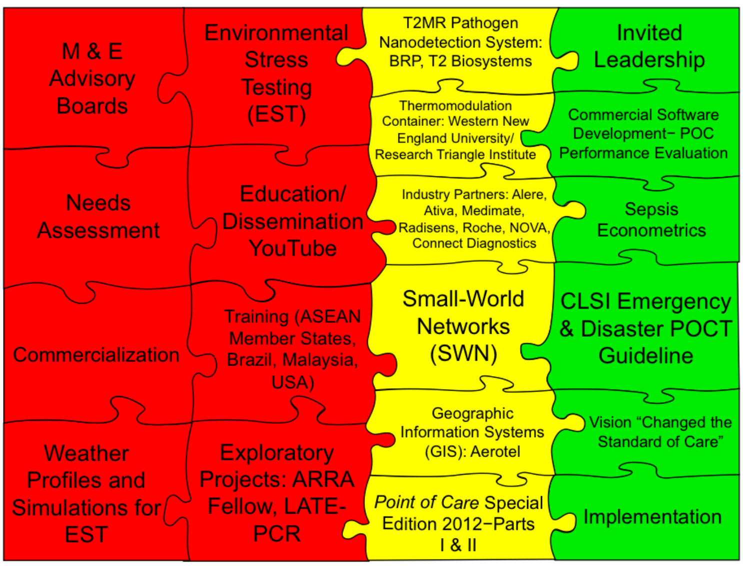

Figure 16. The Fabric of Point-of-Care Resilience: An Integrated Solution. This figure illustrates the essential integration of POC principles, operations, and practice that build the fabric of resilience for urgent, emergency, and disaster care. The completed puzzle leads to a well-integrated complex adaptive system that can improve the fluidity of disaster response when all components are well organized and working efficiently together.

CONCLUSION

We can meet the challenges of complex adaptive systems encountered during emergencies and natural disasters by devising and implementing new needs-based POC approaches, by positioning them in evidence-based care paths for rapid decision-making, and

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by assuring continuity of diagnosis, triage, monitoring, and therapy in small-world networks, their regional neighboring communities, and the associated referral centers. The overriding mission of this teamwork is to form a flexible and integrated "fabric" (Figure 16) of support for enhanced crisis standards of care [35] and a suitably resilient point-of-care culture [124].

The Clinical Laboratory Standards Institute (CLSI) and chapter authors, with participation by academia, industry, and government, are developing a consensus guideline (POCT-15) titled, "Emergency and Disaster POC Testing." The practice principles, operations recommendations, and practice guidelines presented in this chapter will help provide the necessary framework for simultaneous point-of-care integration, synthesis by care teams at the point of need, and optimization of practical practice strategies for preparedness and response. Then, networks of resilient communities will create resilient nations, the ultimate goal.

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Chapter 3

MANAGEMENT STRATEGIES FOR CHILDREN DURING NATURAL DISASTERS

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ABSTRACT

Children are vulnerable during a disaster due to differences in physiology, limited self–sufficiency, and increased susceptibility to hazards. It is necessary to have comprehensive plans in place in order to mitigate the events after a disaster occurs.

Many disaster plans do not effectively incorporate children into disaster management and fail to prepare for the needs of this population. Disaster drills are needed to identify roles, identify needed supplies, and understand surge capacity. Appropriate preparation will optimize response and coordination of large numbers of trauma victims in an efficient manner. Additional resources are needed for inter-hospital communication, family reunification, and vigilance against secondary injuries in this vulnerable population.

In this chapter, we will discuss disaster mitigation, preparation, response, and recovery strategies by healthcare personnel to limit social, psychological, and medical effects of natural disasters on children.

INTRODUCTION

Modern society has magnified the risk of catastrophe from natural disasters with the rise of modern cities and enormous populations of people in high density. Some of the world's largest and most populated cities are susceptible to a number of natural disasters (Tokyo – earthquake, flood; Mexico City – earthquake, flood, landslide; Los Angeles – earthquake,

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flood, wild fires, drought; Lagos – flood; Mumbai – flood, cyclone, earthquake; Jakarta – earthquake, volcano). [1] Within these mega-cities exists large numbers of vulnerable populations. These include the elderly, homeless including street children, those with chronic medical needs, and children. This chapter will focus on natural disaster management in modern society and its effect on children.

FAILURE TO ADDRESS VULNERABLE POPULATIONS

Failure to identify risks and implement preventive measures has resulted in a large number of childhood fatalities from a variety of natural disasters over a wide geographic area and time frame (Table 1). A major concern is the widespread lack of preparation for response to a disaster involving children. Only ~ 25% of emergency services have appropriate equipment for the pediatric populous. [2] Further, designated children's hospitals near disaster sites may lose capacity as did Children's Hospital of New Orleans in the days following Hurricane Katrina. [3] Tragedies such as the 2005 Hurricane Katrina and 2008 Sichuan Earthquake highlight the failure of implementing mitigation and response systems for pediatric trauma.

Table 1. Natural Disasters and the Pediatric Population

Natural Disaster Type	Location	Year	Est. Children Deaths	Reference
Meteorite	Shanxi, China	1490	~4,000	Jewitt, D. [82]
Blizzard	Great Plains, US	1888	235	Stommel et al. [83]
Fire	Chicago, IL	1958	87	Groves et al. [84]
Landslide	Aberfan, Wales	1966	116	Sugar et al. [85]
Volcano	Ruiz, Columbia	1985	~7,,500	Tanguy et al. [86]
Tornado	Daultipur-Salturia, Bangladesh	1989	~450	Prokos et al. [87]
Tsunami	Indonesia	2004	~80,000	Paris et al. [88]
Hurricane/Cyclone	Myanmar	2008	~70,000	Than, T. [89]
Earthquake	Sichuan, China	2008	>5000	Roney et al. [90]
Flood	Bangkok, Thailand	2009	> 200	Minh, T. [91]
Drought/Famine	Somalia	2011	>29,000	Lowenberg et al. [92]
Lightning	Uganda	2011	19	IB Times [93]
Avalanche	Shirim Nazem, Afghanistan	2012	>50	ABC News [94]
Fog	Bhita, India	2012	11	India Today [95]
Post Disaster Disease Outbreak - Select Examples			Disease Incidence	
Measles	Philippines	1991	>18,000	Watson et al. [98]
Cholera	Bangladesh	1994	> 17,000	Watson et al. [98]
Coccidiomycosis	Southern California	1994	30 per 100,000	Watson et al. [98]
Cholera	Somalia	2007	82	WHO [96]
Cholera	Haiti	2011	~1,300	CDC [97]

*Children are assumed to represent 1/3 of the population if not specifically stated in reference article.

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It took more than six months to reunite the more than 5,000 children separated from their parents following Hurricane Katrina. [4] The 2008 tragedy in China highlights the failure to recognize risk of natural disaster in schools and to provide a protective environment for children. This same tragedy was witnessed just five years earlier when more than 180 schools collapsed in Bam, Iran, contributing to the death of more than 12,000 children. [5]

Beyond failure to implement systems of prevention and infrastructure is the widespread lack of pediatric resources, equipment, and personnel to deal with the response. Failure of adequate response has witnessed severe consequences with increased mortality in the short-term followed by development of disease outbreak (cholera, measles, etc.), and finally long-term negative psychological and social effects.

Mitigation

Mitigation includes all those actions that are taken before, during, and after the occurrence of a natural event to minimize its impact. [6] Benefits of mitigation include:

1. Creating safer communities by reducing loss of life and property;
2. Enabling individuals and communities to recover more rapidly from disasters; and
3. Decreasing the financial burden of disasters on individuals. [7]

Examples include providing early warnings to enable evacuation immediately preceding hazards [6] and reducing vulnerability by strengthening structures to withstand the forces caused by seismic shaking. [6] US disaster managers have recognized the inadequacy of current mitigation systems that rely primarily on strategies of response and recovery. [8] To this end, numerous governmental and nongovernmental organizations (NGO) have shifted priorities. [8] Most significantly, the Federal Emergency Management Agency (FEMA) has established a Mitigation Directorate, on par with its Response and Recovery Directorate, and developed a National Mitigation Strategy. [6, 8] The two main goals are:

1. To raise public awareness of natural hazard risk; and
2. To reduce the loss of life, injury, financial cost, and destruction of natural and cultural resources due to natural disasters. [9]

Prevention, Mitigation, and the Health Sector

Given the high economic, health, and political costs associated with loss of critical healthcare facilities, health authorities and funding agencies should require all new health infrastructure projects to undergo a comprehensive mitigation process to ensure continuous maintenance of capacity. Foremost in this process is recognition of local natural hazards and this should be the critical factor for selecting the facility's location and for formulating the design specifications at the earliest stage of the process. [10] Optimizing this process of hospital mitigation includes the following:

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1. Functional mitigation to ensure that the necessary supporting infrastructure services allow for uninterrupted operation. Examples include water, electricity, road access, and communications.
2. Nonstructural mitigation to reduce losses and health injuries from falling or moving objects. Measures include proper securing of equipment for earthquakes or strong winds or the location of only noncritical services on flood-prone floors.
3. Structural mitigation to ensure the safety of the structure itself. [10]

In addition to infrastructure and hospitals, it is critically important to involve communities and first responders in the mitigation process. This will greatly impact the quality, timing, efficiency, and preparation during the response and recovery phase. One productive and effective way to implement these measures is to develop or build local healthcare coping capacity. [10] However, establishing effective coping mechanisms requires education and training and should include the following:

1. Development of simple and realistic healthcare scenarios toto simuate a probable disaster event.
2. Incorporation of disaster management in the academic curriculum of medical, nursing, first responder, and public health schools. [17]

These strategies enable the health sector to execute its two significant roles in the mitigation process: directly reducing the risks to its facilities and programs and advocating for risk reduction measures within the healthcare community. [11] Educational programs targeting special/vulnerable populations are also very necessary. For children, these efforts include education and training of the healthcare workforce. [12] It is important to recognize that children are not "little adults," and they require different medical supplies, nutritional provisions, infrastructure, and psychological support. Formal training allows professionals to recognize and manage pediatric health needs from the mundane to the life-threatening events that may occur during time of disaster.

Communities, Families, and Children

Apart from governmental and institutional organizations, individuals and families can help mitigate the effects of natural disasters. Of primary interest is mitigating the impact of an event on children through continued awareness and preventive practices. [12] This includes practicing home fire drills, teaching of safe behaviors during an earthquake, and ensuring children are aware of emergency contact numbers. Parents educating their children can increase their resiliency and ability to handle stress. These preventive practices and building of family awareness help children to develop coping strategies and improve their outcome when faced with severe unexpected stressors such as natural disasters. [12]

Local communities can assist families and children in their efforts by recognizing their own vulnerabilities and raising public awareness. For children, 'Awareness Raising' can begin in schools and thus be expanded to children's parents and gradually to all levels of the community. [13] Since over a quarter of the population is under the age of 15, [14] it is also possible for governments to implement their existing disaster plans and risk reduction

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strategies to a large and vulnerable population. Moreover, the enthusiastic motivation of children may disseminate messages to their parents and to the greater community. [13]

PREPARATION FOR DISASTER

To minimize the impact of a natural disaster on children, there are a number of areas that preparation should focus on. An optimal response to a natural disaster requires healthcare providers with adequate training in disaster management and mass critical care within the context of constrained resources, as well as an adequate stockpile of resources for those providers to utilize.

Education

Provider education is implemented both empirically in preparation for a natural disaster (advanced training), and just-in-time in response to a natural disaster. [15] Both methodologies are necessary to ensure the care team is not only prepared for a disaster, but is prepared for adaptation. The response to a pediatric disaster will require many providers to practice outside of their usual scope of practice and development and maintenance of skills must be provided for. Pediatric providers without critical care training or expertise may be asked to care for critically ill or injured patients. Adult surgical specialists without particular pediatric expertise may need to provide surgical care to neonates and small children. Adult facilities may need to provide care for small children. Experienced pediatric critical care providers may acutely be asked to manage triple the usual pediatric intensive care unit (PICU) capacity.

All of these are examples of scenarios that can potentially be addressed up front with educational interventions, or just-in-time training on an as-needed basis. Despite this understanding, many have questioned society’s preparedness to respond to a pediatric disaster. [16]

Empiric Education

Advanced provider training can encompass a large audience and also be targeted to specialized groups. Many national curricula and courses leading to certification are available (Table 2). These courses are ideal for providers who are looking to extend their existing skill set outside their usual scope of practice (i.e., non-intensivists looking for preparation in emergency critical care management or non-pediatric specialists looking for pediatric-specific fundamental training). This modality of training allows thoughtful and timed education of providers who will be asked to provide care during a mass casualty incident. In addition to national courses, locally implemented didactic lectures combined with low-fidelity tabletop simulation have been shown to increase provider comfort in caring for patients during a disaster. [17]

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Table 2. Pediatric Training Courses

Course	Sponsoring Organization	Duration
Pediatric Advanced Life Support (PALS)	American Heart Association	2 days
Advanced Trauma Life Support (ATLS)	American College of Surgeons	2 days
Pediatric Fundamental Critical Care Support (PFCCS)	Society of Critical Care Medicine	2 days
Fundamental Disaster Management (FDM)	Society of Critical Care Medicine	1 day
Advanced Pediatric Life Support (APLS)	American College of Emergency Physicians and American Academy of Pediatrics	2 days
Neonatal Resuscitation Program (NRP)	American Heart Association and American Academy of Pediatrics	2 days
Emergency Nursing Pediatric CourseCourse (ENPC)	Emergency Nurses Association	2 days
Trauma Nursing Core CourseCourse (TNCC)	Emergency Nurses Association	2 days

The main downside of advanced training is a potential lack of perceived need leading to decreased learner retention of information and skills learned during the courses – especially if the skills are not frequently utilized. This lack of immediate utilization and lack of acceptance from both the learner and the institution that is funding the training limit its use to individuals and institutions that are: 1) highly motivated to pursue this training, and 2) endowed with the resources to train providers. Finally, the knowledge tends to be broad-based and is not necessarily tailored to a specific disaster scenario. Therefore, while advanced training is certainly useful, in many instances it is a luxury and the limitations associated with it render it useful only as a foundation for subsequent just-in-time training.

Just-In-Time Training

While advanced training carries the many benefits listed above, just-in-time training has its own unique benefits, the greatest of which are intrinsic learner motivation and the ability to tailor the training to the exact scenario at hand. The greatest downside is the demand for resources to implement the training – with the 'experts' also needed to care for critically ill patients.

Effective just-in-time training requires anticipation of training needs prior to a disaster so that teaching aides and pocket cards (normal vital signs by age, Broselow tapes, common drug dosing, weight-based algorithms) can be implemented on the spot. Abbreviated primers delivered via e-learning or podcast to target specific training gaps (adult intensivist training in pediatric ventilator management) can be developed in advance, although the reliability of communications and electricity must be anticipated. Libraries of educational resources are currently available online at www.PedsCCM.org and www.LearnICU.org.

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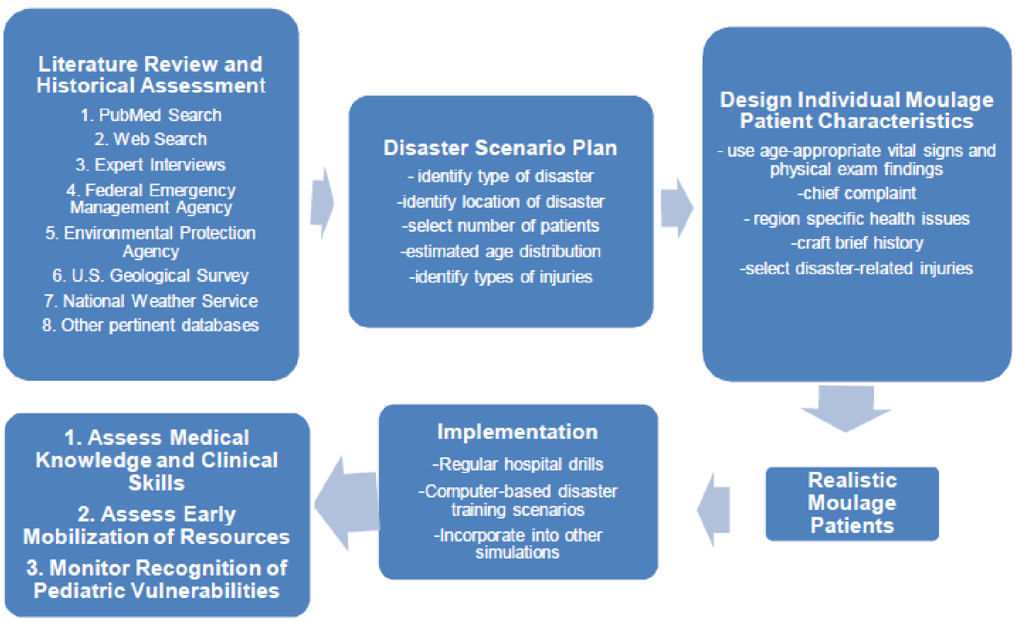
Drilling to Standard

Mass casualties carry the risk of overwhelming a local emergency medical system. It has been shown in simulated scenarios that an increase in errors related to performance of procedures, administration of medication, and accuracy of diagnosis are exacerbated in times of mass casualty. [18] Simulated disaster scenarios have the dual advantage of evaluating a community's response to disaster as well as educating providers taking part in the drill, although experience with simulated pediatric disaster is lacking. [19] These disaster preparedness drills can inform local leaders as to areas for improvement that can be targeted with educational interventions. For simulated mass casualty drills, attention to detail in planning and implementation is paramount to gaining an accurate assessment of the local system and providers. Drill victims should be representative of the region and should include patients with representative co-morbidities; mock disasters should mimic scenarios expected in the region; and injuries should be assigned to patients in accordance with what would be expected in that scenario. [20] A flowsheet for designing a local disaster drill is shown in Figure 1.



Adapted and reproduced courtesy of Ballow, *et al*. [20].

Figure 1. Realistic Patient Moulage Development.

The major disadvantage of large-scale disaster drills is the cost. High-fidelity simulation requires the cooperation from the local hospitals to provide time for physicians, nurses, and other providers to participate in addition to the cost of the standardized patients and supplies needed to complete the simulation. Low-fidelity tabletop drills, however, are also of value – although it is uncertain to what degree as compared to high-fidelity models. [17] Targeted educational exercises can be implemented to address specific tasks related to disaster management and have been well-received by hospital staff. [21] Further study is needed to

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determine if repetitive drills can improve individual and institutional performance in response to mass casualty. An analysis of two mass casualty incidents in Southern California demonstrated an improvement in triage system performance in the second casualty incident – suggesting repetition can lead to systematic improvements. [22]

Supplies

In the event of a natural disaster, supplies to sustain mass pediatric critical care may become scarce. An abrupt increase not only in patient volume, but also in patient acuity, may place an overwhelming burden on a hospital's existing store of supplies. Furthermore, regional demands in response to a disaster will potentially limit the ability of hospitals to share resources withwith each other. Additional threats to the provision of supplies is the impact on local and regional transportation infrastructure (roads, bridges, railways, airports) followingfollowing a natural disaster. Any available transportation resources will likely be used for damage control and patient transport, making the provision of medical supplies a secondary priority. Usual hospital practices of just-in-time rental and borrowing equipment from remote locations cannot be assumed to be reliable.

With these factors in mind, the current recommendation is for each hospital to have an on-hand stockpile to accommodate a tripling of usual PICU capacity for a sustained period of at least ten days. [23] Calculated needs should consider age- and size-specific equipment and include the ability to provide mechanical ventilation, inotropic support, anti-infectives, sedation and analgesia, intravenous fluids, and blankets and active warming measures to prevent hypothermia. Additional resources that may need to be implemented, but are likely to be exceedingly scarce, include adjunctive measures such as parenteral nutrition and renal replacement therapy.

Numerous factors should be considered in planning the appropriate local stockpile of equipment and supplies. Multiple patients utilizing a single bed space over a ten-day period should be anticipated. Assuming a standard PICU length-of-stay of 3.9 days, each bed space will be used for an average of 2.5 patients over a ten-day surge period. [24] Some supplies (i.e., bedside monitor) are re-used for all patients in each bed, while others (i.e., yankauer suction catheter) need to be changed with each new patient. Based on prior pandemic experiences, experts anticipate a need to triple the usual capacity of US PICU beds. [25] Therefore, supply stockpiles should assume a tripling of capacity for reusable supplies and 7.5-fold increase in non-reusable supplies to sustain capacity for a ten-day surge. At a minimum, considerations for bedside monitoring should include continuous oximetry, telemetry, and apnea monitoring. Invasive blood pressure and central venous pressure monitoring as well as other routine measures such as end-tidal CO2 are desirable if possible, but may need to be foregone to expand capacity.

The impact of a natural disaster on the pediatric population is likely to mirror the distribution of the standard daily PICU population. It is, however, possible that a disaster may disproportionately affect an isolated age group if a single age group is intentionally targeted, rendering stockpiles, based on typical PICU census demographics, potentially inadequate. Recommendations of the Pediatric Emergency Mass Critical Care Task Force for equipment stockpiles for responses to both a) normally distributed disasters, and b) to include targeted age groups are shown in Appendix 1. [23]

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Mass pediatric mechanical ventilation is a topic that warrants special attention in the response to natural disaster. Hospitals should have surge capacity to ventilate one patient per PICU bed (threefold increase accounting for triple capacity). In addition to traditional ventilators, creative solutions such as the use of transport ventilators, non-invasive bi-level ventilators, and potentially anesthesia ventilators, may be necessary – although anesthesia ventilators cannot be relied upon due to the likely need for high operating room (OR) throughput due to multiple injured patients. Unfortunately, adult ventilators are generally not suitable for use in small children. While freestanding children's hospitals may have a stockpile of pediatric and neonatal ventilators, other combined pediatric and adult facilities may share a common pool of machines, rendering it necessary to utilize adult ventilators to support small children. Less than half of US ventilators have pediatric capability, forcing some institutions to attempt to utilize adult ventilators for pediatric purposes in a mass casualty situation. [26] Special consideration to ventilating small children and neonates with adult ventilators is merited for a number of reasons. Small children and neonates may not generate sufficient flow to trigger the adult inspiratory flow sensor, rendering spontaneous modes of ventilation (pressure support or synchronized intermittent mandatory ventilation [SIMV]) difficult. Conversely, the use of mandatory volume control modes may be precluded by unreliable delivery produced by large airleaks around uncuffed tubes or compressible circuits with large breath-to-breath variability. Furthermore, adult ventilators may not be able to deliver controlled (precise) small tidal volumes with low inspiratory flow rates required for neonatal ventilation. For these reasons, neonates and small children should preferentially be treated at centers with pediatric capacity, with larger children treated at adult facilities if needed. Alternative or advanced modes of ventilation including high-frequency oscillation are utilized at children's hospitals and may not be available at adult facilities. Regional stockpiles of oscillators should be considered, although their deployment to satellite facilities will be limited by infrastructure and by expertise at those facilities in the use of this modality. The use of extracorporeal life support (ELS or ECMO) is likely to be too resource-intensive to utilize on a large scale during a natural disaster.

The provision of mass critical care will also require the utilization of a significant amount of medications. While not all medications will be able to be provided for, essential therapies include: crystalloids, antibiotics, vasopressors, sedatives, analgesics, bronchodilators, corticosteroids, insulin, and antidotes. There is currently no evidence-based guideline to predict anticipated pediatric needs upon. Within the context of a natural disaster, however, medications (especially analgesics) are likely to exceed usual daily patient needs due to increased patient acuity level. [27]

RESPONSE TO DISASTER

Although the principles of disaster response remain the same regardless of incident, geography, and population impacted, there are fundamental needs of children that differ from adults that must be met in the response phase. Children are often overlooked in the preparation phase, [12, 28-30] and we know children require a different set of response strategies for clinical care, safety and security, and general care. [31, 32] The disaster response can be improved if an organization develops preparedness plans, implements

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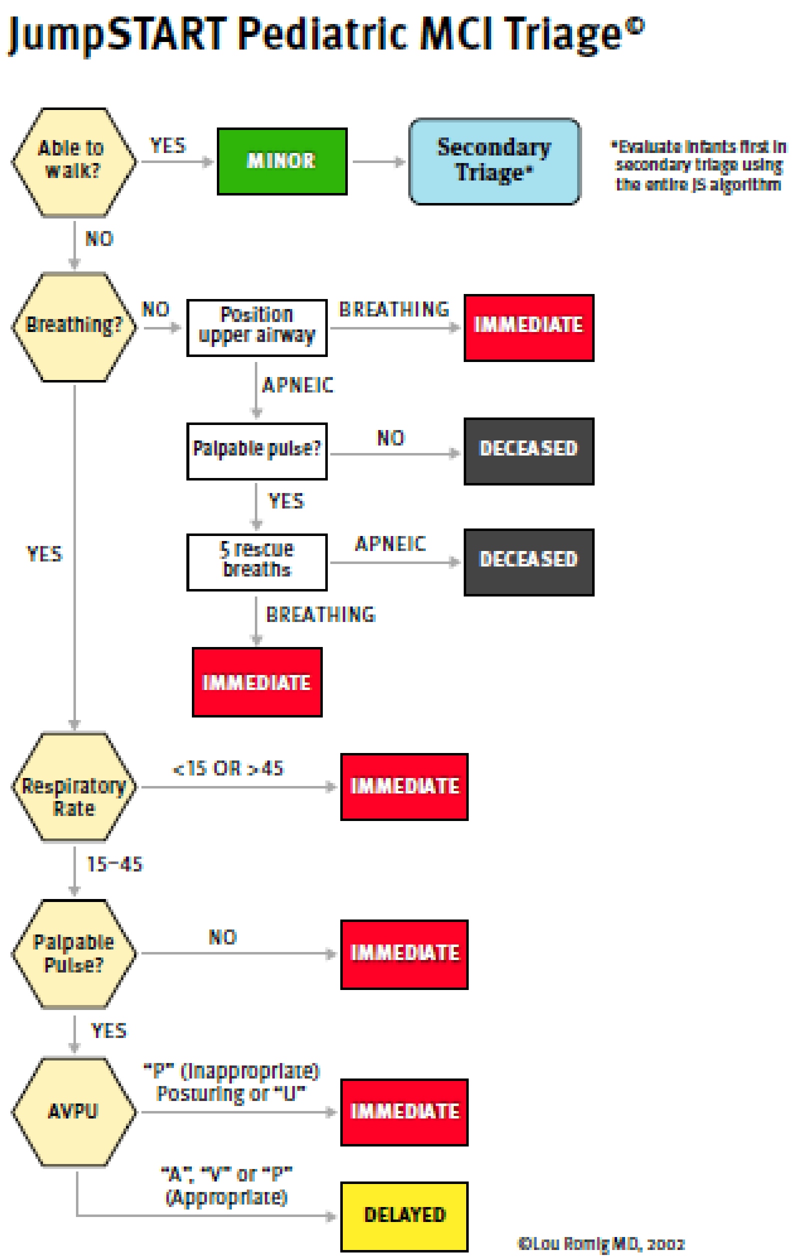
mitigation efforts, and acts on known high-risk vulnerabilities (see prior section). [12] Despite widespread recognition that children are not “little adults” and that they require special consideration, hospitals tend to exclude children in their practice exercises. [19] This may limit capabilities and effectiveness of response to a disaster.



Courtesy of Lou E. Romig, MD, FAAP, FACEP.

Figure 2. Pediatric MCI Triage Algorithm.

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Responding to a Disaster Surge

Natural disasters can range in type, location, and number of individuals injured. The number of casualties often depends on the mitigation efforts, environment, and type of disaster. [33] Similarly, the geographic location and type of natural disaster are indicators of the types of injuries that may occur. [20] Children may be more vulnerable to traumatic injury and rapid physiological deterioration than adults. They have different nutritional requirements and are less tolerant to periods without food or water; these factors vary greatly depending on their age. [30, 31, 34] The ability of a healthcare facility, specifically a hospital and accompanying emergency department, to respond in a disaster and meet a surge of patients is dependent on the resources available: namely the “space, staff, and stuff.” [35]

To meet a large surge of children, a facility must have the right-sized supplies and equipment as well as a safe space to effectively respond to children’s needs. When children arrive at a hospital, they need to be triaged. Triage comes from the French word “to sort.” [33, 36] For children, the type of triage method typically used is JumpSTART. [37] JumpSTART is based on an adult version of triage that categorizes patients as minor, delayed, immediate, and expectant (Figure 2). These categories are associated with a color and prioritize the timing and care that will be provided.

What Is Surge?

There are many definitions used for surge. Dayton and colleagues define surge capacity as “a healthcare system’s ability to rapidly expand beyond normal services to meet the increased demand for appropriate space, qualified personnel, medical care and public health in the event of … a natural disaster.” [38] Surge response functions on a continuum. According to a conceptual framework presented by Hick for the Institute of Medicine (IOM) Medical Surge Workshop, he describes this continuum with three distinct stages: conventional capacity, contingency capacity, and crisis capacity. [31]

Table 3. Institute of Medicine: Continuum of Conventional, Contingency, and Crisis Capacity (Reprinted by permission: Crisis Standards of Care, 2010 [31])

Conventional capacity: The spaces, staff, and supplies are consistent with daily practices within the institution. These spaces and practices are used during a major mass casualty incident that triggers activation of the facility emergency operations plan.
Contingency capacity: The spaces, staff, and supplies are consistent with daily practices, but maintain or have minimal impact on usual patient care practices. These spaces or practices may be used temporarily during a major mass casualty incident or on a more sustained basis during a disaster (when the demands of the incident exceed community resources).
Crisis capacity: Adaptive spaces, staff, and supplies are not consistent with usual standards of care, but provide sufficiency of care in the setting of a catastrophic disaster (i.e. provide the best possible care to patients given the circumstances and resources available) (Hick *et al*., 2009).

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How Surge Differs for Children?

A disaster response in which a majority of children are injured presents several challenges to a healthcare system. First, the number of hospitals that provide care to children is limited. Secondly, even hospitals with emergency departments that provide care to children often do not have the appropriate supplies, staff, medications, and equipment to provide comprehensive care for children. [28] Lastly, the public and healthcare workers often find it difficult to limit care to a child, withdraw life-saving treatments, or leave a child to die. [39]

A hospital's ability to surge to the needs of children varies based on their existing capacity and capabilities. [36, 40] During a disaster, children may arrive at facilities that do not usually care for children. This makes it critical for all disaster planners and emergency departments to be ready to respond to children's needs. Definitive care for children is typically managed in a pediatric acute setting, PICU, neonatal intensive care unit, or a specialized intensive care service. The most acutely injured children require care within a PICU, which is staffed by a pediatric intensivist, critical care nurses, and respiratory therapists with an accompaniment of various support staff.

Throughout the United States, the availability of pediatric care and particularly PICUs' are limited. This brings to question how a geographic location (community, region, or state) will deal with a large surge of injured children. The New York City Department of Health and Mental Hygiene (NYC DOHMH) sponsored work in creating a regional approach for PICU care, and a similar effort is underway in Los Angeles County, Contra Costa County, and the California Central Valley. [40, 41] Many hospitals will be unlikely able to meet a large surge of children; therefore, a regional system needs to be in place when resources are overwhelmed in one locale. [29, 40, 42] Coordination with local EMS or public health can establish a support system for facilities that lack the appropriate resources. [43]

Ensuring Child-Appropriate Staff, Space, and Stuff

Staff

The ability of staff to successfully stay and/or respond to a disaster at work continues to be studied, but often is based on the following factors: 1) safety of themselves, 2) safety of their loved ones, and 3) proximity to work. [44]

There are several strategies that can be implemented when accommodating a medical surge to maintain staffing levelsincluding:

- Employee call back protocols; [45]
- Modifying staff assignments to focus on patient care;
- Modifying staffing ratios;
- Using care teams; [36]
- Providing resources for staff on-site and arranging for rotating healthcare teams to cover 24 hour shifts; and

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- Using pre-arranged sharing of personnel either through memorandums of agreements (MOUs) with other hospitals, Disaster Medical Assistance Teams (DMAT), or Advanced Registry for Volunteer Health Professionals (formerly ESAR-VHP).

It is important to recognize that staff are likely affected by the disaster and are unlikely to come to work or stay at work unless they are provided adequate support. This may include providing shelter and sustenance for them and possibly their loved ones, including pets. This will require identification of space and the necessary food and security to maintain operations.

Frequently, staff has prior work experience that may become helpful in a disaster response. For example, there may be clinical staff who function in an administrative or non-clinical role. During a disaster response, these individuals may be called upon to support clinical care and leverage their past experience. Additionally, there may be nurse/patient staffing ratios required by licensing agencies [46]. If a disaster declaration is made, these ratios may need to be modified forcing a hospital into altered standards of care. Development of care teams is another approach to effectively utilize staff during disasters. Within this model, an experienced team member leads a group who has skills for the area but may not routinely practice in that environment. For example, when there is need to expand PICU capacity, critical care nurses may work with nurses from other areas to expand coverage through supervision of non-critical care nurses. [36]

In 2002, the US Congress passed an act to establish a method for states to quickly identify and use pre-registered and credentialed healthcare professionals in a disaster response. It is important to remember that many of the teams may not have pediatric expertise and that DMAT teams are primarily focused on acute care and primary care management. [36] It may take some time before a volunteer (pediatric) staff will arrive and support the facility. In addition to the DMAT program, ESAR-VHP is an available state-run and federally funded program for staffing support during disasters. This advanced registry program pre-identifies individuals interested in disaster response and validates their identity and credentials or expertise. Each state is responsible for handling the registration, credentialing, and activation of responders. If a disaster responseresponse required the activation of this federal resource, a federal declaration of a disaster would be required. All members within the database have the right to refuse activation. Upon activation, individual volunteers would be sent to the organization.

It is recommended that hospitals validate credentials upon a volunteer's arrival even if they are part of a pre-credentialed process such as ESAR-VHP. It is required by The Joint Commission (TJC) in the emergency standards to identify who will grant disaster privileges and responsibilities for licensed independent practitioners (LIPs) and how the hospital will oversee the performance of these volunteers. Expedited credentialing and privileging are allowable if the hospital's emergency operation plan has been activated and the organization is unable to meet immediate patient needs. For a volunteer to practice, the hospital must have the volunteer's government-issued photo identification and at least a current picture identification card from a healthcare organization that clearly identifies professional designation, and a current license to practice or verification of licensure from a primary source. [47] Schultz *et al*. suggest a coordinated county-based credentialing program built on a database to meet a local surge event. [45] Volunteers arriving for deployment would need at minimum orientation to the specific organization, just-in-time training for their specific

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assignment, and may function best under a “buddy” system. It is required by TJC for hospitals to oversee the care that is being provided by volunteers.

Space

There are many strategies that a healthcare facility may utilize to accommodate a surge of patients. Some measures include the following:

- Discharging patients that can go home;
- Postponing elective surgeries;
- Opening alternate care sites – either using non-traditional clinical areas for beds or tent set up;
- Altering standards of care; and
- Sending pediatric medical care teams to non-pediatric facilities. [36]

Discharging patients from the facility is the first step in responding to a surge. This requires physicians and nurses to assess which patients can be discharged. One study suggested that one-third to one-half of patients could be discharged between 24 and 72 hours post incident. [48] The second approach includes postponing elective surgeries and scheduled surgeries to accommodate patients expected to arrive. This frees up the space and staff for operating rooms, pre- and post-anesthetic care units, and ultimately beds to accommodate some of the surge. Another option for meeting a surge of patients includes use of non-traditional space for care.

Pre-identifying strategies for surge space support a more coordinated response. To establish an alternate care site one must assess the type of care that needs to be provided. For example, is space needed for patients whowho require medical gases and bio-medical equipment, triaging incoming patients, or sheltering non-injured individuals? Depending on the type of care required will dictate what type of space may be used. For clinical care requiring medical gases and a functioning hospital bed, the post-anesthesia care unit could be used. For a shelter type of space, a conference room or equivalent can be adapted.

It is critical for individuals involved in disaster planning to ensure that any space intended for gathering or caring for children is assessed prior to entry and identified as being child-safe. The NYC DOHMH created a pediatric-safe area checklist that can be used to assess the safety. Some of the elements to be considered include access control, access to windows and window accessories that may pose strangulation hazards, appropriate staffing, and diversional activities for children. [30] Additional assurance that areas are inaccessible to harmful substances including pharmaceuticals is required. Facilities may contact the local Safe Kids chapter to assess the space for child safety. [49]

Sending pediatric medical teams to care for children in non-pediatric facilities minimizes the critical transport resources required to physically move critically injured children and may increase local space capacity. [36] This may be beneficial in cases where it is more feasible for pediatric specialists to partner with existing providers and when there is a potential detriment to the child’s life if they were moved.

IncreasingIncreasing effective support during disaster response shouldshould occur with the initial planning phase and design of a hospital. By incorporating disaster preparation

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during the design phase of a hospital, a facility can be better equipped to respond to the disaster by ensuring that disaster concepts are addressed, i.e., ability to surge in nearby or proximal space, ability to have quarantined areas, daily use of the space minimizes time to set up alternate areas. [50]

Stuff

A hospital's ability to maintain the appropriate supplies, equipment, and medication for children throughout the age spectrum is often unfeasible due to cost and space constraints, and infrequent use of the items. Pediatric-specific supplies will include clinical and non-clinical items. Several resources are available that document the types of supplies, equipment, and medications required to care for children (see prior portion of chapter). For adult hospitals these resource lists should include materials for stabilizing pediatric patients in need of eventual transfer to a pediatric hospital. [30]

CARING FOR CHILDREN IN A DISASTER

Shelter

In order to provide accommodations for children and families, potential shelter sites must be selected and incorporated into both hospital and community disaster plans. It is important to meet with community members and leaders to assist in the selection of alternate sites. [51] Appropriateness of the site should include the following:

- Separate area for families and unaccompanied minors;
- Adequate hygiene and waste disposal resources;
- "Child-proof" (no physical hazards);
- Safe and secure environment;
- Ability to exclude smoking, drugs, alcohol, and weapons around children;
- Area for childcare; and
- Access to medical and mental health professionals. [51-53]

MOU's must be developed and processed, and all shelter employees and volunteers must have background checks completed. [51, 53] These sites must be clear that no spontaneous volunteers will be allowed into the shelter since a background check will not have been completed. [53] The safety of children, an especially vulnerable population during and after a disaster, must be ensured.

When a family or unaccompanied child presents at a shelter, a standardized shelter intake form should be used and immediate medical needs identified and treated. [49, 52, 53] Shelters may receive children with special healthcare needs; partnerships with community clinics and physician offices to address these needs should be developed during the planning phase. [52] Shelters should expect to receive victims from various cultural backgrounds and some may not speak English (need to have available picture cards, translators to obtain information).

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[51] Due to crowded living arrangements, staff should be alert for children with new injuries and/or illnesses and should distribute general health and hygiene brochures. [54] Availability of adequate food supplies for all age groups must be available (Appendix 2) and a safe, secure environment provided. The shelter must provide supervision and ensure that children are not left alone with a non-parent adult. [53] Additional consideration for implementation of a schedule and age-appropriate activities should be done as this is beneficial for children during the recovery process. [51, 53, 55]

Security

Children are especially vulnerable during a disaster. Their lack of knowledge and experience make it difficult for them to care for themselves and identify dangerous situations. They are susceptible to predatory behavior and are more likely to suffer maltreatment because they may not understand their environment and are often unable to defend themselves. [56] Children who become separated from their primary caregiver(s) also pose a challenge for hospital providers in that hospitals must implement protocols to identify and support reunification with their legal guardian, including children who are pre-verbal. This makes it critical for disaster planners and all individuals responding to include children as a priority in their planning and response to natural disasters. The intake process for the patient should include documentation of the initial information provided (location, name) as well as any identifying characteristics such as birthmarks, eye and hair color, and approximate age if the child is unconscious or pre-verbal. [54] Additional photographs can be taken to be used as documentation of the child and may help in reunifying children and their families. The intake child identification survey should include questions regarding medical treatment, history of problems, and special needs. If accompanied by a supervising adult, documentation of who the adult is and if they were the usual guardian and living with the child prior to the disaster needs to be noted. [49] This information can be shared with the National Center for Missing and Exploited Children (NCMEC). If a child is unaccompanied this information can be written with an indelible marker on the child or on paper and pinned to the victim. [34]

Tracking

The tracking of children is critical to maintain a safe environment for children and is important for future reunification of separated or displaced children. One simple method for tracking children accompanied by an adult caregiver is providing wristbands for children that are matched with a wristband for their documented adult caregiver. This is a cheap and effective tool that can be used to continually validate that a child is with the correct adult caregiver. [34] Other tools exist to support capture of identifying information as well as tracking and sharing with other organizations. This includes use of barcodes that can be read by optical scanners, biometric technology that uses physical or behavioral traits such as fingerprint or iris scanners, spatial technology, and global positioning systems (GPS) that use information signaled between satellites and a receiver such as a phone. Further, smart cards or radio frequency identification (RFID) chips, which capture information, can be embedded into items (ID bands) and used to track and monitor individuals through use of Internet-based

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software systems. However, these systems rely upon power, compatible software and/or equipment that “reads” the information. [39] Many of these methods may be unavailable or only partially available following a natural disaster.

Social media sites and open public domains present another avenue for identifying, documenting, and searching for missing and separated loved ones. The American Red Cross supports a web site to be used in the aftermath of a disaster called safe and well. Facebook is an example of a social media site that has been used for identifying missing persons. [57] Individuals affected by a disaster are able to input their name and location into this database indicating that they are safe and well. This information is accessible by friends and family who visit and search the site.

Family Reunification Strategies

The process of reunification of families separated during and following a disaster begins with planning before there is an actual disaster. The Tsunami in Asia in 2004 and Hurricane Katrina in 2005, highlighted the inadequacies of the plans at that time, and there is evidence that prolonged separation from families has a negative impact on the child’s physical and mental well-being. [51, 55, 58] Guiding principles to develop a plan for reunification include the following:

- Each child must be registered by governmental authorities or specific agencies mandated to assist.
- The information must be confidential and only shared with mandated agencies specifically for tracing family members in order to reunify them.
- Agencies conducting the tracing of family members should use standardized procedures and forms.
- Traced relationships must be verified for each child and the willingness of the child to be reunited with a family member must also be confirmed.
- Actions such as adoption, changing of name, or moving the child out of the expected family location until tracing has been exhausted. [59]

There are numerous reasons for children to become separated from their parents including:

- At school or daycare when disaster struck;
- Parent died during event;
- Parent seriously injured and child not able to stay with parent;
- Child and parent seriously injured and sent to separate facilities; and
- During evacuation child separated from parent. [60, 61]

Following facility standardized procedures as well as the WHO Guiding Principles should result in prompt reunification of families. MOU’s should be developed with various governmental and non-governmental agencies in the region to provide various services should

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disaster strike. Processes must be developed to ensure that standardized information is collected on each child that presents (as previously described) for tracking and reunification.

A special area for family reunification should be identified. [61] One pilot study had an auditorium where parents came to view photos of the unaccompanied children. The authors indicate that this raises issues with privacy and also the risk of increased anxiety in the parents being exposed to photos of children with obvious injuries. [61] Unaccompanied children should have their information sent to NCMEC (see previous section). [49] Once a healthcare facility develops policies and procedures for family reunification, these strategies should be exercised during facility disaster drills in order to assess for gaps and areas for improvement.

Mental Health Assistance for Personnel and Families

Mental health issues and the potential for long-term consequences following a disaster have been explored in recent times, both for disaster victims and the personnel who care for them (who may also be victims of the disaster). [62-74] Norris *et al*. reviewed 60,000 disaster victims and reported psychological issues post-disaster in some of the children. [75] In a recent study of teens after the Parnitha earthquake, 9% of teens reported moderate to severe symptoms of post-traumatic stress disorder (PTSD) and 13.6% met clinical depression criteria. [66] These two areas (victims and disaster personnel) will be explored separately, but it is important to note that some personnel will also be disaster victims and may have additional stress that must be evaluated.

Disaster preparedness training for healthcare providers must address mental health issues. Providers should be aware that many disaster victims experience acute stress reactions and this is typical; it can be beneficial to educate the general public about common, “normal” reactions. [55, 68] The use of Psychological First Aid can assist with recovery as it focuses on emotional distress, aids in developing coping mechanisms, links victims with support services, and fosters the return to “normal” routines. [55, 76, 77] A link to the Psychological First Aid Handbook can be found in Resources.

It is critical that healthcare providers be able to recognize those victims who require more in-depth mental health interventions. Post-disaster mental health problems include: suicide, PTSD, depression, and drug/alcohol problems. [68] PsySTART is a mental health triage tool that can be used in both children and adults; healthcare providers can quickly learn to implement the tool through just-in-time training. [55, 69]

Personnel

Following Hurricane Katrina, a small sample of Emergency Department nurses completed a survey; 20% reported symptoms of PTSD. They also indicated that their facility did not offer any type of Critical Incident Stress Management. [63] A study of first responders in New Orleans revealed that more than 10% of respondents had high levels of PTSD symptoms, 25% had depressive symptoms, and more than 40% described increased use of alcohol. [74] Another report stressed the importance of orienting disaster volunteers and providing shift rotations. However, the report also stated that in a mega-disaster there may not

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be increased available personnel and resources may become scarce. [62] There are several factors that can affect healthcare personnel including their actual personal loss in the disaster (also a victim), the degree of impact that the disaster has on the actual healthcare system in the area or region, political stability of the affected region, possible security issues, and witnessing the impact of the disaster on others. [68] Therefore, it is imperative that healthcare providers are cognizant of their own mental health needs. Partnering with a community mental health specialty group during the planning phase may be an effective means for promoting the mental well-being for providers. [62]

Families

It is important to remember that children vary in their ability to respond to a disaster depending on their developmental level. Children pick up on emotional cues from their parents. [78, 79] They also feel secure from their routine and by staying connected with their families and institutions such as school or daycare. [58] Parents who are overcome with the events of the disaster may not recognize signs and symptoms of distress in their child. [67] Studies also show that women are disproportionately at increased risk for PTSD following a disaster compared to males. [65] Therefore, it is important for healthcare providers to understand the developmental levels of a child and common signs and symptoms of mental health distress. They should also provide anticipatory guidance to parents about behaviors to watch for. [72] Children, especially younger age groups, may not be able to verbalize their feelings. [65] Common signs of distress include: behavior changes and/or regression, sleep issues, changes in appetite, preoccupation with the event, poor school performance, and somatic complaints. [65, 67, 72, 78, 80, 81] When recognized, a prompt referral to a mental health specialist is imperative.

CONCLUSION

The approach to natural disaster preparedness is multifaceted. It begins with understanding one's context and identifying local hazards. Understanding the history, geography, geology, and local culture are key to implementing systems of mitigation. Mitigation or the "effort to reduce loss of life and property" requires efforts of national, state, and local governments. This is necessary to prevent construction of unsound structures such as the "tofu-dreg" schools in China, prevention of building in the wrong place (e.g., flood plain), and ensuring the appropriate infrastructure is in place to prevent loss of vital facilities (e.g., hospitals, schools). While these measures are important, an adequate response system must be designed, implemented, and tested prior to an event. Healthcare facilities must have redundant resources in place, the ability to deal with surges in capacity, and child-specific equipment. They must develop disaster protocols specific to children and the ability to utilize or access pediatric specialty care. Further, staff and communities (including first responders) must be educated and included in the planning process so they understand their roles during time of disaster. Ethical guidelines must exist for situations in which resources become limited and facilities become unable to maintain standards of care.

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Resources, space, and security are especially important in the process. Failure to prepare or account for these factors increases risk of secondary harm particularly in children. Children have a limited capacity to care for themselves and may become subject to predation or repeat injury. Careful tracking, secure environments, and family reunification procedures are of utmost importance.

In summary, children are a unique populace and they need to be included in disaster plans at all levels of government and community. Further, pediatric-related resources must be allocated for mitigation, preparation, response, and recovery activities.

APPENDIX 1.
Equipment Stockpiles in Event of Disaster

Item	Size	Number of Items per Ten Mass Critical Care Beds over 10 Days	
		Uniformly Affected Population	Age Group Targeted Population
Respiratory			
Oral Airway	Infant	7	21
	Small Child	3	7
	Child	8	18
	Small Adult	5	13
	Adult	3	9
Self-inflatable bag	Child	17	24
	Adult	9	22
Resuscitation Mask	Infant	7	21
	Small Child	6	17
	Child	5	13
	Small Adult	5	13
	Adult	3	9
Oxygen Mask	Infant	5	21
	Child	16	24
	Adult	5	21
Endotracheal tube (cuffed)	3.0	2	26
	3.5	7	22
	4.0	6	13
	5.0	7	17
	6.0	8	22
	7.0	2	6
Stylette	Pediatric	14	23
	Adult	12	23
Closed-circuit suction catheter	6F	2	20
	8F	5	17
	10F	14	23
	12F	5	5
Yankauer suction device	Standard	26	26

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Item	Size	Number of Items per Ten Mass Critical Care Beds over 10 Days	
		Uniformly Affected Population	Age Group Targeted Population
Other			
Ventilator circuit	Child	8	22
	Adult	18	24
Peripheral intravenous catheter	24 gauge	39	107
	22 gauge	112	184
	20 gauge	61	132
	18 gauge	36	126
	16 gauge	9	41
Central venous catheters	4F / 8cm	1	10
	5F / 15cm	11	13
	7F / 30cm	1	4
Nasogastric tube	5F	2	20
	8F	9	22
	10F	3	11
	12F	4	13
	14F	5	13
	18F	3	9
Urinary catheter	5F	2	20
	8F	6	11
	10F	6	11
	12F	12	22
Chest tube	10F	1	5
	16F	1	3
	20F	1	3
	24F	1	3
	28F	2	3
	38F	1	1
Blood pressure cuff	Neonate	1	8
	Infant	2	5
	Child	6	9
	Small Adult	1	4
	Adult	1	4

Reprinted with permissions from “Supplies and equipment for pediatric emergency mass critical care.” [23].

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APPENDIX 2.

Recommended Supplies for Immediate Delivery within 3 Hours

Perishable		Non-Perishables	
Quantity	Description	Quantity	Description
40 Jars	Baby Food - Stage 2 (jar size is 3.5 - 4 oz)	25	Infant feeding bottles
1 box (16oz)	Cereal - single grain cereal preferred (e.g. rice, barley, oatmeal)	30	Infant Feeding Spoons
Min 200 wipes	Diaper wipes - fragrance free (hypoallergenic)	50	Nipples for Baby Bottles
40	Diapers - Size 1 (up to 14 lbs.)	25 ounces	Diaper Rash Ointment
40	Diapers - Size 2 (12 - 18 lbs.)	100 pads	Disposable Changing Pads
40	Diapers - Size 3 (16 - 28 lbs.)	10	Infant bathing basin
40	Diapers - Size 4 (22 - 37 lbs.)	100 ounces	Infant wash, hypoallergenic
40	Diapers - Size 5 (27 lbs. +)	10	Wash cloths
40	Pull Ups 4T - 5T (38 lbs. +)	10	Towels (for drying after bathing)
320oz	Formula, milk-based, ready to feed	2 sets	Infant hat and booties
64oz	Formula, hypoallergenic-hydrolyzed protein, ready to feed	10	Lightweight Blankets
64oz	Formula, soy-based, ready to feed	5	Folding, portable cribs or playpens
1 Quart	Oral Electrolyte solution for children, ready-to-use, unflavored (e.g. Pedialyte)	2	Toddler potty seat
40	Baby Food – Stage 1 (jar size ~ 2.5 oz)	5	High Chairs
40	Baby Food - Stage 3 (jar size ~ 6 oz)	1 pack	Electrical Receptacle Covers
40	Diapers - Preemie Size (up to 6 lbs.)	10	Sip Cups

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RESOURCES

American Red Cross: www.redcross.org
FEMA for Kids: www.ready.gov/kids
Children's Hospital Los Angeles Disaster Center: http://www. chladisastercenter.org
National Center for PTSD: www.ptsd.va.gov
NAPNAP: www.napnap.org/DisasterResources.aspx
Florida Center for Public Health Preparedness: http://www.fcphp.usf.edu/courses/search/search.asp
National Child Traumatic Stress Network: www.nctsnet.org

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Psychological First Aid Handbook: http://www.ptsd.va.gov/professional/manuals/manual-pdf/pfa/PFA_2ndEditionwithappendices.pdf
SAMHSA: http://www.samhsa.gov/disaster/traumaticevents.aspx

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Chapter 4

THE NEW QUANTILE APPROACH: APPLICATION TO THE SEISMIC RISK ASSESSMENT

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ABSTRACT

We examine the earthquake size distributions in the uppermost range of extremely rare events using a new method for statistical estimation of the tail distribution. The main problem in the statistical study of the extremely rare strongest earthquakes (and this applies to distributions of other rarely observable extremes) is the estimation of quantiles which are “beyond the data range”, i.e., quantiles of level $q > 1 - 1/n$, where n is the sample size. The estimation of quantiles of levels $q > 1 - 1/n$ can’t be obtained without additional assumptions on the behavior of the tail of the distribution. As the assumptions we use the two main theorems in the theory of extreme values and the derived duality between the Generalized Pareto Distribution (GPD) and the Generalized Extreme Value distribution (GEV). This approach provides a possibility to estimate the quantiles of a high level. It should be noted that for some values of parameters of GPD and GEV distributions the widely used parameter - maximum possible magnitude m_{max} and other similar parameters (i.e., peak ground acceleration, PGA) are unstable statistically. This feature is a mathematical aspect of the regularly repeating cases of occurrence of strong earthquakes in the areas believed before to be of negligible seismic activity. Note that very these unexpected strong earthquakes cause huge losses rather frequently.

To avoid this instability we have suggested a new parameter $Q_q(\tau)$ – the quantile of a given level q of the maximum magnitude in a future time interval τ. In contrast to m_{max}, the parameter $Q_q(\tau)$ is stable and robust. The quantiles $Q_q(\tau)$ can be very useful tools for pricing risks in the insurance business and for optimizing the allocation of resources and preparedness by governments.

We illustrate our theoretical conclusions applying described technique to earthquakes in Japan (1900-2010) and Fennoscandia (1900-2005). In the case of Japan we have found that earthquakes with magnitude M~9.0 are possible despite the fact that no such events are specified in the historical catalog of Usami (599-1884). We have applied this approach to a new object: peak ground acceleration (PGA) caused by earthquakes. The

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regular part of PGA was modeled in form of a function depending on magnitude and epicentral distance [Steinberg et al., 1993]. The random errors of several types were taken into account. The resulting statistical technique was applied to 4 sites in Japan: Tokyo, Hiroshima, Osaka, Fukushima atomic power station (Fukushima Daiichi).

The estimated PGA for these sites were derived. These estimates can be useful for the seismic hazard assessment.

We emphasize also that the methods used here to parameterize the recurrence of major earthquakes are very general and are applicable, not only to the assessment of earthquake hazard, but also to all those cases where the recurrence of rare large events is to be estimated.

INTRODUCTION

We have introduced in [Pisarenko and Rodkin 2010], [Pisarenko et al. 2010] the new method of statistical evaluation of seismic hazard and applied it to some seismic regions. Now we extend this method to estimation of the ground acceleration, caused by earthquakes, that can be directly used in the seismic risk assessment. The maximum peak ground acceleration A_{max} was statistically studied in [Pisarenko and Lyubushin1997], [Pisarenko and Lyubushin 1999], [Lyubushin et al. 2002] with the help of the Bayesian approach. The chief innovation, suggested in [Pisarenko and Rodkin 2010], [Pisarenko et al. 2010] consists in combining the two main limit theorems of Extreme Value Theory *(EVT)* that allowed us to derive the distribution of τ-maxima (maximum ground acceleration occurring at a given point in future time interval of duration τ) for arbitrary τ. This distribution enables one to derive any desired statistical characteristic of the future τ-maximum. The two limit theorems of *EVT* correspond respectively to the Generalized Extreme Value distribution (*GEV*) and to the Generalized Pareto Distribution (*GPD*). Pisarenko and Rodkin [2010] have established the direct relations between the parameters of these two distributions. The duality between the *GEV* and *GPD* provides a new way to check the consistency of the estimation of the tail characteristics of the distribution of earthquake magnitudes for earthquake occurring *over arbitrary time interval*.

Instead of focusing on the unstable parameters m_{max} , a_{max} (maximum possible regional magnitude and maximum peak ground acceleration at a given point correspondingly) we suggest a new characteristics $M_{max}(\tau)$ – defined as the maximum earthquake that can be recorded over a future time interval of duration τ and $A_{max}(\tau)$ - the maximum peak ground acceleration at a given point over a future time interval of duration τ. The *random values* $M_{max}(\tau)$, $A_{max}(\tau)$ can be described by their distribution functions, or (which is an equivalent description) by their quantiles $Q_q^M(\tau)$, $Q_q^A(\tau)$ that are, in contrast with m_{max} , a_{max} stable and robust characteristics. The quantil Q_q of level q , $0 < q < 1$, is defined as the root of the equation

$$F(x) = q, \tag{1}$$

where $F(x)$ is distribution function of random value in question that is assumed to be continuous.

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It should be noted, that we do not give off any information using $M_{max}(\tau)$, $A_{max}(\tau)$, since if $\tau\to\infty$, then $M_{max}(\tau) \to m_{max}$ (correspondingly $A_{max}(\tau) \to a_{max}$) with probability one. The methods of calculation of quantiles $Q_q^M(\tau)$, are exposed below. In particular, we can estimate these quantiles for, say, $q = 10, 5$ and 1%, as well as for the median $q = 50\%$ for any desirable time interval τ. These methods are illustrated below on the magnitude catalog of the Japanese Meteorological Agency (JMA), over the time period 1900-2011 and for the regional catalog of Fennoscandia (1900-2005). We have chosen also 4 points on Japan territory for the estimation of ground acceleration: Tokyo, Hiroshima, Osaka, Fukushima Daiichi. The exact coordinates are given below.

1. The Method

According to the theory of extreme values, the limit distribution of maxima can be obtained in two ways. The first one, sometimes called the "peak over threshold" method, consists in increasing a threshold h above which observations are kept. Then, the distribution of event sizes, which exceed h, tends (as h tends to the right limit point of the distribution) to the Generalized Pareto Distribution (GPD). The GDP depends on two unknown parameters (ξ, s) and on the known threshold h (see e.g. [Embrechts et al., 1997]). For the case of random values that are limited from above, the GPD can be written as follows:

$$GPD_h(x\,|\xi, s) = 1 - [1 + (\xi/s)\cdot(x - h)]^{-1/\xi},\ \xi < 0;\ s > 0;\ h \le x \le h - s/\xi. \quad (2)$$

Here, ξ is the form parameter, s is the scale parameter and the combination $h - s/\xi$ represents the uppermost value. We expose below the method for magnitudes (changes for accelerations are evident). Thus, we denote the uppermost value as M_{max} :

$$M_{max} = h - s/\xi\,,\ \xi < 0. \quad (3)$$

The second way consists in selecting directly the maxima occurring in sequences of n successive observations $M_n = max(m_1, \dots, m_n)$, and in studying their distribution as n goes to infinity. In accordance with the main theorem of the theory of extreme values (see e.g. [Embrechts et al., 1997]), this distribution, named the Generalized Extreme Value distribution (GEV), can be written (for the case of random values limited from above) in the form:

$$GEV(x\mid \zeta, \sigma, \mu) = exp(\,-[1 + (\zeta/\sigma)\cdot(x - \mu)]^{-1/\zeta},\ \zeta < 0;\ \sigma > 0;\ x \le \mu - \sigma/\zeta. \quad (4)$$

The conditions guaranteeing the validity of these two limit theorems include the regularity of the original distributions of magnitudes in their tail and boil down to the existence of a *non-degenerate* limit distribution of M_n after a proper centering and normalization.

We shall study the maximum magnitudes occurring in time interval $(0, T)$. We assume that the flow of main shocks is a Poissonian stationary process with some intensity λ. This property for main shocks was studied and confirmed in Appendix A of [Pisarenko et al.,

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2008], for the Harvard catalog of seismic moments over the time period 01.01.77 – 20.12.04. The term «main shock» refers here to the events remaining after using a suitable desclustering algorithm (see [Pisarenko et al., 2008] and below). Given the intensity λ and the duration T of the time window, the average number of observations (main shocks) within the interval $(0, T)$ is equal to $<n> = \lambda T$. For $T \to \infty$, the number of observations in $(0, T)$ tends to infinity with probability one and we can use (4) as the limit distribution of the maximum magnitudes m_T of the main shocks occurring in time interval $(0, T)$ of growing sizes [Pisarenko et al., 2008].

Pisarenko et al. [2009] have shown that, for a Poissonian flow of main shocks, the two limit distributions, the GPD given by (2) and the GEV given by (4), are related in a simple way. We briefly summarize the main points, and refer to [Pisarenko and Rodkin 2010] for details. If the random variable (rv) X has the GPD-distribution (2) and one takes the maximum of a random sequence of observations X_k,

$$M_T = max(X_1 , ..., X_\nu), \tag{5}$$

where ν is a random Poissonian value with parameter λT, with $\lambda T>>1$, then M_T has the GEV-distribution (4) with the following parameters:

$$\zeta(T) = \xi ; \tag{6}$$

$$\sigma(T) = s \cdot (\lambda T)^{\xi} ; \tag{7}$$

$$\mu(T) = h - (s/\xi) \cdot [1 - (\lambda T)^{\xi}]. \tag{8}$$

These expressions are valid up to small terms of order $exp(-\lambda T)$, which are neglected.

The inverse is true as well: if $M_T = max(X_1 , ..., X_\nu)$ has the GEV-distribution (4) with parameters ζ, σ, μ, then the original distribution of X_k has the GPD-distribution (2) with parameters:

$$\xi = \zeta; \tag{9}$$

$$s = \sigma \cdot (\lambda T)^{-\xi} ; \tag{10}$$

$$h = \mu + (\sigma/\xi) \cdot [(\lambda T)^{-\xi} - 1]. \tag{11}$$

The proof can be found in [Pisarenko et al., 2009]. We see that the form parameter in the GPD and the GEV is always identical, whereas the centering and normalizing parameters differ.

Using relations (6)-(11), one can recalculate the estimates $\zeta(T)$, $\sigma(T)$, $\mu(T)$ obtained for some T into corresponding estimates for another time interval of different duration τ:

$$\mu(\tau) = \mu(T) + (\sigma(T) /\xi) \cdot [(\tau/T)^{\xi} - 1] ; \tag{12}$$

$$\sigma(\tau) = \sigma(T) \cdot (\tau/T)^{\xi}. \tag{13}$$

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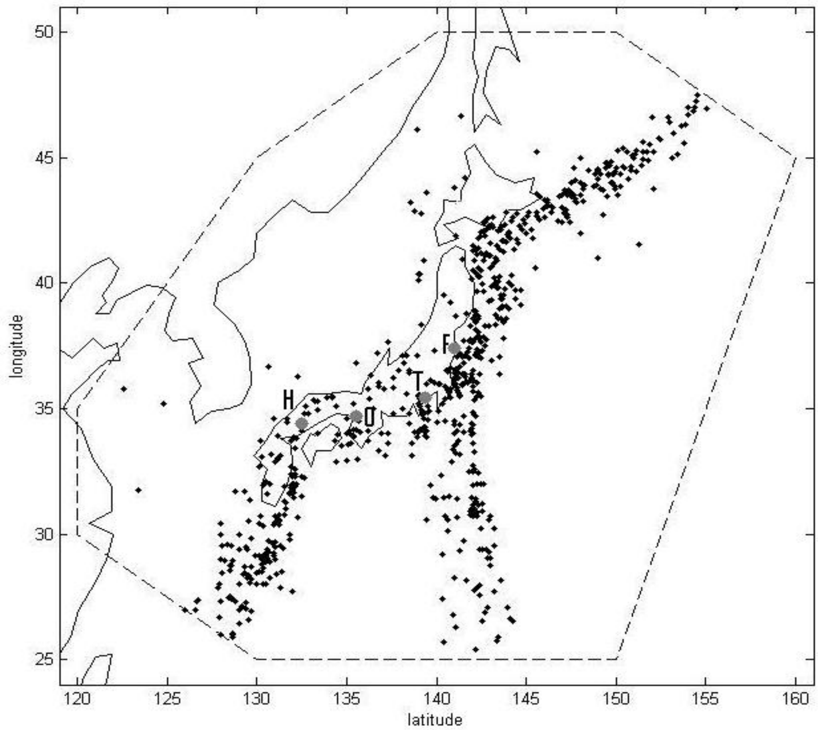

Figure 1. The contour map of the Japan region with the polygon of study and earthquake epicenters, 1900 – 2011.

Relations (6)-(13) are very convenient, and we shall use them in our estimation procedures. In the following, we use the notation T to denote the duration of a window in the known catalog (or part of the catalog) used for the estimation of the parameters, whereas we use τ to refer to a future time interval (prediction).

From the GPD-distribution (2) or the GEV-distribution (4), we can obtain the quantiles $Q_q(\tau)$, proposed as stable robust characteristics of the tail distribution. These quantiles are the roots of the following equations:

$$GPD_h(x \mid \xi, s) = q; \tag{14}$$

$$GEV(x \mid \zeta, \sigma, \mu) = q. \tag{15}$$

Inverting (14)-(15) for x as a function of q, we get:

$$Q_q(\tau) = \mu(T) + (\sigma(T) / \xi) \cdot [a \cdot (\tau/T)^{\xi} - 1] \text{ ; from (15)} \tag{16}$$

$$Q_q(\tau) = h + (s/\xi) \cdot [a \cdot (\lambda\tau)^{\xi} - 1] \text{ , from (14)} \tag{17}$$

where $a = [log(1/q)]^{-\xi}$.

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2. Application of the GPD-Method to the Estimation of τ-Maximum for Binned Magnitudes

The full JMA catalog covers the spatial domain delimited by $25.02 \leq latitude \leq 49.53$ *degree* and $121.01 \leq longitude \leq 156.36$ *degree.* The depths of earthquakes fall in the interval $0 \leq depth \leq 657$ *km.* The magnitudes are expressed in 0.1-bins. The spatial domain covered by the JMA catalog covers besides Japan the Kuril Islands and the East border of Asia. Here, we focus our study to earthquakes occurring within the central Japanese islands. We thus restrict the territory of our study to earthquakes occurring within the polygon with coordinates [*(160.00; 45.00); (150.00; 50.00); (140.00; 50.00); (130.00; 45.00); (120.00; 35.00): (120.00; 30.00); (130.00; 25.00); (150.00; 25.00); (160.00; 45.00)*]. Next, we keep earthquakes whose depths are smaller than 70 km and magnitudes are larger than 5.5 since only such shocks can represent a seismic danger. Time window covered period 01.01.1900 – 10.03.2011 (the last date is the day before the greatest Japanese earthquake that generated a huge tsunami wave). There are 3048 earthquakes in this space-time-magnitude domain. Figure 1 shows the map of the region delineated by the polygon, in which we perform our study. The corresponding magnitude-frequency relations are shown in Figure 2 and the magnitude histograms are shown in Figure 3.

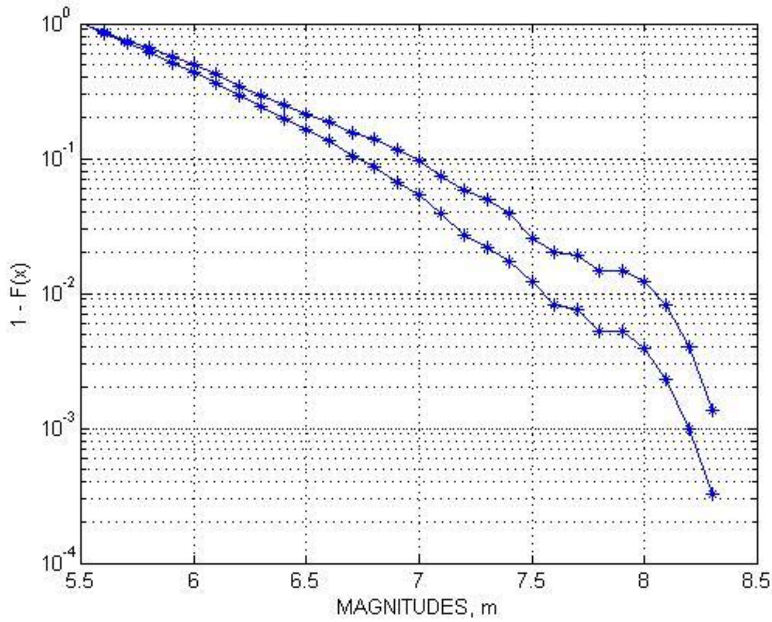

Figure 2. The complimentary sample distribution functions of all events (lower curve, $n = 3047$) and main shocks (upper curve, $n = 740$).

We then applied the declustering Knopoff-Kagan space-time window algorithm [Knopoff and Kagan, 1977]. The remaining events constitute our “main shocks”, on which we are going to apply the method described above. There are 740 main shocks in the polygon shown in Figure 1. The magnitude-frequency curve of these main shocks is shown in Figure 2 (lower curve). It should be noted that the *b*-slope of the magnitude-frequency of main shocks is

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significantly smaller (by 0.15 or so) than the corresponding *b*-slope of the magnitude-frequency for all events. From the relatively small number of remaining main shocks, one concludes that the percentage of aftershocks in Japan is very high (about 75% according to the Knopoff-Kagan algorithm). One can observe irregularities and a non-monotonic behavior of histogram. These irregularities presumably can be caused by artificial reasons not connected with the seismic process, and we decided to reduce their influence by aggregating 0.1-bins into 0.2-bins. The discreteness in the magnitudes requires a special treatment (in particular the use of Chi-square test), which is explained below.

Figure 4 plots the yearly number of earthquakes averaged over 10 years for three magnitude thresholds: $m \geq 5.5$; $m \geq 6.0$; and $m \geq 7.0$; *main events*. The time series with $m \geq 6.0$ appears approximately stationary, with an intensity of about 3 events per year.

As shown in Figs. 2 and 3, the earthquake magnitudes of the JMA catalog are discrete. Moreover, the oscillations decorating the decay with magnitudes shown in Figure 3 require further coarse-graining with bins of 0.2 units of magnitudes as explained above. But, all considerations exposed in section 2 refer to continuous random values, with continuous distribution functions. For discrete random variables, the theory of extreme values is not directly applicable. This contradiction is avoided as follows.

Consider a catalog in which magnitudes are reported with a magnitude step Δm. Usually, in the most part of existing catalogs, including the catalog of Japan, $\Delta m = 0.1$. In some catalogs, two decimal digits are reported, but the last digit is fictitious unless the magnitudes are recalculated from seismic moments, themselves determined with several exact digits (such as for the m_W magnitude in the Harvard catalog). Here, we assume that the digitization is fulfilled exactly without random errors in intervals $((k\text{-}1)\cdot \Delta m;\ k\cdot\Delta m)$, where k is an integer. As a consequence, in the GPD approach, we should use only half-integer thresholds $h = (k\text{-}1/2)\cdot \Delta m$, which is not a serious restriction.

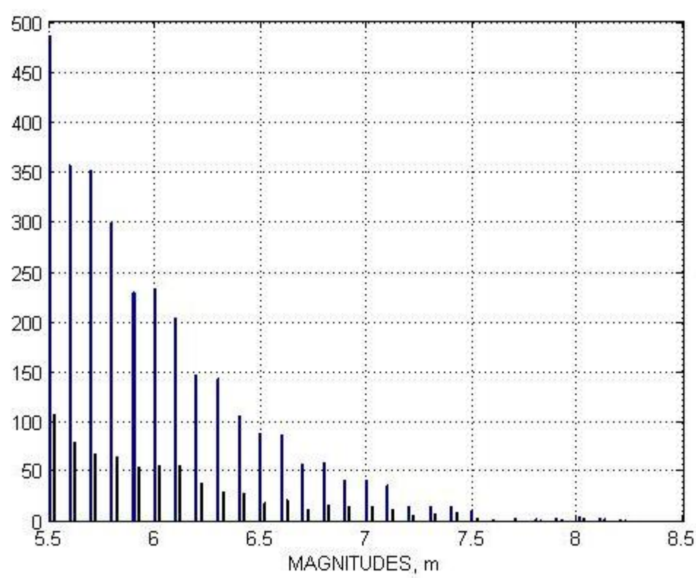

Figure 3. The histograms of all events (left bars) and the main shocks (right bars), Japan, 1900-2011.

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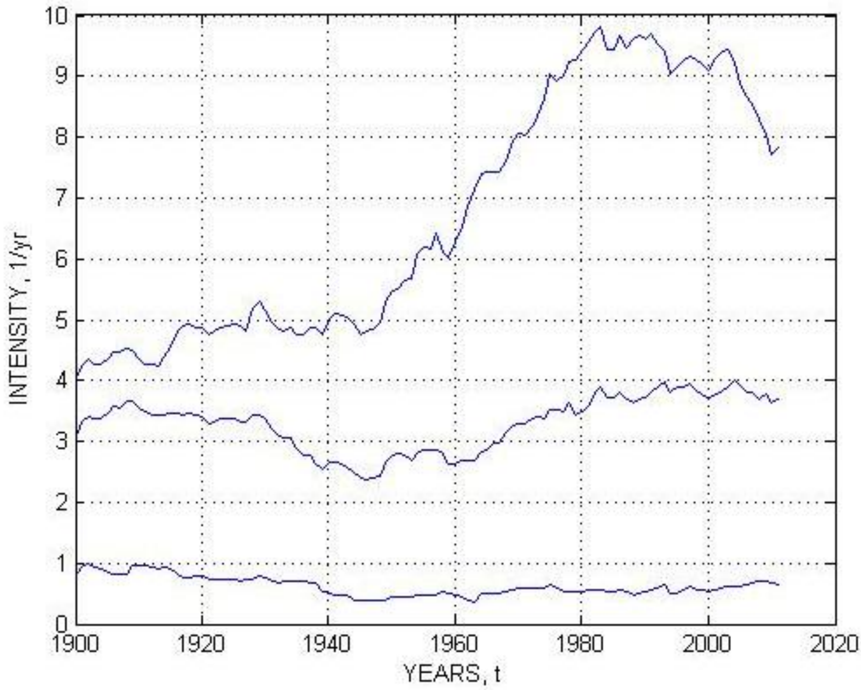

Figure 4. The intensities (1/year) for the JMA catalog, main events. Thresholds: $h = 5.5$ (top, $n = 740$); $h = 6.0$ (middle, $n = 365$); $h = 7.0$ (bottom, $n = 71$).

We assume that a lower threshold h is sufficiently high, so that the limit GPD distribution for unobservable "continuous" magnitudes is applicable. These continuous magnitudes are digitized into binned magnitude catalog. Having a sample of magnitudes exceeding some $h = (k\text{-}1/2)\cdot \Delta m$, and fitting the GPD-distribution to it, we need to test the goodness of fit of the GPD model to the data. For continuous random variables, the Kolmogorov test or the Anderson-Darling test was previously used successfully [Pisarenko et al., 2008; 2009]. For discrete variables, such statistical tools tailored for continuous random variables are incorrect. We are thus forced to use statistical tools adapted to discrete random variables. We have chosen the standard χ^2-method, that provides both a way to estimate unknown parameters and to strictly evaluate the goodness of fit. The Chi-square test has two peculiarities:

1. In order to be able to apply the Chi-square test, a sufficient number of observations is needed in each bin (we choose this minimum number as being equal to 10 (see for discussion [Borovkov, 1987]).
2. In order to compare two different fits (corresponding to two different vectors of parameters), it is highly desirable to have the same binning in both experiments. Otherwise, the significance levels, which depend on the binning, can vary considerably.
3. As it was marked above, it is desirable to use 0.2-magnitude bins (or even more coarse bins) in order to avoid the irregularities clearly seen in the magnitude histograms (see e.g. Figure 3).

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In general, the Chi-square test is less sensitive and less efficient than the Kolmogorov test or the Anderson-Darling test. This results from the fact that the Chi-square coarsens data by putting them into discrete bins.

We have accepted the following scheme for the aggregation of binned magnitude samples.

We start from the largest magnitudes and collect so many 0.1-bins that resulting aggregated bin would contain 10 or more observations. In our Japanese catalog we need to collect in one bin magnitudes 8.3; 8.2; 8.1; 8.0; 7.9. There were 11 events in this bin. Then we took magnitudes 7.8; 7.7; 7.6; 7.5; 7.4. There were 18 observations in this bin. Further, it was sufficient to take 0.2-magnitude bins: (7.3; 7.2), (7.1; 7.0), … , (6.3; 6.2), (6.1; 6.0). Thus, we have fulfilled all demands to the aggregation mentioned above.

Now we are going to show how to apply the Chi-square test to the aggregated magnitude sample.

Consider the discrete set of magnitudes registered with step Δm over threshold h,

$$h + (k-1)\,\Delta m/2 \le m < h + k\Delta m/2;\ k=1,\dots r\ ;\ \Delta m = 0.1. \tag{18}$$

The corresponding discrete probabilities read

$$\begin{aligned} p_k(\xi,s\,|h) &= P\{h + (k-1)\cdot 0.05 \le m < h + k\cdot 0.05\} = \\ &= GPD(h + k\cdot 0.05\,|\xi,s,h) - GPD(h + (k-1)\cdot 0.05\,|\xi,s,h); \end{aligned} \tag{19}$$

$$p_{r+1}(\xi,s\,|h) = 1 - GPD(h + r\cdot 0.05\,|\xi,s,h). \tag{20}$$

The last $(r+1)$-*th* bin covers the interval $(h + r\cdot 0.05;\ \infty)$. We use the following expression

$$GPD(x\,|\xi,s,h) = 1 - [1+(\xi/s)(x-h)]^{-1/\xi},\ h \le x \le h - s/\xi,\ \xi < 0. \tag{21}$$

Let us assume that the interval (18) contains n_k observations. Summing over the $r+1$ intervals, the total number of observations is $n = n_1 + n_2 + \dots n_r + n_{r+1}$. Then, the Chi-square sum $S(\xi,s)$ is written as follows:

$$S(\xi,s) = \sum_{k=1}^{r+1} [n_k - n\cdot p_k(\xi,s\,|h)]^2 / n\cdot p_k(\xi,s\,|h), \tag{22}$$

$S(\xi,s)$ should be minimized over the parameters (ξ,s). This minimum value is distributed according to the χ^2-distribution with $(r-2)$ degrees of freedom. The quality of the fit of the empirical distribution by expressions (19) and (20) is quantified by the probability $P_{exc} = P\{\chi^2(r-2) \ge min(S)\}$, where $\chi^2(r-2)$ is the Chi-square random value with $(r-2)$ degrees of freedom, i.e. P_{exc} is the probability of exceeding the minimum fitted Chi-square sum. The larger P_{exc} is, the better is the goodness of fit.

For magnitude thresholds $h \le 5.95$ and $h \ge 6.65$, the Chi-square sums $min(S)$ happened to be very large, leading to very small P_{exc} values, indicating that such thresholds are not

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acceptable. For thresholds in the interval $(6.05 \le h \le 6.55)$, the results of the Chi-square fitting procedure are collected in Table 1.

Having estimated the triple (ξ,s,h), we use these estimates to predict the quantile of τ-maxima for any arbitrary future time interval $(0, \tau)$, since these τ-maxima have the distribution $GEV(x\,|\xi,\sigma_\tau,\mu_\tau)$, as seen from equations (6)-(13). Recall that, in equations (6)-(13), λ denotes the intensity of the Poissonian flow of events whose magnitudes exceed the threshold h.

In Table 1, two thresholds $h=6.25$: $h=6.45$ give very close estimates. In contrast, the estimates obtained for the thresholds $h=6.05$ and $h=6.65$ have smaller goodness of fit (smaller P_{exc}). This suggests accepting the estimates corresponding to the highest goodness of fit $(h=6.25)$:

Table 1. Chi-square fitting procedure using the GPD approach

h	6.05	6.25	6.45	6.65
degrees of freedom	6	5	4	3
ξ	-0.094	-0.20	-0.23	-0.16
s	0.62	0.70	0.68	0.60
M_{max}	12.7	9.8	9.5	10.3
$Q_{0.90}(30)$	9.2	8.8	8.7	8.9
P_{exc}	0.048	0.17	0.11	0.061

The parameters are estimated by minimizing $S(\xi,s)$, defined by expression (22). M_{max} is the rightmost point of the magnitude distribution given by expression (3). $Q_{0.90}(30)$ is the 90% quantile of the maximum magnitude distribution (τ-maximum magnitude) in 30-year intervals.

$$\xi_{GPD} = -0.20;\ s_{GPD} = 0.70;\ M_{max,GPD} = 9.8;\ Q_{0.90,GPD}(30)= 8.8. \quad (23)$$

In order to estimate the statistical scatter of these estimates, we simulated our whole procedure of estimation $N_b = 100$ times on artificial GPD-samples with known parameters and calculated standard deviations. The final results of the GPD approach to the binned magnitudes can be summarized by

$$\begin{aligned} &\xi_{GPD} = -0.20 \pm 0.09;\ s_{GPD} = 0.70 \pm 0.07;\\ &M_{max,GPD} = 9.8 \pm 6.4;\\ &Q_{0.90,GPD}(30)= 8.8 \pm 2.4; \end{aligned} \quad (24)$$

One can observe that the std of M_{max} exceeds std of the quantile $Q_{0.90}(30)$ by a factor larger than two, confirming once more our earlier conclusion on the instability of M_{max}.

Figure 5 shows 3 quantiles $Q_{0.90}(\tau)$, $Q_{0.95}(\tau)$, $Q_{0.99}(\tau)$ as function of τ for $\tau = 1 \div 50$ years.

The JMA catalog was analyzed on the same territory but at different time interval 1923-2007 in [Pisarenko, Sornette and Rodkin, 2010]. Statistical estimates of the GPD parameters obtained in this paper are close to the results presented here, but the present results refer to larger time period and thus, can be considered as somewhat more representative.

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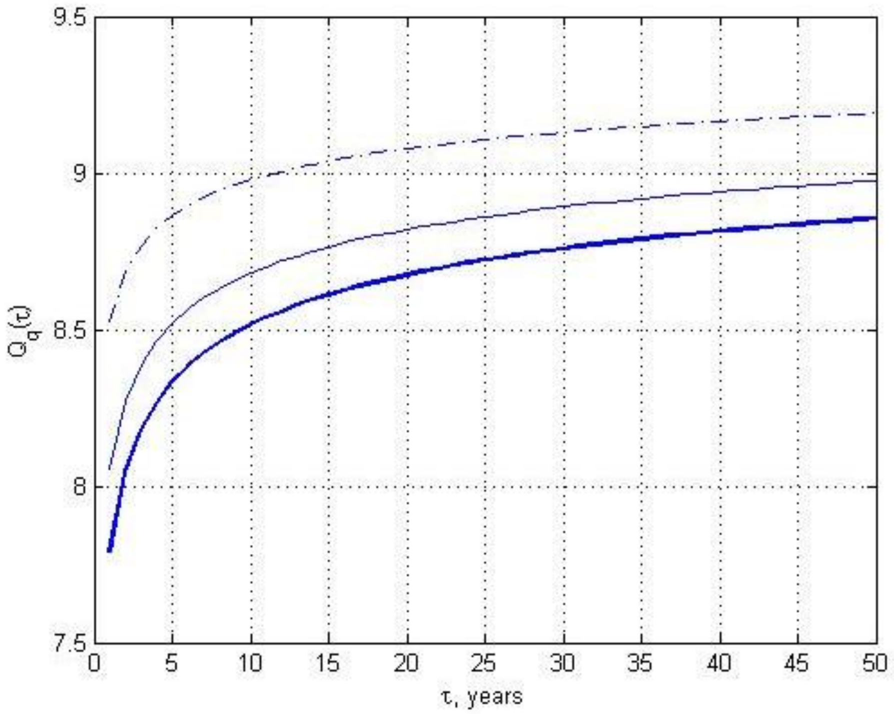

Figure 5. The GPD-quantiles of future τ-maxima, Japan, *99%* (top, dotted line), *95%* (middle, light line), *90%* (bottom, heavy line).

3. Comparison with the Usami's Catalog

It is interesting to check our quantiles $Q_q(\tau)$ on another, independent seismic data. We took for this purpose the historical catalog by Usami (HCU) [Usami, 2002]. This catalog covers time period 599-1884 and the territory of Japan islands. It contains 288 events (this number refers to events with completely known parameters of earthquake: date, latitude, longitude, magnitude). We have no possibility to discuss here the representativeness and accuracy of the HCU parameters. We are going to make only formal application of the quantiles $Q_q(\tau)$ derived above to the HCU, having in mind possible uncertainties and inaccuracies of the HCU.

The flow of events in this catalog is shown in Figure 6. It is seen that this flow is non-stationary: The data before 1600 and after 1600 evidently look as two different populations. So, we have decided to compare our JMA-parameters with two parts of HCU: 1-st part HCU-1 *599-1599* years; and 2-nd part HCU-2 *1600-1884* years. We choose for comparison the 90%-quantile $Q_{0.90}(\tau)$, shown on Figure 5. For $\tau = 1$ year we have $Q_{0.90}(\tau) = 7.85$. We shall studying statistics of large events with $m \geq 7.85$ since such events determine mainly behavior of the quantile of high level q. First of all, it is necessary to normalize average seismic intensity of HCU-1 and HCU-2 with respect to JMA catalog. There are 10 events in HCU-1; 8 events in HCU-2 and 11 events in JMA (we recall that we consider only events with $m \geq 7.85$). Having applied our declustering algorithm, we got 9 events in HCU-1 and 6 events in

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HCU-2. Thus, average seismic intensities (average number of events per year) are: I_1 = $9/1000 = 0.009\dfrac{1}{yr}$ for HCU-1; $I_2 = 6/290 = 0.0207\dfrac{1}{yr}$ for HCU-2 ; $I_{JMA} = 11/111 = 0.099$ $\dfrac{1}{yr}$ for JMA. Thus, if we take for JMA intervals

$$\tau = 1;\ 2;\ 3; 10;\ 30\ , \tag{25}$$

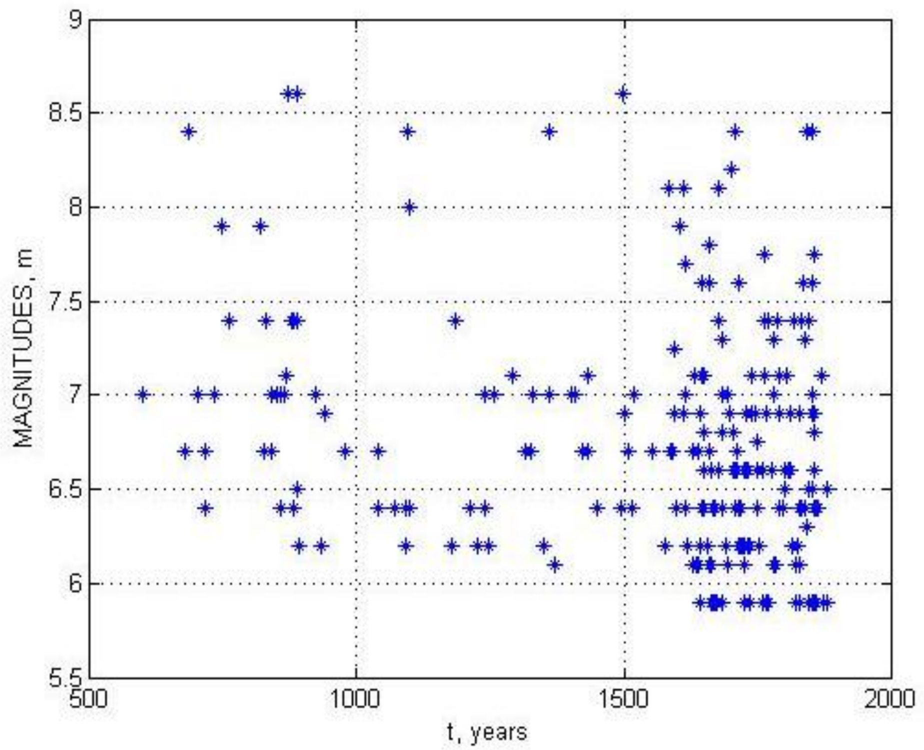

Figure 6. Time-magnitude diagram, Usami's historical catalog, Japan, 599-1884.

then it would be fair to take for HCU-1 intervals:

$$\tau_1 = 1\times\frac{I_{JMA}}{I_1};\ 2\times\frac{I_{JMA}}{I_1};\ 3\times\frac{I_{JMA}}{I_1};\ 10\times\frac{I_{JMA}}{I_1};\ 30\times\frac{I_{JMA}}{I_1},$$

and for HCU-2 intervals:

$$\tau_2 = 1\times\frac{I_{JMA}}{I_2};\ 2\times\frac{I_{JMA}}{I_2};\ 3\times\frac{I_{JMA}}{I_2};\ 10\times\frac{I_{JMA}}{I_2};\ 30\times\frac{I_{JMA}}{I_2}.$$

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After calculation we get:

$$\tau_1 = 11.0;\ 22.0;\ 33.0;\ 110.1;\ 330.3; \tag{26}$$

$$\tau_2 = 4.7;\ 9.6;\ 14.4;\ 47.9;\ 143.6. \tag{27}$$

Thus, we can apply the JMA-quantiles $Q_{0.90}(\tau)$ with intervals (25), to HCU-1 with intervals (26), to HCU-2 with intervals (27) and estimate empirically the quantile level *0.90*, i.e. we estimate sample probability of non-exceeding corresponding quantile. Perhaps, the assumptions (26)-(27) about τ-intervals are not completely accurate, but we have no other possibility to compare JMA and HCU catalogues.

It should be remarked that sample statistical estimates of probabilities have random errors that can be evaluated. Their standard deviation decreases as $n^{-0.5}$ (n is sample size), and for small samples they can be considerable. The results of estimation are represented in Table 2.

Table 2. Estimates of sample probabilities of non-exceeding JMA-quantiles of the level $q = 0.90$

τ	1	2	3	10	30
τ_1	11.0	22.0	33.0	110.1	330.3
τ_2	4.8	9.6	14.4	47.9	143.6
$Q_{0.90}(\tau)$	7.85	8.11	8.24	8.58	8.82
$P\{ m(\tau_1) \le Q_{0.90}(\tau) \}$	0.90 ± 0.05	0.87 ± 0.08	0.83 ± 0.09	0.78 ± 0.17	1.0 ± 0.29
$n(\tau_1)$	90	45	30	9	3
$P\{ m(\tau_2) \le Q_{0.90}(\tau) \}$	0.90 ± 0.07	0.86 ± 0.09	0.84 ± 0.12	1.0 ± 0.22	1.0 ± 0.35
$n(\tau_2)$	60	30	20	6	2

We see from Table 2 that all estimates differ from its theoretical value *0.90* by less than one standard deviation, which can be considered as a good agreement of HCU data with the quantiles $Q_{0.90}(\tau)$ derived from independent JMA catalog.

4. Fennoscandia Catalog

In this section we apply our methods to the Magnitude Catalog of Fennoscandia [Uski and Pelkonen, 2006], which was provided by WDC for Solid Earth Physics (Moscow).

The catalog covers the area $46.4 \le$ latitude ≤ 85.8 degree; $-24.9 \le$ longitude ≤ 57.9 degree and the time period *01.01.1375 – 31.12.2005*. Focal depth varies in the interval $0 \le$ depth ≤ 97.0 km; magnitude varies in the interval $-0.7 \le$ magnitude ≤ 6.6. There are 15,230 events in this time-space volume. The area includes Iceland and the mid-Atlantic ridge. Since we are interested in earthquakes occurring only in the Fennoscandia peninsula, we restrict our area of study by the polygon with coordinates

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Latitude	Longitude
72.0	20.0
72.0	40.0
70.0	40.0
50.0	10.0
55.0	0
60.0	-5.0
65.0	0

The contour map of this area is shown in Figure 7. The earthquake with maximum magnitude *5.8* occurred in this area on *01.09.1819* at the point $\lambda = 66.4; \phi = 14.4;$ depth unknown (Norway). Since we are interested in the analysis of main shocks, we have applied the Knopoff-Kagan algorithm used above to remove aftershocks from the catalog. We got the following numbers of main shocks:

h = *-0.7 6868* main shocks; intensity λ =*0.177* events/day = *64.7* events/year
h = *2.7 1576* main shocks; intensity λ =*0.041* events/day = *14.9* events/year
h = *3.3 594* main shocks; intensity λ =*0.0154* events/day = *5.6* events/year

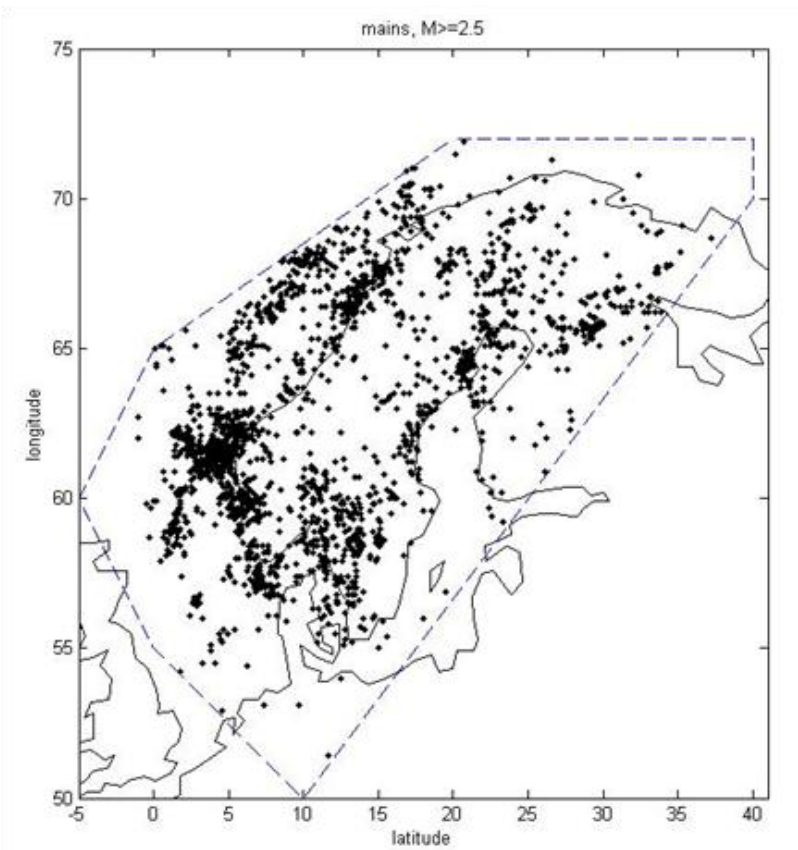

Figure 7. The contour map of the Fennoscandia region with the polygon of study and earthquake epicenters, 1900-2005.

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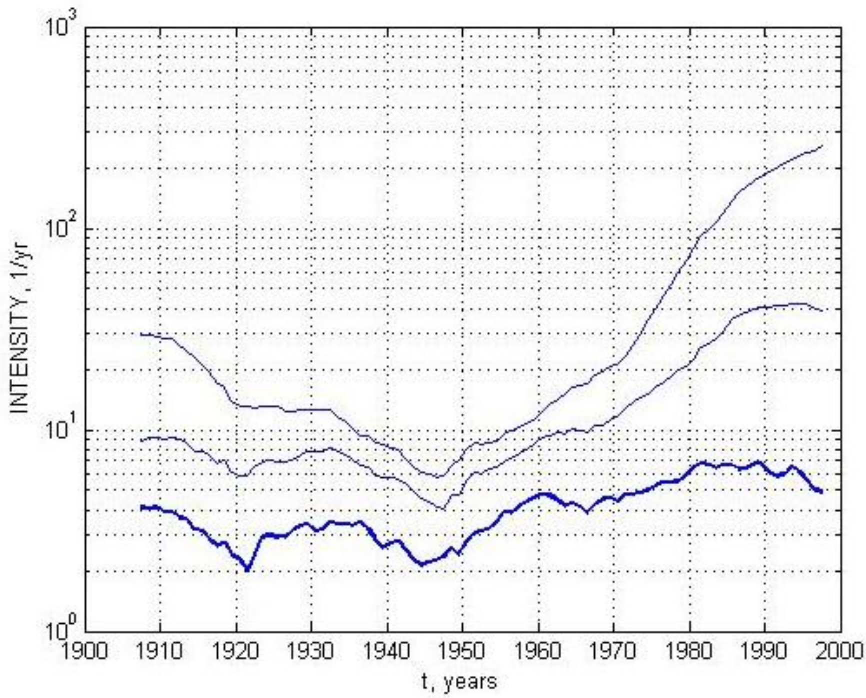

Figure 8. The intensities (1/year) for the Fennoscandia catalog. Thresholds: $h = -0.7$ (top, $n = 6868$): $h = 2.7$ (middle, $n = 1576$); $h = 3.3$ (bottom, $n = 594$).

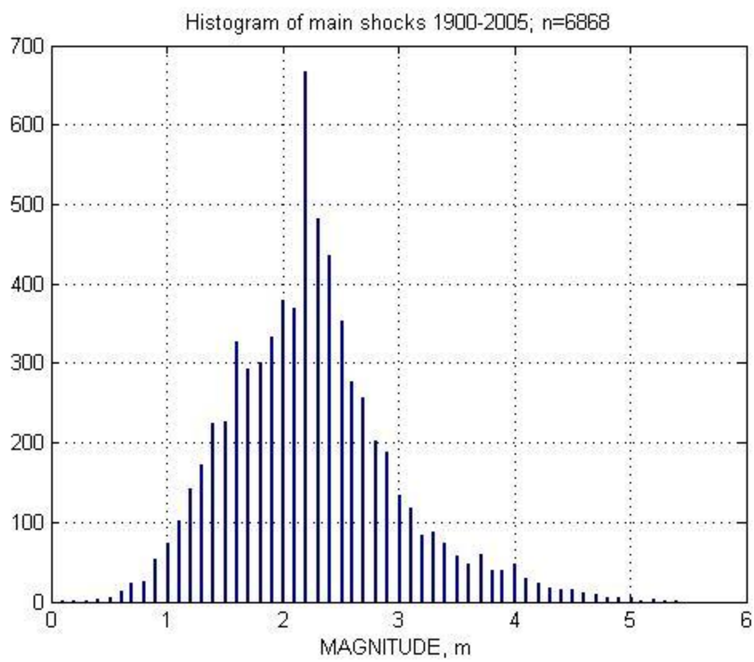

Figure 9. The histogram of main shocks, Fennoscandia, 1900-2005, $n = 6868$.

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The intensity of the 1900-2005 main shocks for 3 thresholds in a moving 15-year window is shown in Figure 8 (each intensity value is plotted versus the window center). It should be noted that the percentage of aftershocks is very low for Fennoscandia, about 6%, whereas for the other seismic zones it reaches 50% and even more. We believe that this is connected with lower seismicity level in the Fennoscandia. An intensive positive trends of intensity are present for $h = -0.7$ and $h = 2.7$ is it is almost invisible for $h = 3.3$. Figure 9 shows a histogram of main shocks. We see that the histogram becomes more or less regular and decreasing for $m \geq 2.2$. Perhaps there is some tendency toward half-integer values, but not a very prominent one. Figure 10 shows the sample tail $1 - F(x)$ for the *1900-2005* main shocks. We see that for $m \geq 2.2$ a linear dependence is clearly seen, although after $m = 4.0$ a somewhat steeper slope appears, which tells us about a faster decay of the magnitude PDF in this range.

To sum up, we can take for the analysis a more or less stationary sequence of events in the magnitude range $m \geq 3.3$. Above this threshold there are $n = 594$ events.

We apply the GPD fitting to the Fennoscandia catalog. First of all, we have to specify the bins for the Chi-square test. The histogram of main events is shown in Figure 9. One can observe some irregularities in the range under analysis $(m \geq 3.3)$, besides a non-monotonic behavior of the magnitude histogram. These irregularities forced us to combine the 0.1 bins into 0.2 bins. The use of 0.2 bins must be sufficient to remove or at least to diminish the irregularities.

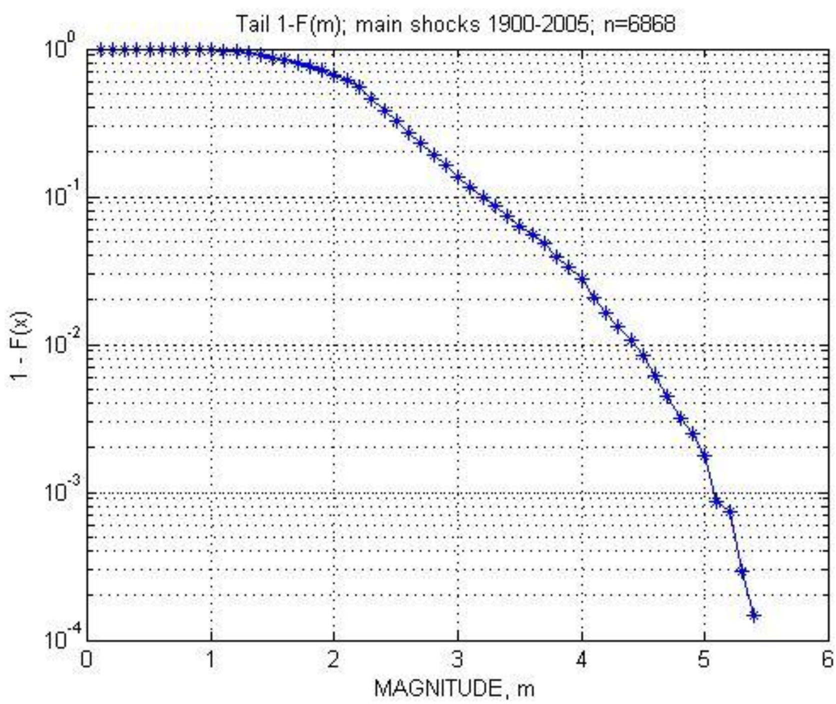

Figure 10. The complementary sample distribution function $1 - F(x)$ of main shocks, Fennoscandia, 1900-2005, $m \geq -0.7$; $n = 6868$.

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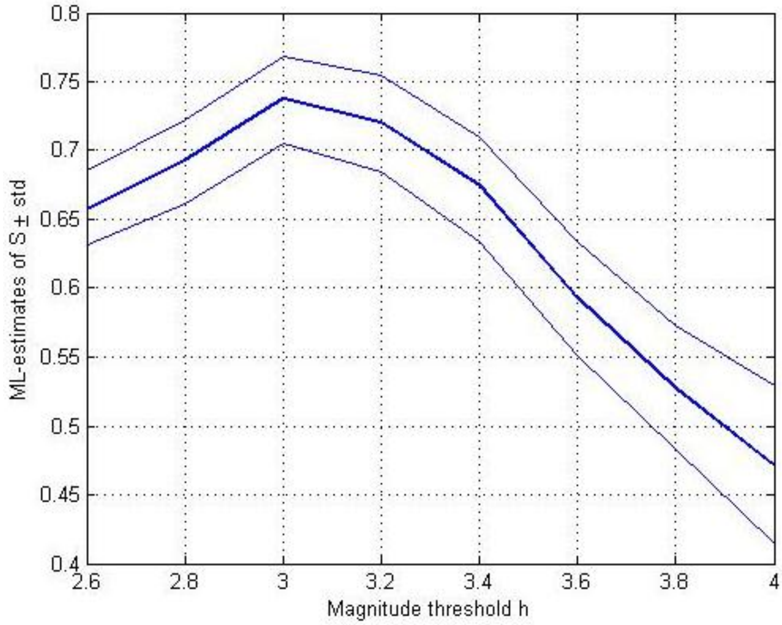

Figure 11. The *s*-estimates for different thresholds *h* by GPD-fitting. Fennoscandia, 100 bootstraps.

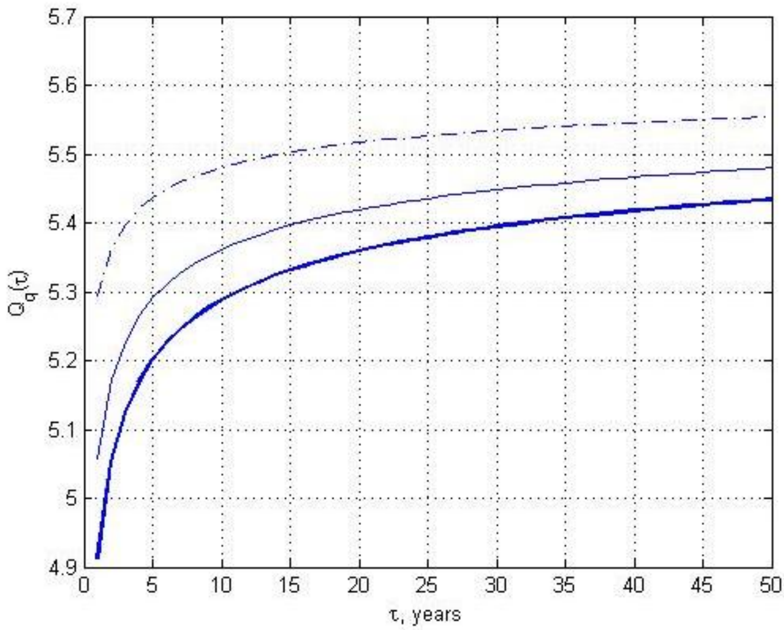

Figure 12. The GPD-quantiles of future τ-maxima. Fennoscandia, *99%* (top), *95%* (middle), *90%* (bottom).

Figure 11 shows the estimates of the parameters *s* for different thresholds *h*. As can be seen in Figure 11, the estimates begin decreasing in accordance with the theoretically expected tendency at $h \geq 3.15$. The range under analysis $(m \geq 3.3)$ thus satisfies the

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requirement of a monotone decrease of s. As mentioned above, the number of discrete bins for the Chi-square test should be as great as possible, in particular in the farther tail, provided the number of observations in each bin is no less than *10*. By several numerical experiments we determined that the best number of *0.2* bins is *7*, whereas the last, *8*-th non-standard bin which contains the tail as far as M_{max}, can have a width different from *0.2*. For thresholds $h \geq 3.65$ the data were scarce, and the number of observations per bin is less than *8* in the tail. Thus, we have to restrict the thresholds from above by this value and to analyze the estimation results for the interval of thresholds $3.25 < h < 3.65$. We show in Table 6.3 the results of this estimation for $h = 3.25; 3.35; 3.45; 3.55$. For each threshold we derived the Chi-square estimates that minimize the sum (22). We again used *100* bootstraps for each threshold value.

In Table 3, all the four thresholds give rather similar estimates. The significance levels of the Chi-square sums are not much different, and none of them is critical. This suggests averaging the parameters ξ, $Q_{0.95}(10)$ for these thresholds. The resulting averaged values are

$$<\xi_{GPD}> = -0.30; <Q_{0.95}(10)> = 5.3. \quad (28)$$

Since the theoretical parameters s and s_1 corresponding to thresholds h, h_1 are connected by equation

$$s_1 = s + \xi(h_1 - h),$$

Table 3. Estimates provided by the chi-square fitting procedure using the GPD approach

h	3.25	3.35	3.45	3.55
r	7	7	7	7
degrees of freedom	5	5	5	5
ξ	-0.30	-0.32	-0.30	-0.27
s	0.71	0.70	0.67	0.62
M_{max}	5.6	5.5	5.6	5.8
$Q_{0.95}(10)$	5.2	5.2	5.3	5.4
P_{exc}	0.11	0.13	0.19	0.12

The parameters are estimated by minimizing $S(\xi,s)$, as given by (22). M_{max} is the rightmost point of the magnitude distribution given by (3). $Q_{0.95}(10)$ is the 95% quantile of the maximum magnitude distribution (τ-maximum magnitude) in *10*-year intervals

(see [Pisarenko and Rodkin, 2010]), we converted the *s*-estimates for thresholds $h = 3.35; 3.45; 3.55$ into estimates of s $(h=3.25)$:

$$0.692 - <\xi_{GPD}> \cdot (3.35-3.25) = 0.722;$$
$$0.667 - <\xi_{GPD}> \cdot (3.45-3.25) = 0.726;$$
$$0.617 - <\xi_{GPD}> \cdot (3.55-3.25) = 0.706.$$

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Now we get the mean value:

$$<s_{GPD}(h=3.25)>=(0.705+0.722+0.726+0.706)/4 = 0.714 \approx 0.71. \quad (29)$$

Using equation (3) and estimates (28),(29), we get an estimate of M_{max} :

$$< M_{max} > = 3.25 - <s_{GPD}(3.25)>/<\xi_{GPD}> = 5.67 \approx 5.7. \quad (30)$$

In order to estimate the statistical scatter of the estimates, we simulated our whole procedure of estimation *1000* times by generating GPD-samples with parameters (28),(29). As well as for the Japanese catalog, we characterized the scatter by sample standard deviations, since all estimates but those of M_{max} had light tails and small skewness values. As to the estimates of M_{max}, their distribution was skewed towards larger values. Combining the std estimates derived from simulations with the mean values (28),(29) based on the actual catalog, the final results of the GPD approach for the Fennoscandia catalog can be summarized by

$$\xi_{GPD} = -0.30 \pm 0.03 \ ; \ s_{GPD}(3.25)= 0.72 \pm 0.03; \quad (31)$$

$$M_{max,GPD} = 5.7 \pm 0.17; \ Q_{0.95}(10)= 5.3 \pm 0.07. \quad (32)$$

One can observe that the std of M_{max} exceeds the std of the quantile $Q_{0.95}(10)$ by a factor greater than two, confirming once more our earlier conclusion as to a larger instability of M_{max} compared with $Q_{0.95}(10)$.

Finally, we show in Figure 12 the quantiles $Q_q(\tau)$, $q = 0.90; 0.95; 0.99$ as functions of τ for $\tau = 1 \div 50$ years obtained by the GPD fitting. Figure 13 plots the median of $Q_q(\tau)$ together with two accompanying quantiles *16%* and *84%* which enclose the *68%* confidence interval.

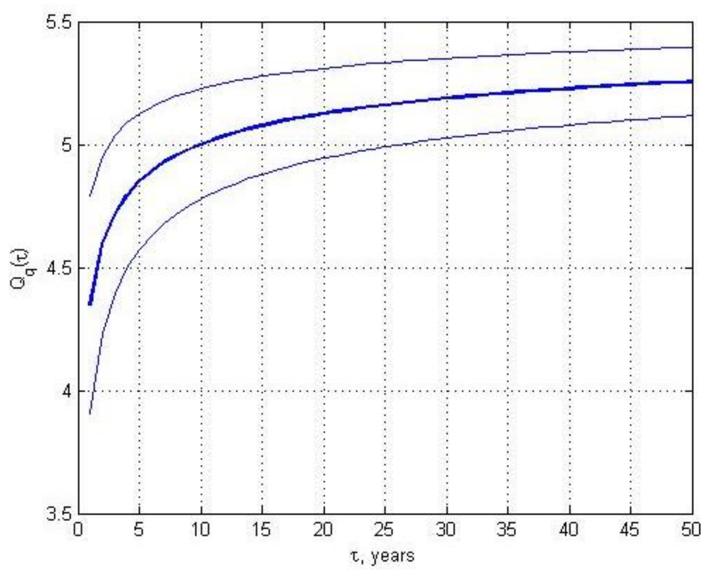

Figure 13. The GPD-quantiles of future τ-maxima. Fennoscandia, *84%* (top), *50%, median* (middle), *16%* (bottom).

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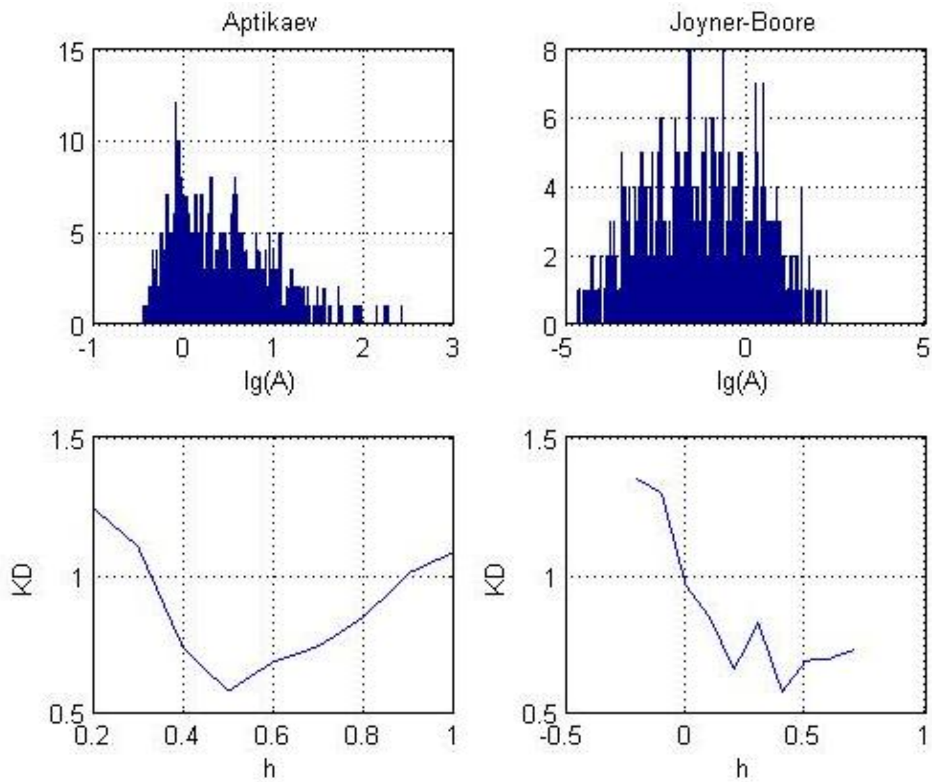

Figure 14. The histograms (upper pair) of the estimated acceleration and the Kolmogorov distance (KD) curves (lower pair) for Tokyo site. Left column: the Aptikaev relation (36), right column: the Joyner-Boore relation (35).

5. Estimation of τ-Maximum of Peak Ground Acceleration

Although the main seismic parameters like *b*-slope, seismic activity rate and M_{max} can be of considerable interest, estimation of peak ground acceleration, A_{max} , is of more importance in designing structures and in evaluating earthquake hazards. The earthquake hazard has been estimated in a variety of ways [Cornell, 1968], [Kijko and Sellevol, 1989 and 1992], [Lamarre et al., 1992], [Steinberg et al., 1993]. The characterization of the seismic hazard at a fixed site is usually done through the probability of exceeding various levels of ground acceleration in a certain number of years, i.e. through the probability distribution function of maximum peak acceleration, for a given time period τ. An equivalent, but perhaps more convenient characteristic of seismic hazard is furnished by the quantiles of this distribution function. Seismic hazard analysis involves several unknown parameters and relations: seismic activity rate λ, parameters of magnitude-frequency law, attenuation model (for ground acceleration), source model, soil characteristics, a model for earthquake sequence. Thus, it is necessary to estimate these parameters and establish step by step the needed relations. Statistical and modeling uncertainties should be introduced at each of these steps. We are going to apply the statistical method exposed in Section 1 to evaluation of quantiles of distribution of peak ground acceleration.

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Let us consider flow of earthquakes in some space-magnitude window registered at a certain point. We denote magnitudes and epicentral distances as (m_1,R_1), (m_2,R_2), ..., (m_n,R_n), ... We suppose that this flow is a stationary random process. Then any relation of type (33) or any arbitrary function $\Phi(m,R)$ will provide a stationary random process $\Phi(m_1,R_1)$, $\Phi(m_2,R_2)$, ..., $\Phi(m_n,R_n)$... . Thus, if we apply the relation (33) to the series (m_1,R_1), (m_2,R_2), ..., (m_n,R_n), ... we can consider resulting sequence as a stationary random process. We call it *estimated acceleration*. The expression (33) differs from the true peak ground acceleration by a random value ε. We discuss below this random error. Our aim is to study statistical characteristics of the estimated acceleration with the statistical technique exposed in section 1.

We are interested in analysis of ground acceleration A_{max} at a particular site. Suppose this site is located at epicentral distance R from source of earthquake with magnitude m. In the seismic hazard analysis there are a lot relations giving approximate value of A_{max} as some function of (R,m), see e.g. [Steinberg et al. 1993]. In most cases these relations have the following form:

$$lg_{10}(A_{max}) = a + b \cdot m - c \cdot lg(R+d), \qquad (33)$$

where a,b,c,d are some non-negative coefficients, m is magnitude, R is epicentral distance. Numerous modifications of (33) are used, but all of them keep the general property: monotone increase with m and monotone decrease with R.

However the relation (33) was found to be in contradiction with empirical data for the near-field zone. In [Campbell, 1981; Mahdavian et al., 2005; Aptikaev, 2009; Graizer, Kalkan, 2011] it was shown that PGA practically does not depend on magnitude in a vicinity of the earthquake fault zone. The size of this zone D usually varies from a few km to 10 km depending on the magnitude and can be well scaled with distance according to the empirical law

$$\partial\, \mathrm{lgD} / \partial\, \mathrm{Ms} \cong 0.34. \qquad (34)$$

We shall use two relations for the estimated acceleration due to Joyner-Boore [Joyner and Boore, 1988] and to Aptikaev [Aptikaev, 2009] respectively.

The Joyner-Boore relation:

$$lg_{10}(A_{max}) = 2.1 + 0.23 \cdot m - lg_{10}\left(\sqrt{R^2+64}\right) - 0.0027 \cdot R. \qquad (35)$$

The Aptikaev's relation:

$$lg_{10}(A_{max}) \begin{cases} = 2.76\,; & \rho \le 1; \\ = 2.76 - 0.55 \cdot lg_{10}(\rho); & 1 \le \rho \le 10; \\ = 3.50 - 1.29 \cdot lg_{10}(\rho); & 10 \le \rho\,; \end{cases} \qquad (36)$$

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where

A_{max} is estimated peak ground acceleration in cm/sec^2 ;
$\rho = R\cdot 10^{-0.325(m-5)}$; magnitude scaled distance;
R is epicentral distance in km;
m is magnitude.

Thus, relations (35)-(36) give logarithm of estimated peak ground acceleration at a site with epicentral distance R. We are going to derive quantiles of distribution of $lg_{10}(A_{max})$ for 4 points on the territory of Japan islands. The locations of these points are: Tokyo, Hiroshima, Osaka, and Fukushima atomic power station (Fukushima Daiichi) are shown on Figure 1 where they are marked as 'T', 'H', 'O', and 'F'. The distinction between (35) and (36) is connected with different accounting for large source area of strong earthquakes and for strong non-linear attenuation of seismic waves of high amplitudes.

Tokyo, $\lambda = 35.41$; $\varphi = 139.36$;

We have applied the statistical technique exposed in Section 1 to the estimated accelerations calculated by equations (35)-(36). We used the Kolmogorov distance *KD* for to choose the most appropriate threshold value *h* providing the best fitting of *GPD* to the data. The Kolmogorov distance is defined as follows:

$$KD = n_h^{1/2} \max| GPD_h(x \mid \hat{\xi}, \hat{s}) - F_{n_h}(x)|, \tag{37}$$

where $F_{n_h}(x)$ is sample stepwise distribution function generated by observations ($x_1 \le \ldots \le x_{n_h}$) exceeding threshold h:

$$F_{n_h}(x) = \begin{cases} 0; & x \le x_1 ; \\ r/n_h ; & x_r < x \le x_{r+1}; \quad 1 < r < n_h; \\ 1; & x > x_{n_h} . \end{cases}$$

Since we use a theoretical function with parameters fitted to the data, we cannot use the standard Kolmogorov distribution to find the significance level of the observed *KD*. Instead, in order to determine the significance level of a given *KD*-distance (37), we used a numerically calculated distribution of *KD*-distances measured in a simulation procedure with *10,000* GPD-samples and parameters individually fitted to each sample. This method was suggested in [Stephens, 1974] for the Gaussian and the exponential distributions. We use the Kolmogorov distance to test the GPD distribution fitted to estimated accelerations.

The Aptikaev's Relation (36)

The histogram of estimated accelerations calculated in accordance with (35) is shown on Figure 14, upper left figure. We see that a monotone decreasing starts somewhere near $lg_{10}(A_{max})\sim -0.2$. Since the theoretical GPD-density monotonically decreases, we have to

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restrict our analysis by thresholds $h > -0.2$. The *KD*-distance as function of h is shown on Figure 14, lower left figure. We see that the lowest $KD = 0.582$ (the best fitting) corresponds to the threshold $h = 0.5$. Its significance level (called sometimes p-value) equals to 0.72, so that the sample can be considered as belonging to GPD distribution (the testing would reject this distribution in the case of very small p-values, say, $p < 0.10$, $p < 0.05$ or $p < 0.01$). For this threshold there are $n_h = 279$ observations exceeding this threshold. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.23 \pm 0.05; \ \hat{s} = 0.52 \pm 0.06; Q_{0.90}(30) = 2.3. \tag{38}$$

Maximum of logarithmic estimated accelerations was 2.76 (it can't be more because of restriction of estimated acceleration in equation (36)).

The Joyner-Boore relation (35).

The histogram of estimated accelerations calculated in accordance with (35) is shown on Figure 14, upper right figure. We see that monotone decreasing start point is not determined definitely. Perhaps, a monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim +0.3$. For any case we tried thresholds h in the interval $(-0.2; +0.7)$. The *KD*-distance as function of h is shown on Figure 14, lower right figure. We see that the lowest $KD = 0.58$ (the best fitting) corresponds to the threshold $h = 0.4$. Its significance level (called sometimes p-value) equals to 0.68, so that the sample can be considered as belonging to GPD distribution. For this threshold there are $n_h = 125$ observations exceeding this threshold. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.23 \pm 0.07; \ \hat{s} = 0.60 \pm 0.09; Q_{0.90}(30) = 2.3. \tag{39}$$

We see that the Aptikaev's estimates (38) are very close to the Joyner-Boore estimates (39) despite a considerable difference in the histograms shown on Figure 14. It can be explained by the fact that the estimates of quantiles Q are determined essentially by the corresponding tails of distribution and not by the whole range histogram.

Hiroshima, $\lambda = 34.39$; $\varphi = 132.46$;
The Aptikaev's relation (36).

The histogram of estimated accelerations calculated in accordance with (36) is shown on Figure 15, upper left figure. We see that a monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim 0.1$. We restrict our analysis by thresholds h in the interval (0.1; 0.9). The *KD*-distance as function of h is shown on Figure 15, lower left figure. We see that there are 3 thresholds $h = 0.6; 0.7; 0.8$ with *KD* close to 0.6. We prefer to take $h = 0.6$ since sample size for this threshold $(n_h = 118)$ is larger than others $(n_h = 95; n_h = 74)$. Its significance level equals to 0.593, so that the sample can be considered as belonging to GPD distribution. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.21 \pm 0.07; \ \hat{s} = 0.46 \pm 0.08; Q_{0.90}(30) = 2.1. \tag{40}$$

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Maximum of logarithmic estimated accelerations was 2.76 (it can't be more because of restriction of estimated acceleration in equation (36)).

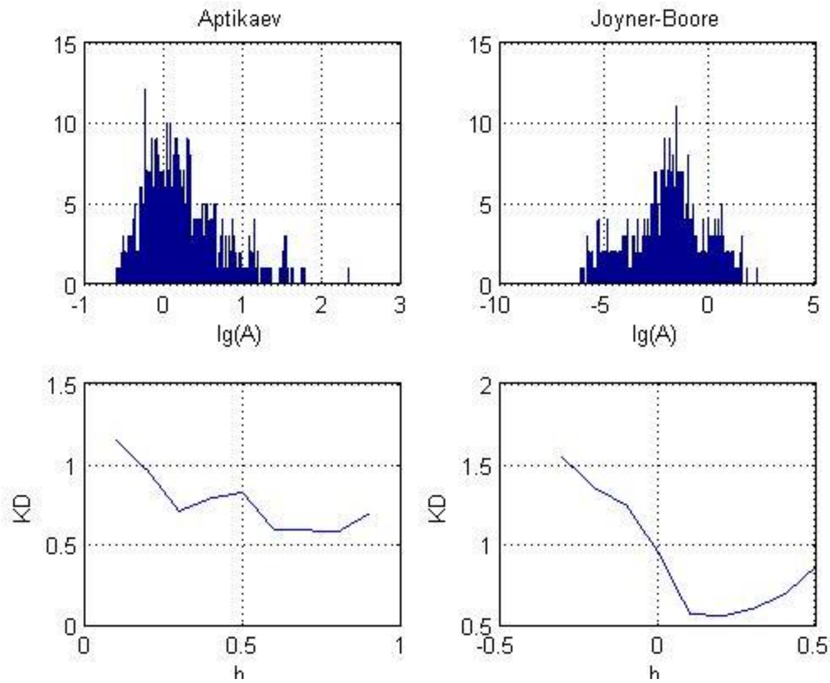

Figure 15. The histograms (upper pair) of the estimated acceleration and the Kolmogorov distance (KD) curves (lower pair) for Hiroshima site. Left column: the Aptikaev relation (36), right column: the Joyner-Boore relation (35).

The Joyner-Boore relation (35).

The histogram of estimated accelerations calculated in accordance with (35) is shown on Figure 15, upper right figure. We see that monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim -1.5$. We tried thresholds h in the interval $(-1.5;\ +0.5)$. The KD-distance as function of h is shown on Figure 15, lower right figure. We see that the lowest $KD = 0.562$ (the best fitting) corresponds to the threshold $h = 0.2$. Its p-value equals to 0.713, so that the sample can be considered as belonging to GPD distribution. For this threshold there are $n_h = 76$ observations exceeding this threshold. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.23 \pm 0.09;\ \ \hat{s} = 0.62 \pm 0.12;\ Q_{0.90}(30) = 2.1. \tag{41}$$

We see that the Aptikaev's estimates (40) are rather close to the Joyner-Boore estimates (41) despite a considerable difference in the histograms.

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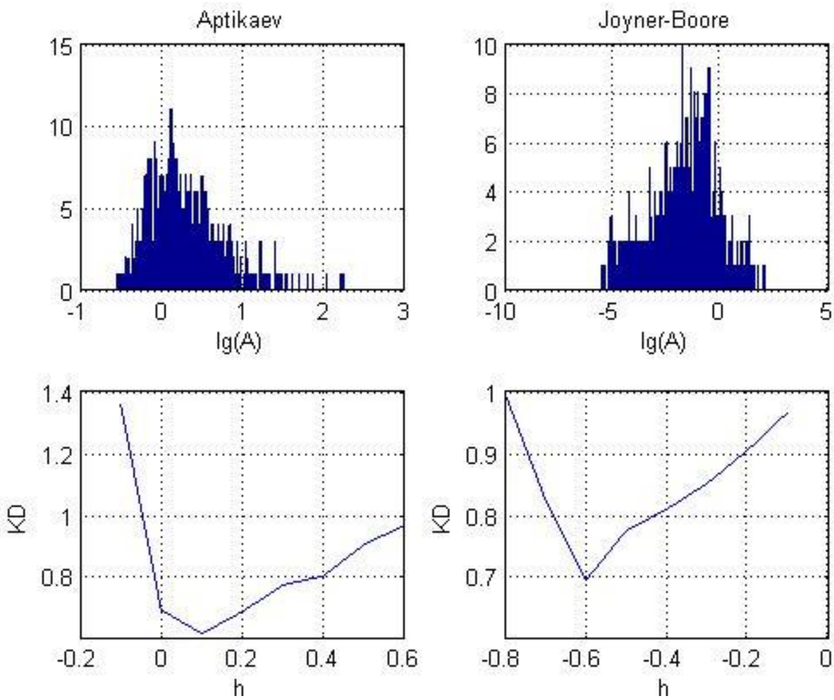

Figure 16. The histograms (upper pair) of the estimated acceleration and the Kolmogorov distance (KD) curves (lower pair) for Osaka site. Left column: the Aptikaev relation (36), right column: the Joyner-Boore relation (35).

Osaka, $\lambda = 34.69$; $\varphi = 135.50$;

The Aptikaev's relation (36).

The histogram of estimated accelerations calculated in accordance with (36) is shown on Figure 16, upper left figure. We see that a monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim 0.1$. We restrict our analysis by thresholds h in the interval (-0.1; 0.6). The *KD*-distance as function of h is shown on Figure 16, lower left figure. We see that the best fitting corresponds to the threshold there $h = 0.1$ with $KD = 0.62$. Its p-value equals to *0.63*, so that the sample can be considered as belonging to GPD distribution. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.19 \pm 0.04; \ \hat{s} = 0.50 \pm 0.04; \ Q_{0.90}(30) = 2.1. \qquad (42)$$

Maximum of logarithmic estimated acceleration was 2.76 (it can't be more because of restriction of estimated acceleration in equation (36)).

The Joyner-Boore relation (35).

The histogram of estimated accelerations calculated in accordance with (35) is shown on Figure 16, upper right figure. We see that monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim -0.8$. We tried thresholds h in the interval *(-0.8; -0.1)*. The *KD*-distance as function of h is shown on Figure 16, lower right figure. We see that the lowest $KD = 0.694$ (the best fitting) corresponds to the threshold $h = -0.6$. Its p-value equals to *0.415*, so that the

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sample can be considered as belonging to GPD distribution. For this threshold there are $n_h = 173$ observations exceeding this threshold. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.34 \pm 0.05; \ \hat{s} = 1.03 \pm 0.13 \ ; Q_{0.90}(30) = 2.1. \quad (43)$$

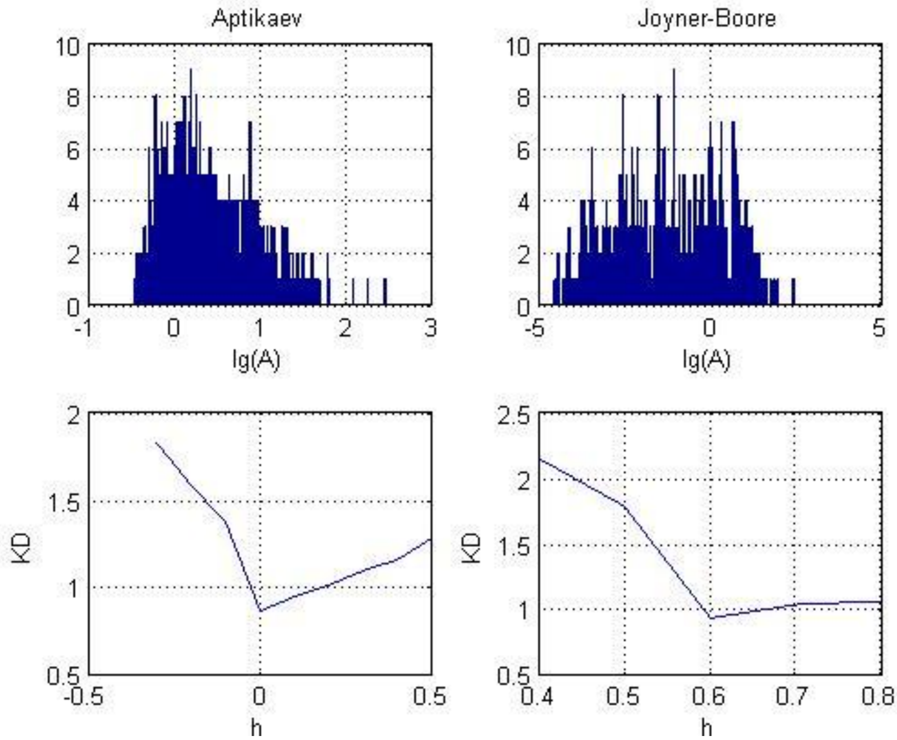

Figure 17. The histograms (upper pair) of the estimated acceleration and the Kolmogorov distance (KD) curves (lower pair) for Fukushima site. Left column: the Aptikaev relation (36), right column: the Joyner-Boore relation (35).

We see that the Aptikaev's estimates (42) differ rather significantly from the Joyner-Boore estimates (43). But in the same time the estimates of the quantile $Q_{0.90}(30)$ are very close which confirms once more the robustness of this characteristic.

Fukushima Daiichi, $\lambda = 37.4214$; $\varphi = 141.0325$.

The Aptikaev's relation (36).

The histogram of estimated accelerations calculated in accordance with (36) is shown on Figure 17, upper left figure. We see that a monotone decreasing starts somewhere near $lg_{10}(A_{max}) \sim 0.2$. We restrict our analysis by thresholds h in the interval $(-0.3; 0.5)$. The KD-distance as function of h is shown on Figure 17, lower left figure. We see that the best fitting corresponds to the threshold there $h = 0$ with $KD = 0.87$. Its p-value equals to 0.13, so that the sample still can be considered as belonging to GPD distribution. We got following estimates of unknown parameters:

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$$\hat{\xi} = -0.29 \pm 0.03;\ \hat{s} = 0.76 \pm 0.06;\ Q_{0.90}(30) = 2.3. \quad (44)$$

Maximum of logarithmic estimated accelerations was 2.63.

The Joyner-Boore relation (35).

The histogram of estimated accelerations calculated in accordance with (35) is shown on Figure 17, upper right figure. We see that monotone decreasing starts somewhere near $lg_{10}(A_{max})\sim 0.6$. We tried thresholds h in the interval $(0.4; 0.8)$. The KD-distance as function of h is shown on Figure 17, lower right figure. We see that the lowest $KD = 0.937$ (the best fitting) corresponds to the threshold $h = 0.6$. Its p-value equals to 0.072, which means that even the best possible fitting is not quite satisfactory. For this threshold there are $n_h = 111$ observations exceeding this threshold. We got following estimates of unknown parameters:

$$\hat{\xi} = -0.22 \pm 0.07;\ \hat{s} = 0.51 \pm 0.09;\ Q_{0.90}(30) = 2.3. \quad (45)$$

We see that the Aptikaev's estimates (44) somewhat differ from the Joyner-Boore estimates (45). But in the same time the estimates of the quantile $Q_{0.90}(30)$ are rather close again which confirms once more the robustness of these characteristics.

The results of estimation of the parameters of GPD distribution fitted to the estimated acceleration data are summarized in Table 4. The Aptikaev and the Joyner-Boore estimates are separated by vertical bar Apt | J-B. In the fifth column the maximum possible values of the estimated acceleration are shown calculated by formula $lg(A_{max}) = h - s/\xi$. $Q_{0.90}(30)$ is the quantile of level $q = 0.90$ for the maximum estimated acceleration in a future time interval of 30 years. We can see that the $Q_{0.90}(30)$ for Apt and J-B models are very close in all four cases whereas $\lg(A_{max})$ values can differ essentially. This fact can be connected also with the mentioned above instability of A_{max} values.

Table 4. Statistical estimates of *GPD* parameters fitted to the estimated acceleration data

	h	n_h	ξ	$lg(A_{max})$	$Q_{0.90}(30)$	p-value of GPD
Tokyo	0.5| 0.4	279|125	-0.23 | -0.23	2.8 | 3.1	2.3 | 2.3	0.72 | 0.68
Hiroshima	0.6| 0.2	118| 76	-0.21 | -0.23	2.8 | 2.9	2.1 | 2.1	0.69 | 0.71
Osaka	0.1|-0.6	462|173	-0.19 | -0.34	2.8 | 2.5	2.1 | 2.1	0.63 | 0.42
Fukushima	0 | 0.6	544|111	-0.29 | -0.22	2.6 | 2.9	2.3 | 2.3	0.13 | 0.07

6. The Accounting for Inaccuracy of the Estimated Acceleration

The estimated acceleration (35), (36) differs from the true acceleration by a random value ε. We assume that

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$$\varepsilon = \varepsilon_1 + \varepsilon_2,$$

where ε_1, ε_2 are independent random errors; ε_1 refers to inaccuracy of the used relations and ε_2 characterizes the influence of the seismic source mechanism on the ground acceleration. In accordance with [Aptikaev, 2011] the random error of the relation (36) has standard deviation $\varepsilon_1 = 0.18$. The distribution of ε_1 is not critical: we compared on several artificial examples the Gauss distribution and the uniform distribution and found no essential differences in the estimates of quantiles $Q_q(\tau)$. So, we accept for ε_1 the Gauss distribution.

In order to evaluate std of ε_2 we suppose that all sources in Japan territory can be classified into 3 types with following relative frequencies:

$$\begin{aligned}&\text{normal fault} \sim 15\%;\\&\text{strike-slip} \sim 20\%;\\&\text{inverse fault (thrust)} \sim 65\%.\end{aligned} \tag{46}$$

These relative frequencies are taken from the regional earthquakes focal mechanism data [Zlobin, Poletz, 2012], and they reflect the predominance of the compression tectonic forces in the Japan region. Following [Aptikaev, 2009] we assume further that these source types produce correspondingly in the epicentral zone the ground accelerations:

$$\begin{aligned}&lg_{10}(A) = 2.65;\\&lg_{10}(A) = 2.76;\\&lg_{10}(A) = 2.95.\end{aligned} \tag{47}$$

If we knew the source mechanism for each earthquake in our catalog, we could take this information into account, but since it is unknown for the JMA catalog (at least for the first half of this catalog), we have to model the influence of the source mechanism by an additional random term ε_2. The mean value of random variable taking values (47) with probabilities (46) is ~ 2.76 and standard deviation is 0.15. Thus, we can accept that std of ε_2 is 0.15. We suppose that the distribution of ε_2 is the Gaussian as well. Then the error $(\varepsilon_1 + \varepsilon_2)$ has standard deviation 0.23. Thus, we can assume that the maximum estimated acceleration analyzed in the previous section differs from the true maximum ground acceleration by a random Gaussian error with zero mean and $std = 0.23$. So, we have to take into account the influence of this random error on the quantile $Q_q(\tau)$. We have done it by a simulation procedure, adding a random Gaussian rv with $std = 0.23$ to the GPD-random variable with estimated parameters (see Table 4) and repeating this operation *10,000* times. Figure 18 shows the quantiles $Q_q(\tau)$ both with error term $\varepsilon = (\varepsilon_1 + \varepsilon_2)$ (upper curve) and without it (lower curve) for the Aptikaev's relation (left column). Similar graphs for the Joyner-Boore relation are shown in Figure 18, right column. We see that the accounting for errors practically is reduced to an increase of the undisturbed quantile by one std of the error.

The quantile $Q_q(\tau)$ is a final result of our statistical technique. It is a robust and meaningful characteristic of the seismic hazard.

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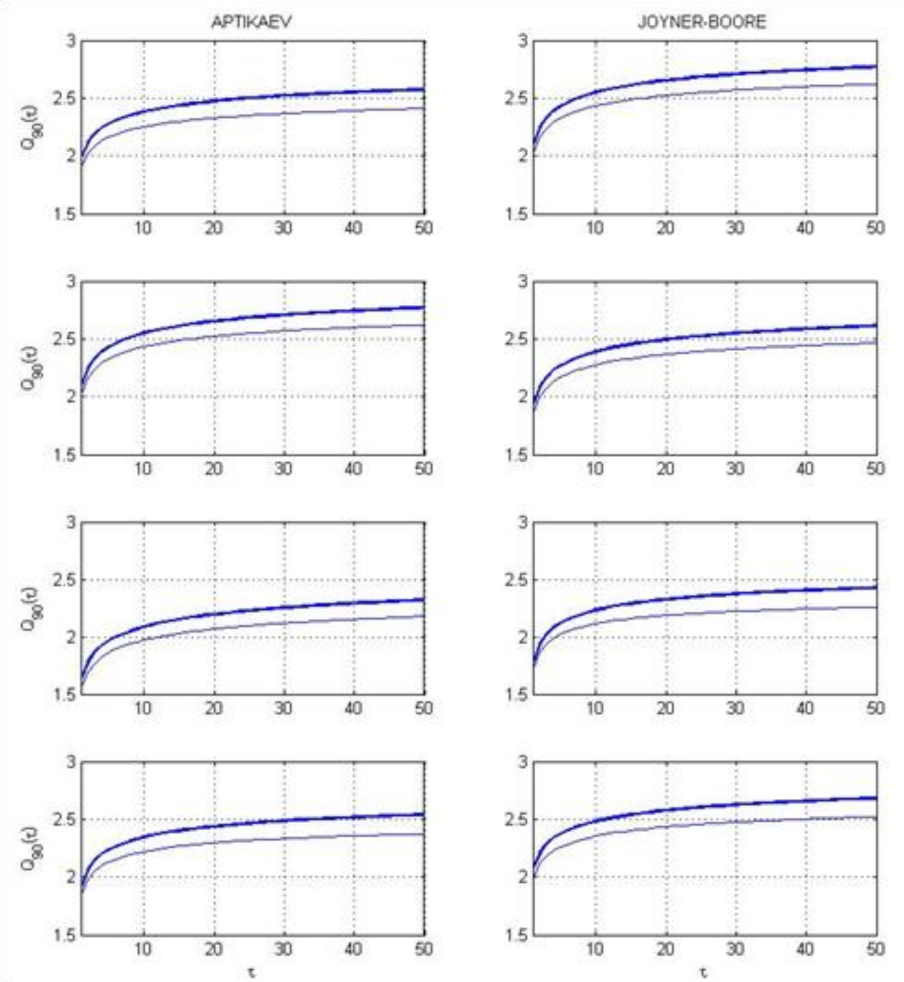

Figure 18. The GPD-quantiles for the maximum estimated acceleration in future τ years. Without random error (light lines) and with account for random errors (heavy lines). Left column: the Aptikaev relation (36), right column: the Joyne-Boore relation (35). Horizontal pairs from top to bottom: Tokyo, Hiroshima, Osaka, Fukushima.

Discussion and Conclusion

We have adapted the new method of statistical estimation suggested in [Pisarenko et al., 2009] to earthquake catalogs with discrete magnitudes. This method is based on the duality of the two main limit theorems of Extreme Value Theory (EVT). One theorem leads to the GPD (peak over threshold approach), the other theorem leads to the GEV (T-maximum method). Both limit distributions must possess the same form parameter ξ. For the Japanese catalog of earthquake magnitudes over the period 1923-2007, both approaches provide almost the same statistical estimates for the form parameter, which is found negative; $\xi \cong -0.2$. A negative form parameter corresponds to a distribution of magnitudes which is bounded from above (by a parameter, named M_{max}). This maximum magnitude corresponds to the finiteness of the

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geological structures supporting earthquakes. The density distribution extends to its final value M_{max} with a very small probability weight in its neighborhood, characterized by a tangency of a high degree ("duck beak" shape). In fact, the limit behavior of the density distribution of Japanese earthquake magnitudes is described by the function $(M_{max} - x)^{-1-1/\xi} \cong (M_{max} - x)^4$, i.e. by a polynomial of degree approximately equal to 4. This is the explanation of the unstable character of the statistical estimates of the parameter M_{max}: a small change of the catalog of earthquake magnitude can give rise to a significant fluctuation of the resulting estimate of M_{max}. In contrast, the estimation of the integral parameter $Q_\tau(q)$ is generally more stable and robust, as we demonstrate quantitatively for the JMA catalog of earthquake magnitudes over the period 1900-2011.

The main problem in the statistical study of the tail of the distribution of earthquake magnitudes (as well as in distributions of other rarely observable extremes) is the estimation of quantiles, which go beyond the data range, i.e. quantiles of level $q > 1 - 1/n$, where n is the sample size. We would like to stress once more that the reliable estimation of quantiles of levels $q > 1 - 1/n$ can be made only with some additional assumptions on the behavior of the tail. Sometimes, such assumptions can be made on the basis of physical processes underlying the phenomena under study. For this purpose, we used general mathematical limit theorems, namely, the theorems of EVT. In our case, the assumptions for the validity of EVT boil down to assuming a regular (power-like) behavior of the tail $1 - F(m)$ of the distribution of earthquake magnitudes in the vicinity of its rightmost point M_{max}. Some justification of such an assumption can serve the fact that, without them, there is no meaningful limit theorem in EVT. Of course, there is no a priori guarantee that these assumptions will hold in some concrete situation, and they should be discussed and possibly verified or supported by other means. In the case of seismic regime the certain irregularity in the behavior of the distribution tail can arise if the rare characteristic earthquakes do exist and their distribution law differs essentially from the distribution law of other strongest earthquakes. In fact, because EVT suggests a statistical methodology for the extrapolation of quantiles beyond the data range, the question whether such interpolation is justified or not in a given problem should be investigated carefully in each concrete situation. But EVT provides the best statistical approach possible in such a situation.

In this work we have applied the described above technique of estimation of maximum magnitudes in a prescribed future time period to a new object: the estimated ground acceleration at a given site. This quantity is directly connected to the seismic risk assessment and the seismic insurance problems. It turned out that the statistical fitting problems for the estimated acceleration are solved, as a rule, in a more satisfactory way. Perhaps, it can be explained by the presence in the relations (35)-(36) the term with epicentral distance that "smooth' out "possible irregularities in the earthquake magnitude registration. Anyhow, the Kolmogorov's distances in GPD fitting are smaller for estimated acceleration as compared to the seismic moments. We have used for illustration of our statistical method the relations (35)-(36) based on the world statistics of the strong motions. Of course, it would be desirable to use a regionalized relation of type (33) or (36). It would provide more accurate and appropriate statistical estimates of the real peak ground acceleration.

We have calculated the quantiles of peak ground acceleration values in 4 sites on Japan territory. In spite of a difference for PGAs by Joyner and Boore (1988) and Aptikaev (2011) the results obtained turned out to be rather close.

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The estimates with $\xi \cong -0.3 \div -0.2$ have been obtained for both logarithmic accelerations and for magnitudes. These results provide a better understanding of how the tail of the distribution of earthquake size (expressed as magnitude, seismic moment, seismic energy, PGA values) behaves. Different authors have tried earlier to describe the distribution of seismic energy and seismic moment values by unlimited functions: the gamma function, the exponential function with a fractional index (the stretched exponential distribution), and the Pareto distribution with an index higher than unity. Our estimates $(\xi \cong -0.3 \div -0.2)$ correspond to models with the distribution limited from the right side. They turned out to be more adequate.

It should be emphasized that statistical estimates of parameters M_{max} , $lg(A_{max})$ are rather unstable, in particular, when the absolute value of the shape parameter ξ is low. To avoid this instability we propose to use the stable quantiles $Q_q(\tau)$. The quantiles $Q_q(\tau)$ can be very useful tools for assessing risks in the insurance business and for optimizing the allocation of resources and preparedness by governments.

We have used the JMA catalog till the time of the recent great Tohoku earthquake 11 Mars 2011 ($\lambda = 38.322; \varphi = 142.369;$ depth = 24 km; $m = 9.0$). It would be interesting to check the stability and robustness of our method by adding this gigantic earthquake to our data. We have done this operation and found that our estimates of the parameters (given in Table 1) practically did not change: the differences for all parameters were no more than 0.01 which is much less than std of the estimates. This fact confirms once more the robustness of the exposed method.

Note that historical catalog Usami [2002] includes no earthquake of size m $\cong 9.0$ in Japan in the long time interval since 599 until 1884. Taking into account an absence of rectilinear parts within subduction zone (with length 1000 km and more) it was generally assumed that such mega-earthquakes are impossible in Japan. Our conclusions derived in [Pisarenko et al, 2010] and reaffirmed here contradicted to this assumption, and our point of view was confirmed by the Tohoku mega-earthquake (2011).

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Chapter 5

TORRENTIAL FLOODS PREVENTION POSSIBILITIES – CASE STUDY OF THE SKRAPEŽ RIVER WATERSHED (WESTERN SERBIA)

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ABSTRACT

Torrential floods, as a natural disaster, which appears suddenly as a two-phase flow (maximal water discharge and high concentrated sediments) on slopes in mountain areas, cause an increased risk to human lives, their activities and material goods. In Serbia, torrential floods are the most frequent natural disaster, regarding the fact that 86.4% of the territory is affected by erosive processes and about 70% with dissected relief prone to torrential floods. In the Skrapež River watershed, located in western Serbia, erosion and flow characteristics of the main stream and its tributaries are conditions for the occurrence of torrential floods. Based on these characteristics, the classification of torrential streams in the basin was carried out. In this case it is also confirmed that the mode of their occurrence is seasonal. Large sediment production, filling of river beds, flooding and material damage point to the need for the appropriate solutions to these problems. They could be solved only by the logical order of removing their causes. The planning document Water Resources Management Basic Plan of Serbia (WRMBPS) implies the construction of two reservoirs for multiple usages, as a possible solution. Regarding the protection from torrential floods and the rational use of water in the watershed, it is necessary to create the conditions, which *sensu stricto* include riverbeds (technical works) and watershed regulation (biological works). On the other hand, *sensu lato* torrential flood prevention implies the existence of a geographic information system (GIS) of the Skrapež River watershed and its streams. GIS data include torrential floods hazard, vulnerability and resilience indicators of the watershed. Highlighting the

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indicators helps reducing risk of torrential floods and their consequences in the environmental, economic and socio-psychological sphere.

1. INTRODUCTION

Torrential floods (in literature also often called flash floods) are one of many various types of floods, which due to their hazardous characteristics and as a serious threat to environment, population and their goods could become a natural disaster. They have characteristics of a two-phase flow (maximal water discharge and high concentrated sediments) with determined position in classification system of mass movements (Coussot and Meunier, 1996). A condition to torrential floods appearance is erosion on steep slopes (meaning they appear mostly in mountain areas), while heavy rains and/ or intensive snow-melting are triggers to mentioned phenomena which appears suddenly. Such natural disaster causes an increased risk to human lives, their activities and material goods.

In Serbia, torrential floods are the most frequent natural disaster, regarding the fact that 86.4% of the territory is affected by erosive processes (Ristić et al, 2012) and about 70 % with dissected relief prone to torrential floods. Ristić and Nikić (2007) also confirmed that torrential floods are the most common hazard in Serbia and most significant natural disaster due to material damage and loss of human lives. In last 10 years the most frequently affected watersheds in mountain areas (south from the Sava and the Danube River) were: the Drina River, the Kolubara River, the Velika Morava River, the Južna Morava River, the Zapadna Morava River, the Lim River, the Pčinja River and the Timok River watersheds (Ristić et al, 2012). The consequences were significant in many spheres except in demographic (but looking further into the past there were also loses of human lives).

The Skrapež River watershed is sub-watershed of Zapadna Morava River watershed, located in western Serbia. It spreads on 647.65 km^2 and is located in mountainous area, with average altitude of 600.76 m. Since the large part of the Skrapež River watershed consists of material subjected to decay and steep slopes, as a result there is an increased erosion in those parts of the basin with erosion coefficient of 0.10 – 0.40 (Lazarević, 1983 a). The average coefficient of erosion (Z) for the whole Skrapež River watershed was 0.322 and belonged to category IV of erodibility (Lazarević, 1983 b). Nowadays it belongs to III category (Gavrilović et al, 2009). In the classification of erosion Gavrilović (1972) the first class means the most intensive erosion and the fifth class means there is almost no erosion. Taking into consideration characteristics of the Skrapež River and its tributaries water regimes (Kovačević-Majkić, 2008), which means: pluvio-nival regime, small runoff coefficient (0.28), higher part of surface in relation to underground runoff (61%:39%), monthly coefficient of variation which reaches 0.96 in summer and 0.73 in autumn and physic-geographical characteristics of the river basin, in the Skrapež River watershed all kind of water management problems, related to high/low water, are present. Therefore, erosion and flow characteristics of the main stream and its tributaries are conditions for the occurrence of torrential floods. Based on these characteristics, the classification of torrential streams in the basin was carried out (Public Water Management Company (PWMC) “Jaroslav Černi”, 1965). The Skrapež River is only one of torrential tributaries of the Zapadna Morava River, which are flooding surrounding plains and towns, and endanger water reservoirs on the Zapadna Morava River with large amount of sediment. Main water management problem is

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flood defense at downstream reaches of torrential rivers. Floods in the Skrapež River basin are caused by rain and snow melting, coincidence of high waters of tributaries and the Skrapež River, and they all have torrential character.

Severe floods happened in years 1910, 1926, 1965, 1975 and 2006. In May 1965 after heavy rainstorms the Skrapež River flooded about 400 ha of land in Kosjerić and Požega municipality. That was when the maximum water discharge of 313 m^3/s was recorded (13.V 1965.). Also in June 1975 severe flood was recorded, when 1000 ha of Kosjerić municipality was flooded by rivers Skrapež, Mionička River and Kladoruba. Many enterprises („Kofeniks", „Moda", „Grad", „Elkok"...) suffered great damage, and as well infrastructure objects like part of a road Kosjerić – Valjevo, part of railway Belgrade – Bar, and number of bridges were washed out (Gavrilović, 1981).

Last severe flood happened in March of 2006, when large part of Serbia was flooded and landslides occurred. The Skrapež River, the Đetinja River and the Zapadna Morava River flooded about 1500 ha of cultivated land in Požega municipality. Dozens of households were in danger and some roads were closed (Beta, 2006). It was caused by great amounts of precipitation, sudden melting of snow, as well as a coincidence of high waters. According to high values of water levels and discharges, Skrapež valley was flooded also in year 1984, 1986, 1987, 1991 and 1999.

Considering the importance of the water and mentioned consequences of torrential floods, water management is imperative, which means water protection, protection against harmful water effects and water usage. Besides, the acceptable concept is the one that merge both integrative and adaptive water resources management (Engle et al, 2011).

Water resources management also means implementation of preventive measures against torrential floods. Simultaneously, prevention is a very important part in Natural Disaster Risk Management Cycle (Smith and Petley, 2009; UNDP, 1992), under whose lows, strengthening prevention activities, will decrease recovery activities. Torrential flood prevention could be divided in *sensu stricto* (in flood protection system known as investment active measures) and *sensu lato* measures (in flood protection system known as non-investment preventive and operative measures).

Sensu stricto measures include riverbeds (technical works) and watershed (biological works) regulation and reservoirs for multiple usage construction, planed by the planning document WRMBPS (Institute for Water Resources Management "Jaroslav Černi", 1996; Institute for Water Resources Management "Jaroslav Černi", 2001).

On the other hand, *sensu lato* torrential flood prevention measures, among the other things, imply the existence of a geographic information system (GIS) of the Skrapež River watershed and its streams. GIS data include torrential floods hazard and vulnerability indicators of the watershed.

Highlighting the indicators helps reducing risk of torrential floods and their consequences in the environmental, economic and socio-psychological sphere. Regarding the protection from torrential floods and the rational use of water in the watershed, it is necessary to create the conditions, which means problems solving only subsequently by the logical order of removing their causes by combined implementation of *sensu stricto* and *sensu lato* measures.

In this chapter conditions for torrential floods were analyzed, hazard, vulnerability and resilience indicators were selected, as well as possible solutions for torrential floods risk reduction were assessed.

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2. Data and Methodology

Collecting, organizing, processing, analyzing, interpreting and presenting torrential floods related data was done using both GIS models (vector and raster GIS model). On figure 1 conceptual model and workflow for torrent floods prevention assessment could be seen. Though there are many classification of prevention regarding natural disaster Risk Management cycle (Smith and Petley, 2009; UNDP, 1992), in this chapter wider approach (*sensu stricto / sensu lato*) was used due to comprehend classification by as many criteria. Selected as components of risk there are three main factors that determine it: Hazard, Vulnerability and Resilience (Wisner et al, 2004). Since for torrential floods appearance there should be two conditions: maximal discharge and erosion (Ristić and Malošević, 2011) segments of Hazard components were discharge regime and erosion.

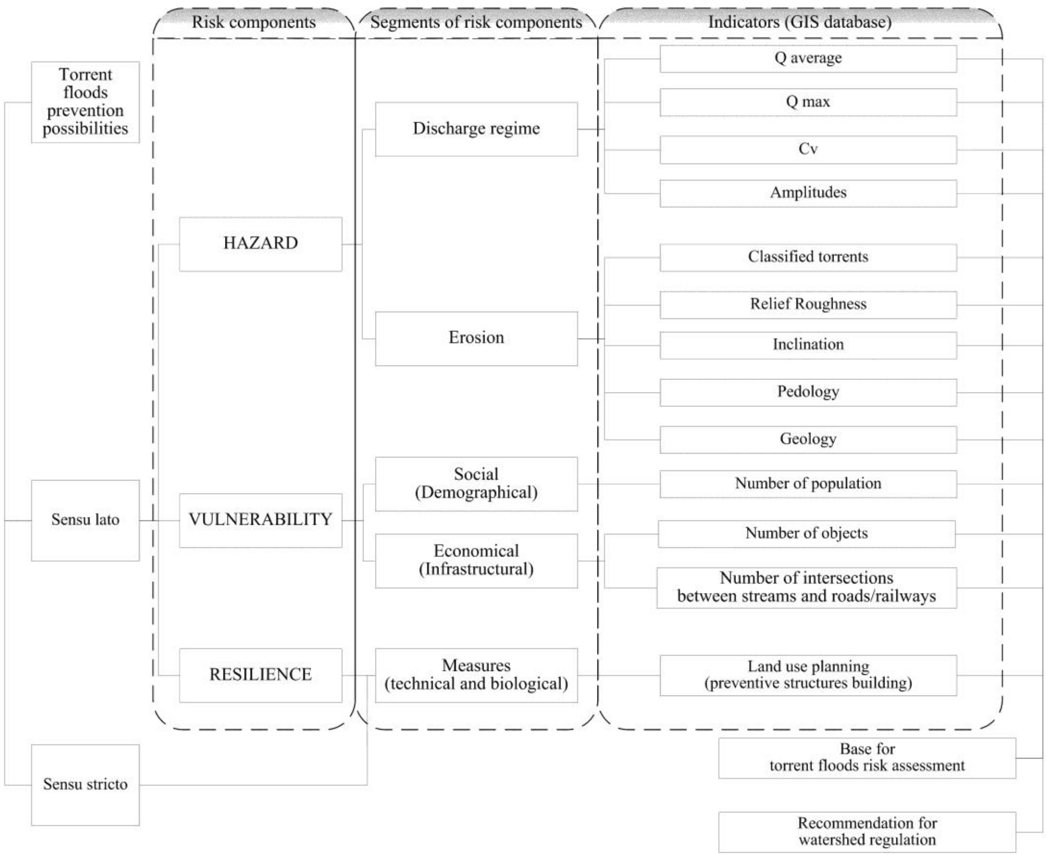

Figure 1. Conceptual model and workflow for torrent floods prevention assessment.

Vulnerability as risk component is in practice often divided into exposure and vulnerability (UNDP, 2004), but since we have chosen three indicators of socio – economical vulnerability (exposure), we have determined them as vulnerability indicators, using the same principle as in the prevention classification. By Hahn et al. (2003) number of population and number of objects are treated as indicators of exposure. Of the many indicators of resilience, we have also selected the one (preventive structure building), which at the same time

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represents a preventive measure in the strict sense. The selected indicator is one of the technical measures (building of reservoir) planed in the WRMBPS (Institute for Water Resources Management "Jaroslav Černi", 2001).

2.1. Data

Since for torrential floods appearance there should be two conditions (maximal discharge and erosion) data were organized thematically.

For discharge of the Skrapež River, data in period from 1953-2010 on the measurement stations Požega and Kosjerić, were taken into consideration. Average monthly, average annual, minimal and maximal annual discharge missing data were completed using correlation method with the nearest station on monthly level.

Annual discharge data on the measurement stations Požega were used for years ranking in period 1953-2010. The measurement stations Kosjerić was relocated so discharge data at that time series were not continuous. Because of that for coefficient of correlation calculation monthly and annual discharge data on both measurement stations were used, but for the period from 1981 to 2010. Minimal and maximal monthly and annual discharge on both measurement stations were used for calculation of amplitudes and relation between minimal and maximal discharge.

For erosion estimation followed data were used: surface area of the Skrapež River watershed affected by erosive processes of certain intensity, ratio 1:50000 (Public Water Management Company (PWMC) "Srbijavode", 1965), SRTM database (cf. Rabus et al., 2003) with 90 m resolution, soil map, 1:50000 (Tanasijević et al, 1963) and geological map, ratio 1:100000 (Filipović et al, 1971, Mojsilović et al, 1972; Brković et al, 1977, Mojsilović et al, 1977). Population data of Statistical Office of the Republic of Serbia (Statistical office of the Republic of Serbia, 2002) were used as one of the indicators of vulnerability and topographical maps (1:25000) were used to determine number of objects and intersections between streams and roads/railways. Data about planed reservoir we have got from the documentation materials for WRMBPS.

2.2. Methodology

Selected indicators for discharge, as a segment of hazard as risk component, are: average annual discharge used for years ranking in regards to water amount, coefficient of variation of discharge, amplitudes and relation between maximal and minimal discharge and maximal discharge used for probability occurrence analyses.

In order to estimate year's ranking in regards to water amount, flood frequency and the probability of the average and maximum water discharges occurrence in the Skrapež River at Požega, we have performed a statistical analysis for the data recorded between 1953 and 2010. In the first stage, 58/53-year long time series of the average/maximum annual discharges was established. It was then necessary to examine the representativeness of the time series of the registered data for the analysed process, seen as a whole. The application of mathematical statistics and probability theory implies that the elements of an available time series of the maximum discharges are random values. In the randomness analysis of the

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average/maximum annual discharges series, the consecutive differences test (Neyman's test) was used. This was followed by a stationarity examination of the statistical parameters for particular sequences of the established time series, i.e. by determining the time series homogeneity. It often happens that a departure of the average discharges from the natural situation arises as a consequence of man-made interventions in a river basin, resulting in the so-called non-homogeneous monthly and annual hydrologic series. In this study, we used Student's t-test for testing the homogeneity of average values, Fischer's F-test for testing the homogeneity of dispersion and the Wilcoxon inversion test for the distribution function.

After the examination of the time series randomness and homogeneity, the empirical distribution and the probability distribution function parameter were calculated. The average/maximum discharges for theoretical functions of the probability distribution commonly used in hydrology were also calculated: the Normal, Log-Normal, Gumbel, three-parameter gamma distribution – Pearson Type 3 and Log-Pearson Type 3 distribution. The testing of the agreement (fitting) between the empirical and theoretical distribution functions was performed using the Chi-squared test, the Kolmogorov-Smirnov test and the Cramér-von-Mises test. On the basis of the data obtained by these tests, the final selection of the applicable theoretical distribution function was made and the corresponding confidence intervals were calculated.

Then for the year's classification seven classes were made according to selected theoretical (Pearson III) distribution and class ranges determined with quartile division of probability of occurrence. In doing so, the second and the third quartiles were labelled as mean (those with average discharges) and first and the fourth quartiles were labelled as extreme ones and were further divided into three groups each (table 1). The selected values of P were treated as a class ranges. As there are differences in water richness by years, there are also monthly differences. A good indicator of monthly differences is the coefficient of variation (Cv), but due to the relatively short time period the results should be taken with reserve. More indicators used for differences consideration are amplitudes of discharges calculated separately for each station and relation between maximal and minimal discharges between these two stations.

Table 1. Years ranking criteria

Range (quartile)	P (%)	Return period/reoccurrence interval (years)	Years ranking
First	< 1	100 and more	Extremely low discharge
	1-5	20-100	Very low discharge
	5-25	4-20	Low discharge
Second and third	25-75	< 4	Average discharge
Fourth	75-95	4-20	High discharge
	95-99	20-100	Very high discharge
	> 99	100 and more	Extremely high discharge

Also calculation of relative size of high water (index A) was done by M. Parde method (1959).

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$$A = \frac{Q_{\max}}{\sqrt{F}} \tag{1}$$

where Q_{max} is maximal discharge for observed period and F is size of surface (watershed) area (Gavrilović, 1981).

Selected indicators for erosion, as another segment of hazard as risk component, are: classified torrents trough coefficient of erosion, class of erodibility, hydrographic class, geology, soil types, and relief inclination and roughness. The division into sub-watersheds used for this chapter research is taken from the study of torrential watersheds (Public Water Management Company (PWMC) ”Srbijavode”, 1965) where the Skrapež River watershed is divided into 127 sub-watersheds.

Analyzing the erosion and hydrographic classes by the method of Gavrilović S. (1972) we have selected torrent river flows with their watersheds and then extracted those which have first (excessive erosion) and second (strong erosion) erodibility class. Those watersheds were further compared with geology and soil types using vector GIS with *Microstation* and *Geomedia* software and relief inclination and roughness using raster GIS with software *Idrisi*.

Firstly analog maps were scanned, delineation lines digitalized and surfaces areas calculated. Some of these processes as well as morphometrical and morpho-hydrographical indices of elements of interest were done before (Jelena Kovačević-Majkić, 2009). Numerical analysis of a digital terrain model (DTM), which produced the value of the relief inclination and surface roughness coefficient, was done with grid cell resolution of 100 m.

For roughness coefficient we have applied the same method as on the Serbia level (Ćalić et al, 2012), but using moving window of 3 x 3 cells, considering the fact that surface area of the Skrapež River watershed is 647.65 km^2.

Selected indicators for vulnerability, as risk component, are: population number, number of objects, number of intersections between streams and roads/railways.

Making intersection between watershed and settlements area with known number of population living there, we have determined number of objects and got number of people living in selected watersheds.

Also using topographical maps (1:25000) we have determined intersections between streams and roads/rails. Number of intersections between streams and roads/railways in relation to sub-watershed surface area was calculated for each sub-watershed using the equation for density, which expressed with the parameters of the present chapter, comes to:

$$\rho = \frac{N}{F} \tag{2}$$

where ρ is density of intersections between streams and roads/railways (number of intersections/km^2), N is number of intersections between streams and roads/railways and F is surface (sub-watershed) area. As an indicator of resilience as risk component, we took planed reservoirs in consideration.

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3. RESULTS

In this chapter results will also be presented subsequently following the given workflow (figure 1).

3.1. Average Annual Discharges

Since discharge is variable on the daily, as well on the monthly and annual level, some years are rich in water, and there are those when the riverbed is almost dry in some part of the year (figure 2).

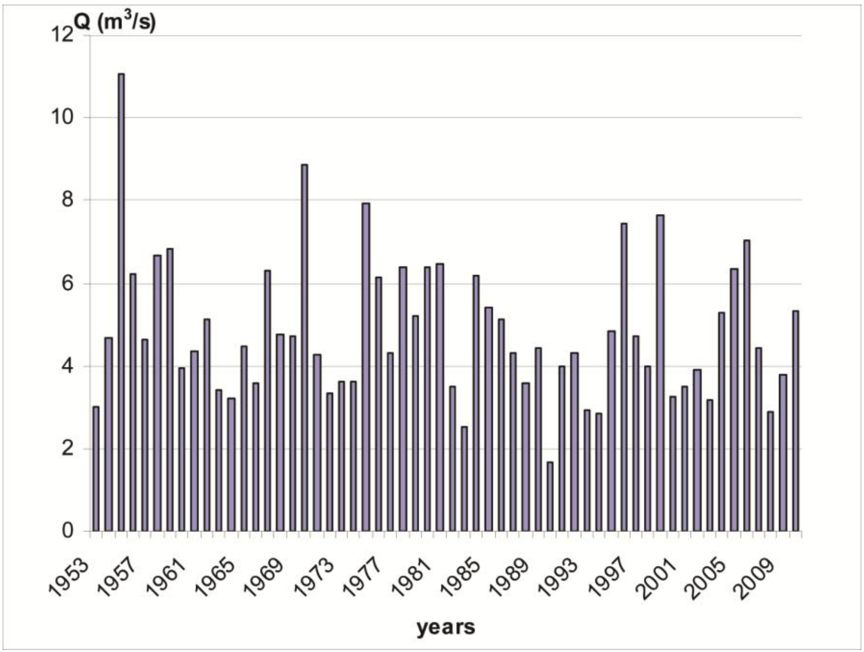

Figure 2. Average annual discharge of the Skrapež River in Požega in period 1953-2010.

Basic statistical parameters of average discharge series of Skrapež River at Požega are: X_{sr}=4.86 m^3/s, S_x=1.72 m^3/s, C_v=0.35, C_s=1.10. Results of randomness test (Neyman's test) is -1.96< -1.2669 <1.96, which means that series is random.Student t-test, Fisher F-test and Wilcoxon inverse test (U) has been used for testing the homogeneity of the time series.

The following values have been calculated: $F=1.562 < F_{kr}=2.193$, $t=1.939 < t_{kr}=2.008$, $U_1=294.465 < 538 < U_2=546.535$, that means that the sample is homogeneous. All tests have been performed with significance level α=0.05. The empirical and theoretical functions of probability distribution are calculated and testing of the agreement (fitting) between the empirical and theoretical distribution functions was performed using the Chi-squared test, the Kolmogorov-Smirnov test and the Cramér-von-Mises test. According to results of these tests best agreement (fitting) with empirical data has a Pearson III distribution. In regards to discharge of the Skrapež River, years ranking in period 1953-2010 on the measurement station Požega was done according to selected theoretical (Pearson III) distribution and

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determined class ranges. The classification on years with extremely low discharges (< 2.25 m^3/s, < 1%, with return period of 100 years and more), very low discharges (2.25 - 2.66, 1-5 %, with return period of 20 to 100 years), low discharges (2.66 – 3.60, 5-25%, with return period of 4 to 20 years), average discharges (3.60 – 5.79, 25-75%, with return period of 4 years and less), high discharges (5.79 – 8.12, 75-95%, with return period of 4 to 20 years), very high discharges (8.12 - 10.16, 95-99%, with return period of 20 to 100 years), extremely high discharges (> 10.16 m^3/s, >99%, with return period of 100 years and more) was made.

Table 2. Years ranking in regards to water amount of the Skrapež River in Požega in the period 1953-2010

Years ranking	Discharge (m^3/s)	Years	Number of years
Extremely low discharge	< 2.25	1990	1
Very low discharge	2.25 – 2.66	1983	1
Low discharge	2.66 - 3.60	1953, 1963, 1964, 1966, 1972, 1974, 1982, 1988, 1993, 1994, 2000, 2001, 2003, 2008	14
Average discharge	3.60 - 5.79	1954, 1957, 1960, 1961, 1962, 1965, 1968, 1969, 1971, 1973, 1977, 1979, 1985, 1986, 1987, 1989, 1991, 1992, 1995, 1997, 1998, 2002, 2004, 2007, 2009, 2010	26
High discharge	5.79 – 8.12	1956, 1958, 1959, 1967, 1975, 1976, 1978, 1980, 1981, 1984, 1996, 1999, 2005, 2006	14
Very high discharge	8.12 – 10.16	1970	1
Extremely high discharge	> 10.16	1955	1

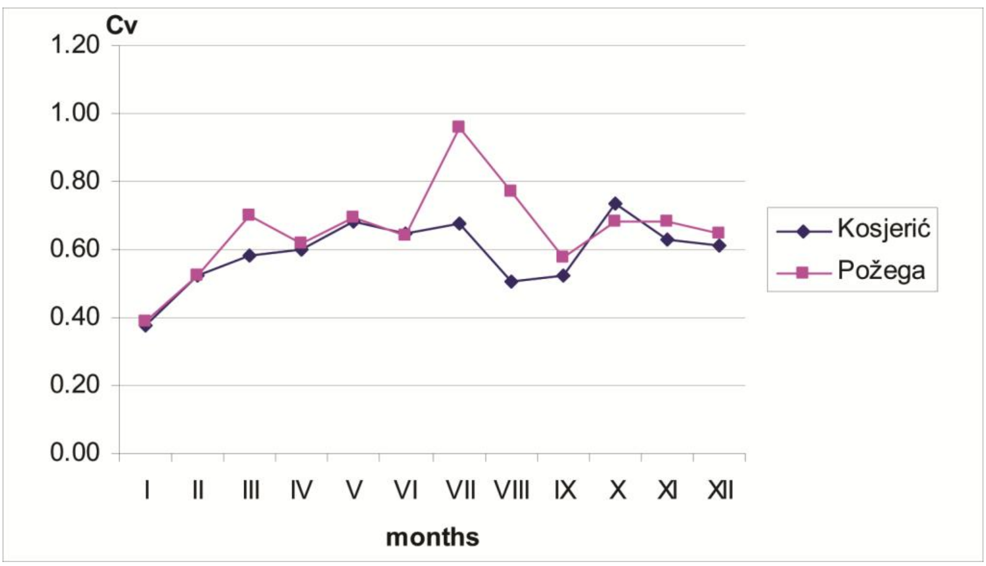

Figure 3. Coefficients of variation of the Skrapež River discharges in the period 1981-2010.

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3.2. Coefficient of Variation

Annual values of coefficient of variation are equalized and are found to be 0.26 in Kosjerić and 0.33 in Požega, which put the Skrapež River in rivers of mild discharge oscillation (Ocokoljić, 1991). Monthly differences are higher. In Požega there are mostly higher coefficients of variation.

Only in June and October in Kosjerić the values are higher. There are, at the same time, periods with maximal *Cv* values (Kosjerić 0.73 in October and Požega 0.96 in July). The lowest values of *Cv* are in January in Požega 0.39 and in Kosjerić 0.37.

3.3. Amplitudes and Relation between Maximal and Minimal Discharge

Amplitudes of average maximal discharges and relation between maximal and minimal discharges are calculated separately for each station and considering replacement of Kosjerić station in 1980 two periods were also separately analyzed.

Table 3. The Skrapež River discharge amplitudes (m^3/s)

Period	Station	Amplitude	Station	Amplitude
1961-1980	Kosjerić	12.27	Požega	24.96
1981-2010	Kosjerić	6.71	Požega	20.96

Amplitudes are considerably higher in Požega in relation to Kosjerić. Also relation between minimal and maximal water in Požega is 1:12.48 (1961-1980) and 1:12.16 (1981-2010), which means it is higher then in Kosjerić where relation is 1: 9.76 (1961-1980) and 1:11.07 (1981-2010). These are average monthly values of high and low water for mentioned two periods, so these values are averaged. In speaking about single years or absolute maximal and minimal discharge, differences become more extreme (table 4).

In period 1961-1980 there was maximal discharge in Kosjerić in May 1961 (128 m^3/s), and minimal in June 1963 (0.12 m^3/s). That means amplitude is 127.88 m^3/s, and the relation between maximum and minimum discharge is 1:1066.67.

In period 1981-2010 maximum was 75.5 m^3/s (in 1986), and minimum was 0.08 m^3/s (in 2000). Amplitude was 75.42 m^3/s, and relation between maximum and minimum discharge 1:943.75. In Požega in period 1961-1980, maximal discharge was 313 m^3/s (in 1965), and minimal 0.15 m^3/s (in 1974).

Amplitude was 312.85 m^3/s, and relation between maximum and minimum discharge 1:2086.7, which means that the Skrapež River has 2086.7 times greater amount of water in maximum than in minimum. Mentioned values are at the same time absolute maximal and absolute minimal discharge values. In period 1981-2010 maximum was 300 m^3/s (in 1986), and minimum was 0.28 m^3/s (in 1993). Amplitude was 299.72 m^3/s, and relation between maximum and minimum discharge 1:1071.4. Maximal discharges have size rank 10^1 and 10^2, while the values of minimal discharges have size rank 10^{-1}.

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Table 4. Relation of maximal and minimal annual discharges of the Skrapež River

Years	**1961**	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**
Požega	11.09	12.83	16.64	3.62	28.83	12.36	24.42	13.86	7.79	11.09
Kosjerić	11.87	10.15	10.89	12.10	15.24	6.52	18.03	7.17	7.70	9.17
Years	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**
Požega	9.19	6.48	6.33	26.72	19.36	6.22	7.19	9.95	20.15	13.98
Kosjerić	6.88	5.28					7.47		8.46	
Years	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Požega	16.89	13.49	16.32	15.21	19.78	23.88	24.35	9.40	14.31	4.90
Kosjerić	8.58	10.39	8.83	9.01	14.47	19.74	37.30	13.19	13.10	5.65
Years	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Požega	33.81	12.56	6.65	11.56	12.59	16.47	5.88	8.24	10.70	3.30
Kosjerić	18.52	9.48	8.21	12.95	8.44	12.09	10.56	9.45	9.98	7.51
Years	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Požega					13.32	5.66	6.84	3.43	10.11	11.39
Kosjerić	19.38	11.87	6.35	6.64	9.91	8.17	10.46	5.38	12.94	9.67

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Differences are considerably higher in Požega than in Kosjerić, but there are years when the relation between maximum and minimum is greater in Kosjerić (1961., 1964., 1977., 1987., 1988., 1990., 1993., 1994., 1997., 1998., 2000., 2006-2009). Relative size of high water for the Skrapež River amounts 12.47.

3.4. Maximal Annual Discharge (Qmax)

Basic statistical parameters of maximum water discharge series of the Skrapež River at Požega are: X_{sr}=93.97 m^3/s, S_x=70.45 m^3/s, C_v=0.75, C_s=1.46. Results of randomness test (Neyman's test) is $-1.96< 0.31<1.96$, which means that series is random. Student t-test, Fisher F-test and Wilcoxon inverse test (U) has been used for testing the homogeneity of the time series. The following values have been calculated: $F=1.133 < F_{kr}=2.232$, $t=0.02 < t_{kr}=2.01$, $U_1=240.838 < 367 < U_2=461.162$, that means that the sample is homogeneous. All tests have been performed with significance level $\alpha=0.05$. The empirical and theoretical functions of probability distribution are calculated and presented at figure 4.

The testing of the agreement (fitting) between the empirical and theoretical distribution functions was performed using the Chi-squared test, the Kolmogorov-Smirnov test and the Cramér-von-Mises test. According to results of these tests best agreement (fitting) with empirical data has a Log-Normal distribution. Maximum observed water discharge of 313 m^3/s, according to selected theoretical (Log-Normal) distribution, has the exeedance probability 2.36% or return period of 42 years.

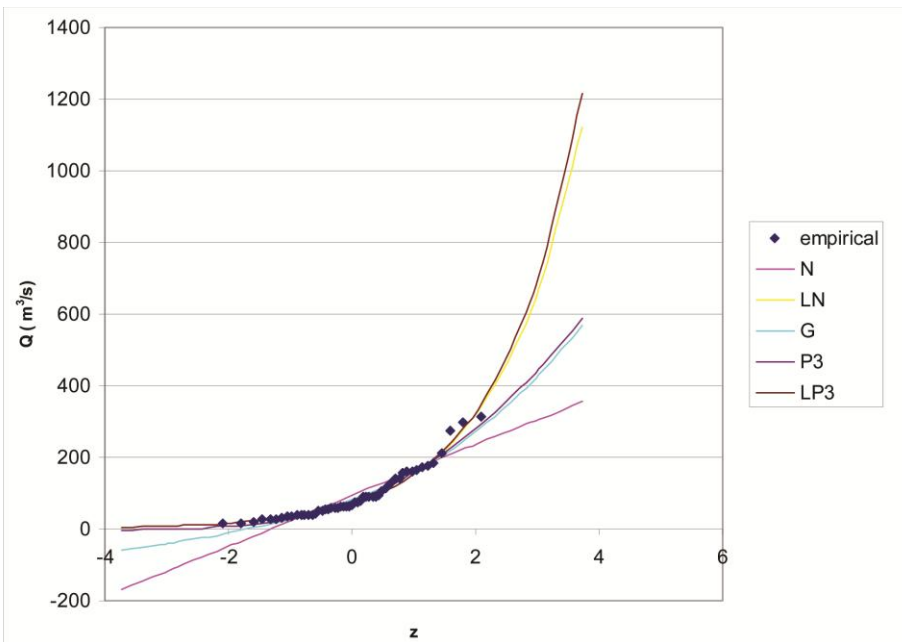

Figure 4. Empirical and theoretical frequency curves of maximum water discharges on the Skrapež River in Požega in the period 1953-2010 (N-Normal, LN-Log-Normal, G-Gumbel, P3-Pearson Type 3, LP3-Log-Pearson Type 3 distribution).

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3.5. Erosion Coefficient, Erodibility Class, Hydrographic Class

According to erosion map of the whole Skrapež River watershed, erosion coefficient is ranged from 0.10 to 1.00 and selected sub-watersheds which have first and second erodibility class have erosion coefficient ranged from 0.70-1.00. Selected sub-watersheds are presented on the figure 5 and their characteristics are given in the table 5. There are 12 torrential flows determined in the Skrapež River watershed according to erodibility class and they are classified with method of S. Gavrilović (1972) in two hydrographic classes according to type of torrential flows. Classification of these streams is also provided in table 5. Hydrographic class C means “Torrential streams” and class D “Dry valleys”.

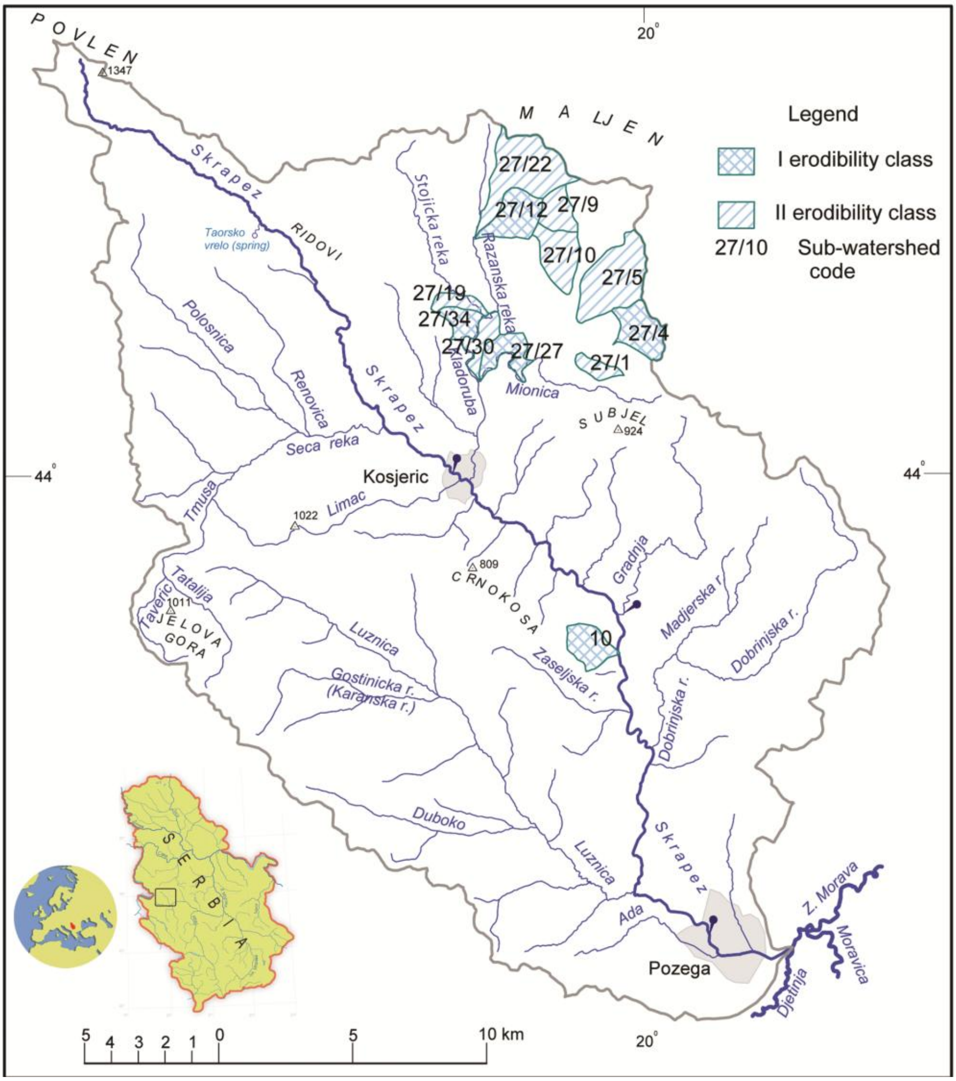

Figure 5. Map of the Skrapež River watershed with selected I and II erodibility class sub-watersheds.

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Table 5. Selected torrential sub-watersheds in the Skrapež River watershed

No	Sub-watershed name	Sub-watershed code	Area (km^2)	Erodibility class	Hydrographic class	Coefficient of erosion
1	Dragutinovića potok	10	2.10	1	D	1.00
2	Spring area of Skakavički potok	27/4	2.69	1	C	1.00
3	No named brook	27/12	2.86	1	C	1.00
4	Right slope of Mionica River	27/27	1.88	1	D	1.00
5	Right slope of Kladoruba River	27/34	1.32	1	D	1.00
6	Poljanski reka	27/1	0.90	2	C	0.92
7	Skakavačka reka	27/5	5.46	2	C	0.77
8	Right slope of Nedića potok	27/9	1.72	2	D	0.70
9	Right slope of Rosićka reka	27/10	2.85	2	D	0.71
10	Right slope of Stojićka reka	27/19	1.01	2	D	0.70
11	Dugi potok	27/22	5.95	2	C	0.72
12	Left slope of Kladoruba River	27/30	1.49	2	C	0.81
	Sum		30.24			

Table 6. Geology and soil types in selected torrential sub-watersheds in the Skrapež River watershed

Sub-watershed code	Geology	Soil types
10	conglomerate, sandstone, limestone, phyllite, shales	gray brown acid skeletoidal soil on crustaline rocks
27/4	peridotite	skeletal soil on serpentine rock, parapodzol (pseudogley)
27/12	peridotite	skeletal soil on serpentine rock, parapodzol (pseudogley), skeletoidal fertile soil on serpentine rock
27/27	peridotite 90%, neogen loose sediments	skeletal soil on serpentine rock, eroded smonitza (shallow)
27/34	peridotite	fertile soil on serpentinite, eroded smonitza (shallow)
27/1	peridotite 70%, neogen loose sediments	skeletal soil on serpentine rock, eroded smonitza (shallow)
27/5	peridotite 80%, neogen loose sediments	skeletal soil on serpentine rock, parapodzol (pseudogley)
27/9	peridotite	skeletal soil on serpentine rock, skeletoidal fertile soil on serpentine rock
27/10	peridotite, neogen loose sediments	skeletal soil on serpentine rock, parapodzol (pseudogley), eroded smonitza (shallow)
27/19	peridotite, neogen loose sediments	skeletoidal fertile soil on serpentine rock, parapodzol (pseudogley), eroded smonitza (shallow)
27/22	peridotite	skeletoidal fertile soil on serpentine rock, skeletal soil on serpentine rock, parapodzol (pseudogley)
27/30	peridotite 90%, neogen loose sediments	skeletal soil on serpentine rock, eroded smonitza (shallow)

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3.6. Geology and Soil Types

Selected sub-watersheds were compared with geology and soil types and results were presented in table 6. In those watersheds peridotites (serpentinites) are dominant with participation of neogen loose sediments. In such geological basis skeletoidal soli types, eroded smonitza and parapodzol have been developed.

3.7. Relief Inclination and Roughness

The relief inclination and surface roughness coefficient done on the basis of numerical analysis of a DTM have given similar results. Inclination distribution for selected sub-watersheds is presented on figure 6. The sub-watersheds with the greatest inclination are Skakavačka reka (27/5) and Dugi potok (27/22). Analysis of roughness coefficient as quantitative indicator of dissected relief has shown significant correlation with inclination values.

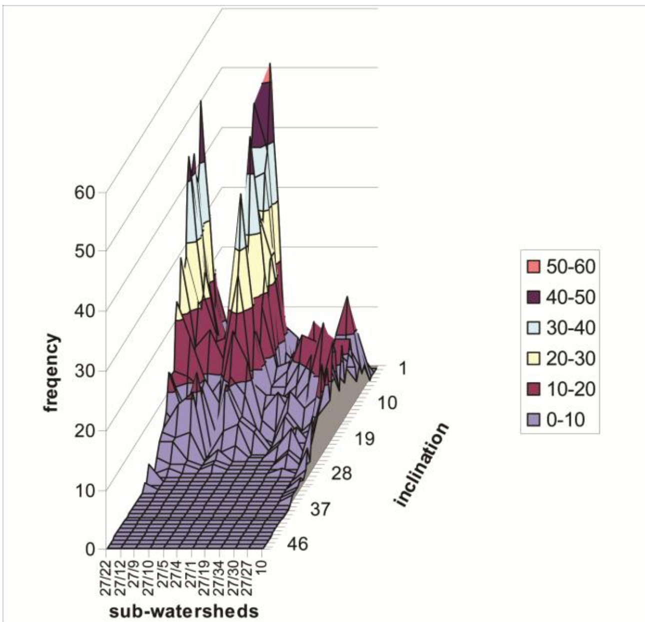

Figure 6. Inclination distribution in selected torrential sub-watersheds.

3.7. Population Number and Number of Objects

Number of population living in selected sub-watersheds was chosen as a social (demographical) indicator of vulnerability. Mentioned sub-watersheds overlap with the administrative borders of seven settlements (Mrčići, Rosići, Skakavci, Mionica, Brajkovići and Stojići belonging to Kosjerić municipality and Kalenići belonging to Požega municipality).

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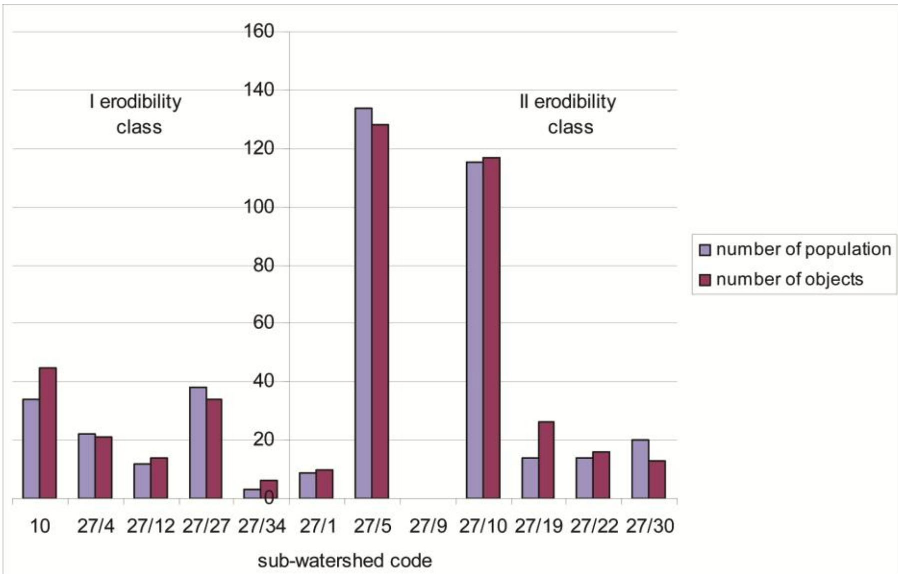

Figure 7. Number of population and objects in selected sub-watersheds.

On the figure 7 numbers of population and objects in selected watersheds is presented. Total number of population, living on those areas amounts 415 and number of objects 430.

3.8. Number of Intersections between Streams and Roads/Railways

Number of intersections between streams and roads/railways shows differences between sub-watersheds and describe possibilities for river-flow obstruction and also potential damages of infrastructure. The most exposed sub-watersheds are Skakavačka reka (27/5), Right slope of Rosićka reka (27/10), Dugi potok (27/22), and Right slope of Mionica River (27/27).

4. Discussion

Analyzing the years ranking regarding discharge it is concluded that the majority of the years belong to category with average discharge and they appear averagely every second year. That is the rule on every other river (Ocokoljić, 1994). In order to fortify some regularity in appearance of years with low and high discharge, period of 58 years is not long enough and regularity in the alternation of years with low and high discharge should be accepted cautiously. To the years with extremely low discharge belongs the year 1990. Then the average annual discharge was only 1.68 m^3/s, the probability of occurrence was under 0.01% and year with such discharge could occur every 10000 year or even rarely. In category of years with extremely high disharge belongs the year 1955, because then the average annual discharge was 11.06 m^3/s. Year with such discharge has return period of 200 years.

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Although according to the annual values of coefficient of variation the Skrapež River belongs to the rivers of mild discharge (Ocokoljić, 1991), it's discharge oscillation is an exception in relation to the other West Morava tributaries which are located upstream from Čačak, and which values oscillate from 0.25 on the Veliki Rzav River (Urošev, 2007) to 0.28 on the Djetinja and Bjelica River (Ocokoljić, 1991). The reason for this is the complete composition (construction) of physical-geographical factors of the river basin (mesoclimate, geological structure, forestation, riverbed stability) (Kovačević-Majkić, 2009). Comparing presented Cv results with those calculated for shorter period (Kovačević and Milanović, 2003, Kovačević-Majkić, 2009) there are no significant differences. Higher values of coefficient of variations in summer coincide with lower values of discharge. In winter discharge is more stabile. Higher values of coefficient of variation in Kosjerić (upstream station) in June and October could be explained with the spring and autumn rainfalls, which are more intensive in the upper part of river basin. Research on spatial distribution of precipitation and their relations with the Skrapež River regime was done by Kovačević-Majkić and Štrbac (2008) and on broader area in 2011. Lower values in Kosjerić in summer in relation with rainy periods mean certain irregularity. The explanation is in geological composition. Namely, karst areas in the upper part of river basin influence discharge stability in period June - September in Kosjerić. High and low water have considerable importance in hydrological researches, because they give more complete picture of river regime. If we take into consideration maximal and minimal discharges and their relation, differences in water amount which runs trough the river bed are more striking.

Considering the size of watershed (647.65 km^2) and relations between maximal and minimal discharges (Vučićević, 1995), the Skrapež River watershed belongs to those with normal erosion processes. But, in speaking about amplitudes differences between maximal and minimal discharges of single years or absolute maximal and minimal discharge, differences are more considerable and point to erosive processes higher than normal.

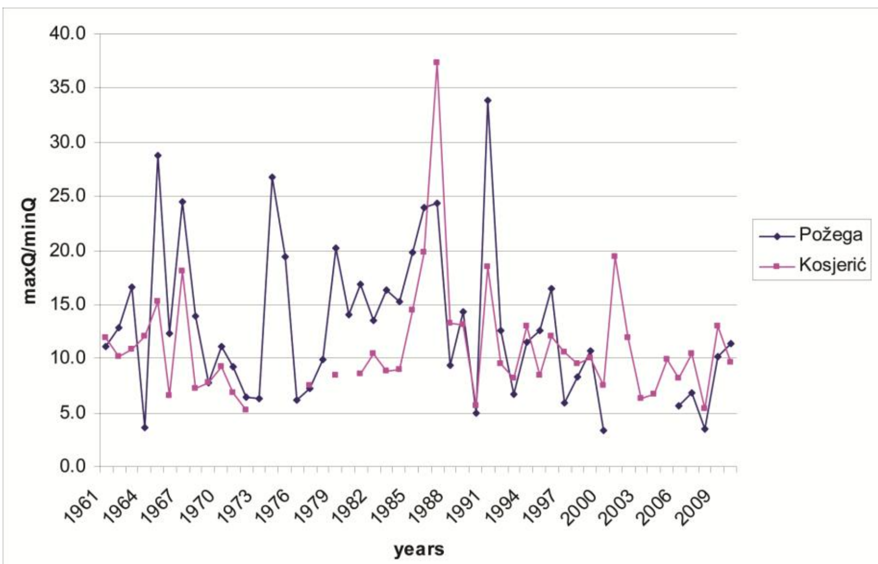

Figure 8. Comparison of relation between maximal and minimal discharges of the Skrapež River in the period 1961-2010.

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On the figure 8 relations between maximal and minimal discharges of the Skrapež River for period 1953-2010 are presented. Since relation between maximal and minimal discharge shows hydrological variability, similarly as coefficient of discharge variation, it is important form practical point of view. Differences between maximal and minimal discharges are higher in Požega. Years when the relation between maximum and minimum is greater in Kosjerić mainly belong to those when discharge is average or low, so these phenomena are being explained by smaller amount of water in upper part of the river basin. Taking into consideration the coefficient of variation, amplitudes and relation of maximal and minimal water, it can be concluded that discharge in Kosjerić is more stabile. According to relative size of high water, the Skrapež River with belongs to III (middle) group of torrential flows (Gavrilović, 1981). Belonging to this group also implies real problems with torrents, but not extreme ones.

The length of high water observed period increases the reliability of calculation in direct proportionality, although appearance of high water could be assigned as "chance", considering the fact that high water depends on huge number of different size causes which happen in the same time (Jevđević, 1956). First three maximum observed water discharges with their characteristics could be seen in table 7.

In 1965 difference between maximal observed discharge and average maximal discharge for observed period was 219.03m^3/s and in relation to average discharge 308.14 m^3/s. Exceedance probability of such discharge is 2.36% and return period 42 years. Appearance of high discharges leads to certain water management problems, first of all to floods in Požega basin in periods of high water.

Table 7. Years with maximal discharges and its characteristics

Year	Qmax (m^3/s)	Qmax-avgQmax	Qmax-avgQ	P(x) %	T(x)
1965	313	219.03	308.14	2.36	42
1986	300	206.03	295.14	2.70	37
1991	274	180.03	269.14	3.57	28

P - exeedance probability, T - return period.

All of these hydrological indicators (characteristics) lead to stormy and unstable discharge of the Skrapež River and contribute to its torrential character.

Since the large part of the Skrapež River watershed consists of schist, serpentine and sandstone, i.e. of material which is subjected to decay and the fact that slopes and shallow soil enable carving of streams and creation of torrents and ravines, there were parts of the watershed with increased erosion with erosion coefficient ranged from 0.10 to 1.00. In early '80s Lazarević has done great scope of erosion in Serbia. According to his results average coefficient of erosion *Z* in the Skrapež River watershed was 0.322 (Lazarević, 1983 a) and it belonged to IV erodibility class (Lazarević, 1983 b). Twenty years later group of authors came to similar conclusions and made more precise descriptions. Erosion of I class (excessive erosion) is related to dirt roads and paths, irregular marked out roads and bare surfaces. Erosion of II class (strong erosion) can be found on agricultural lands with slopes greater than 10^o, while erosion of III class can appear on agricultural areas with more gentle slopes (Faculty of Geography, 2004). Nowadays the whole watershed belongs to III erodibility class (Gavrilović et al, 2009).

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Increased erosion in sub-watersheds of the Ražanska and the Mionica River, which make the Kladoruba River, which flows into the Skrapež River at Kosjerić, leads to deposition of material in the Skrapež riverbed witch increase its elevation. In study about torrents in the Skrapež River watershed (Public Water Management Company (PWMC) ”Srbijavode”, 1965) the most detailed division into sub-watersheds was done in the Kladoruba River sub-watershed, which was divided into 35 sub-watersheds. This follows from the fact that in this part of the Skrapež River watershed the most intensive erosion is determined, which is consistent with the geological and pedological basis. In local dialect the name Kladoruba means "the stream that cuts the trees," which points to its torrential character. Sediment transport is very important for understanding torrential rivers and during high waters and flood waves sediment transport is at its maximum. It is determined on the basis of analysis of erosion processes in river basin. According to Ranitović (1981) specific production of sediment was 412 m^3/km^2/year, of which 70–80% was transported during floods. Similar results got Lazarević (1983 b). According to his results, specific production of sediment is 460 m^3/km^2/year and specific sediment runoff 152.72 m^3/km^2/year. The biggest production of sediments and the biggest erosion problem was and still is in the Kladoruba River sub-watershed, more exactly the Ražanska River. All types of erosion are presented in surface removal, dredging and deepening of channel. The intensity of erosion process is in direct relation with crop growth on forest – agricultural land, i.e. crop growth is smaller if erosion is destructible and opposite.

That’s why it is necessary to stop erosion processes. Anthropogenic influence, like inadequate land use (cultivated fields along slopes and their small size) and cutting down natural vegetation significantly effect increasing erosion. Still, analyzing the erosion map, it is obvious that in the largest part of watersheds there is small or medium erosion going on, while excessive and strong erosion is limited to a small number of dry valleys and torrential streams.

On the figure 9, soil map with selected sub-watersheds of first and second erodibility class is presented. On these sub-watersheds erosion coefficient is ranged from 0.70 to 1.00.

According to the categorization of inclination towards the French and Italian authors (Vučićević, 1995) two sub-watersheds (the Skakavačka reka (27/5) and the Dugi potok (27/22)) are in the category over 7^o, meaning they should be avoided for agricultural activities. By Sylvester categorization, where the slopes are above 5^o, the erosion is strong and causes complete loss of humus (fertile soil). Thereby erosion contributes to the vulnerability of space in the economic sense and is a factor in the torrents appearance.

Considering vulnerability indicators as risk components, analysis has shown following results. Number of population living in selected sub-watersheds is significant. 415 people living in area of 30.24 km^2 means population density of 13.72 people/km^2. In sub-watershed Right slope of Rosićka reka (27/10) population density reaches 40 people/km^2. Number of people, 415, itself means that so many people are vulnerable by excessive and strong erosion and torrent floods.

Number of intersections between streams and roads/railways is a significant indicator in torrent floods vulnerability assessment, especially on the watershed level. As such (as absolute number) could be treated as an exposure indicator, and in relation to stream length or size of watershed area as a vulnerability indicator. In such relation comparison between sub-watersheds (or any region of interest) could be carried out. On the figure 10, density of intersections between streams and roads/railways is presented. Considering this indicator sub-

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watershed the Mionica River (27/27) has the highest potential to obstruct undisturbed flow of high water and sediment and also to have damages.

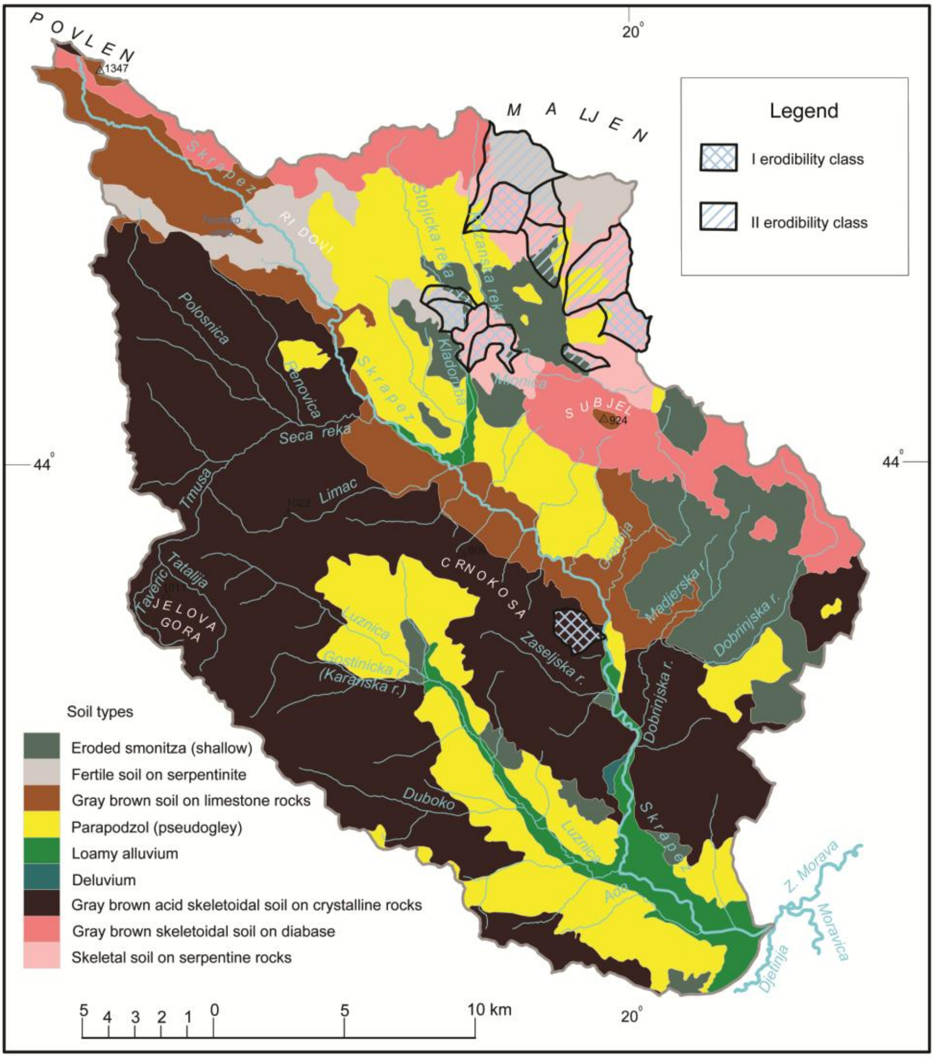

Figure 9. Soil map with selected sub-watersheds of first and second erodibility class.

Considering torrential flood defense several facts are certain. Flood defense is necessary and it is one of the main goals of water management because it is one of the most frequent natural disasters. The largest number of regulation works on the Skrapež River and its tributaries was carried out in period 1965-1969 years (Institute for Water Resources Management “Jaroslav Černi”, 2001), that is why they need to be reconstructed. Considering mentioned facts active flood defense need to be carried out by construction and maintenance of water reservoirs in which big flood waves would be retained. In this chapter we also consider water management solutions proposed in plan document WRMBPS (Institute for Water Resources Management “Jaroslav Černi”, 2001).

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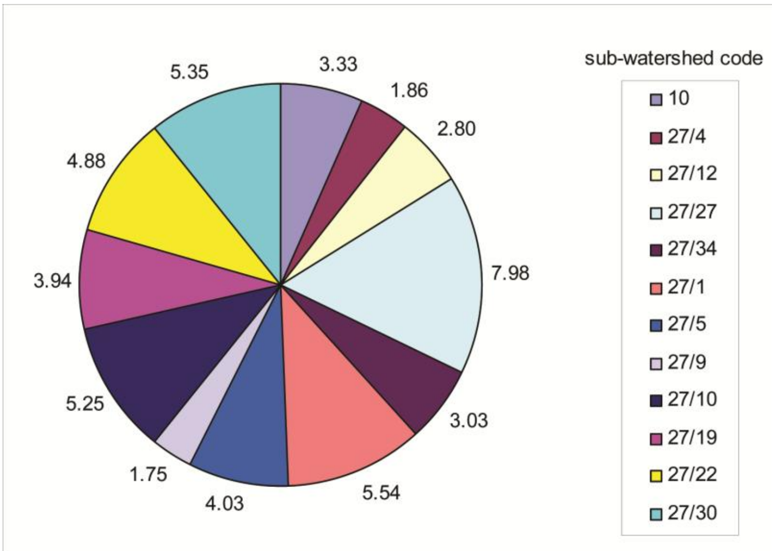

Figure 10. Density of intersections between streams and roads/railways (number of intersections/km^2).

These solutions were assessed as indicators for torrential floods risk reduction. Active measures (biological and technical works) expressed by land use planning (preventive structure building) were treated as both *sensu lato* and *sensu stricto* prevention indicator.

4.1. Suggested Solutions for Water Management Problems

For satisfying water demand, the logical order of declining causes of water management problems should be conditioned. It means that the regulation of unregulated sub-watersheds and the Skrapež riverbed regulation, will be achieved by establishing a balance in the vegetation cover (increasing area under forests), which will prevent the filling of the riverbed with deposits; also underground runoff will be improved, more exactly amplitudes between low and high waters will be decreased. Besides biological measures for regulating the Skrapež River flow, which include active defense measures against floods in terms of reforestation and thus regulation of river regime, it is also necessary to conduct technical regulation measures.

The Skrapež riverbed is partially regulated in the center of the settlement Kosjerić. Existing embankments in Kosjerić satisfy requirements, but some in Požega basin do not, so it would be necessary to renovate them and add new ones. Excessive water, which are most frequent in spring and autumn, which endangers Požega basin, are drained at Požega with minor system, which works on principles of pipe drainage. It is also necessary to regulate the riverbeds of the Skrapež River, the Kladoruba River and the Limac River. On the Skrapež River, the Kladoruba River, the Seča reka River, the Pološnica River, the Mionica reka River, the Ražanska reka River it is necessary to determine parts of the watersheds for the retention, cascades and dams in order to implement active (technical and biological) measures for flood protection. Besides it is necessary to keep the zone of possible irrigation and use them just for those purposes (Institute for Water Resources Management “Jaroslav Černi”, 2001).

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In the Skrapež River basin there are no major water management interventions, nor built multi-purpose reservoirs. The Skrapež River is not suitable for the hydropower use because of the impermanence discharge and its large oscillations. Also, natural hydropower potential is $30.23x10^6$ kWh/year, or a specific potential of $0.76x10^6$ kWh/year is in favor of mentioned claim (Institute for Water Resources Management "Jaroslav Černi", 2001).

One of the ways of solving hydrological and water management problems and river basins regulations in general is construction of small water reservoirs with multipurpose use. Because of denuded middle part of the Skrapež River watershed and also sub-watershed of the Kladoruba tributary, where erosion is great, and without previously forestation it is pointless to talk about building of reservoirs for any purpose. There are three potential locations for reservoir construction.

The first potential location for the reservoir construction is on the Seča Reka River directly in front of its mouth, upstream from the quarry. The reservoir of "Seča Reka" would be part of the regional subsystem Uvac-Rzav for water supply of Kosjerić. Physic-geographical parameters, such as the geological composition (waterproof rocks), relief (large dissection and energy relief), erosion (the lowest coefficient of erosion), specific runoff (the highest in comparison to other sub basins), as well as hydro geological and engineering - geological conditions, were evaluated as acceptable for the construction of the reservoir. However, as the level of normal backwater is on 465 m altitude, and it is determined by village Seča Reka, it would be necessary to solve the problem of waste water and drain them downstream of the reservoir, especially since the primary purpose of reservoir of "Seča Reka" would be the water supply of population and industry. Maximal volume of reservoir would amount $17x10^6$ m^3. It will be also used for fishing and tourism, improvement of small water, flood control and sediment retention (Institute for Water Resources Management "Jaroslav Černi", 1996).

Previously, according to the Morava River basin regulation plan in the period 1966-1985, there were another two specific locations for the construction of reservoirs (Group of authors, 1986). Potential locations have been in Kalenić, on the exit from the Litice gorge and in the Otanj narrow part of gorge downstream from the mouth of the Dobrinjska reka River. In the paper of Vujnović (1995) have been proposed the construction of the reservoir "Bjeloperice" (the second potential location), and as an alternative "Dobrinja" (the third potential location) and "Seča reka". Reservoir "Bjeloperice" in the middle course of the Skrapež River downstream from Bjeloperice, is possible to build by concrete arch dam 43 m high. Construction of the reservoir would not affect settlements and industry, but part of the road (10 km) Požega – Kosjerić would be submerged, and a railway Belgrade - Bar would partially changed the route on the part Kosjerić – the Dobrinjska reka River. The reservoir would solve the problem of flooding in Požega basin, Požega settlement and downstream valley of the Zapadna Morava River and keeping the silt would protect reservoirs in the Ovčar - Kablar gorge. On that way, the matters of winter floods will be solved, as well as high water spreading, downstream the Litice gorge and at the entrance of the Požega basin. From this reservoir during summer period irrigation in the Požega basin could be done, because in this period, there is need for larger amounts of water, which is deficit in that time.

Construction of the reservoir on the Dobrinjska reka River is mentioned as an alternative. Specific runoff of this sub-watershed is low, discharge also (only 0.60 m^3/s), so the reservoir on this river would not be a priority. Construction of reservoirs involves as a prerequisite antierosive measures in the river basin, as well as making detailed analysis of the impact on

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the environment. Also, it is important to fit water management systems ambientally in the environment. Since it is, first of all, necessary to determine the optimal conditions for the construction of reservoirs, in accordance with all limitations that appear, the locations for the mentioned reservoirs are now marked just as areas reserved for this purpose (Official Gazzete of the Republic of Serbia, 1996). Active protection measures have to be implemented, otherwise it comes to filling of reservoirs with deposits, their eutrophication and similar condition that usually effects anthropogenic activities.

In Serbia, there are numerous examples of small reservoirs, which volume and surface area reduced, water quality became worse and therefore they lost their original purpose. In such situation is also the oldest reservoir in Serbia – the Grošničko jezero lake built on the Grošnica River in the Lepenica River basin and which is used for water supply of Kragujevac (Milanović, A., Kovačević-Majkić, J., 2007).

Figure 11. The Litice gorge (potential location for reservoir construction).

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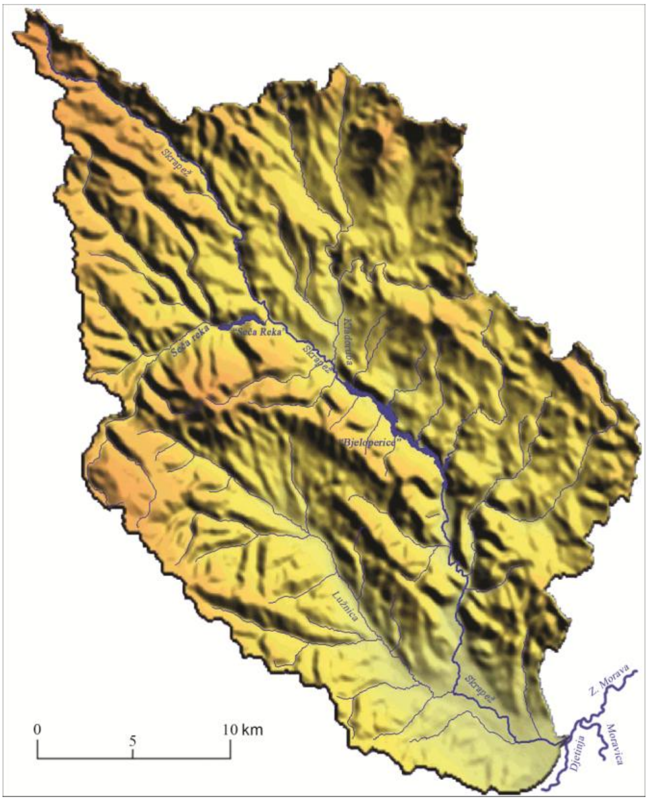

Figure 12. 3D model of the Skrapež River basin with potential reservoirs.

Example of the Zavojsko jezero lake (created when landslide appeared making a dam in the river channel) indicates that the greatest danger of its deposit covering is in the area of its immediate environment, where is the largest antropo-pressure on general condition and quality of the environment (Mustafić, S., Kostadinov, S., Manojlović, P., 2008).

Conclusion

Amount of used data in study about torrent flood prevention possibilities and the increasing needs for water point to the need for the appropriate solutions to the all mentioned water management problems. Today, despite the trend of decreasing number of population in majority of settlements in the Skrapež River watershed and the fact that majority of rural settlements are supplied with water from the local springs and local water supply systems, i.e. anthropo-pressure decrease, there is, according to present state, on some locations, increase of erosion processes. Where the forests were cut down, „bad lands“ are created and are still present. Unfortunately, similarly as 30 years ago, when Ranitović (1981) and Misailović (1981) treated hydrological and water management problems in the Skrapež River basin, we can conclude that the Skrapež River and majority of its tributaries still have torrential character, water level amplitudes are high, riverbeds are unregulated, sediment production is considerable, and all of that lead to unfavorable water balance. Considering these facts the

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Skrapež River watershed still lacks the conditions for its substantial economical usage. That means there have to be carried out both integrative and adoptive measures. Improvement of present state will primarily be result of good prevention in all senses. In order to speak about rational usage of the Skrapež River, it is necessary to fulfill certain conditions, which at first means riverbed and watershed regulation. With antierosional works and construction of “Seča Reka” and “Bjeloperice” reservoirs, part of these problems would certainly be solved. However, it is necessary to foresee positive and negative aspects of “Seča Reka” reservoir. In order to decrease erosion and sediment deposition, special attention should be given to biological protection measures (forestation, forests amelioration, grass overgrowing, pasture amelioration). Just after these measures, building of reservoirs and other technical measures and protection forms of erosion and torrential flows could be done.

In solving these problems, highlighting the indicators of all torrent flood risk components is important. Contribution of this research is that all data (treated as indicators), no matter they are got from public institutions and services or they are result of present research, are arranged in GIS database. Existence of the Skrapež River watershed GIS is of great help, because it is useful for risk reduction and for decreasing consequences in the environmental, economical and socio-psychological sphere. Existing of such information system and analyses of all indicators of torrent floods risk components, means *sensu lato* prevention.

Though there is absence of more detailed data used as torrent flood indicators, contribution of research presented in this chapter is: for the first time in Serbia used methodology for torrent floods risk assessment which includes prevention possibilities as an important part of Natural Disaster Risk Management. Also this kind of study as well as methods presented and applied in this chapter could be used as a model for similar researches.

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Chapter 6

NATURAL DISASTERS IN TOURISTIC DESTINATIONS: THE CASE OF PORTUGUESE ISLANDS

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ABSTRACT

People in general have become more concerned about their physical safety, wherever they live or travel, in a more complex, interconnected world in which environmental issues clearly demonstrate that organisms and all the elements of nature, including air, land and water cannot be exploited without implications, including impacts on the image of international destinations, that can dramatically affect the tourism Industry. Disasters which occurred in Atlantic Islands (Azores, Madeira and Canary Islands) is clearly causing the drop in tourism and damaging the image and local economy. Higher perceived risk is associated with decreased visitation. Perceived risk can have a connection with the general idea that, as a result of global warming the environment will change and sea levels will rise. In Many regions, the impact of such changes are likely to arrive through changes in the frequency of the climatic extremes like, floods, droughts, volcanoes, storm surges etc..

This chapter proposes that previous destination image research has tended to underestimate the importance of safety, security and risk- It also proposes a strategic approach to destination management from proactive pre-crisis planning through to strategic implementation and finally evaluation and feedback.

Keywords: Safety and security crisis, crisis in Atlantic Islands, managing crisis, place image

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INTRODUCTION

Last decade can be remembered for the multiplicity of negative events including natural disasters, terrorist attacks and bird flu, that have severely impacted tourist destinations. Whether the incidence of disasters or crises, both natural and man-made, is increasing, people have become more concerned about their safety, particularly when they decide to go travelling.

There is also in general, considerable concern when discussing climate change, caused by global warming in recent years. The idea that a changing climate can persuade the ground to shake, volcanoes to rumble and tsunamis to crash on to unsuspecting coastlines seems, at first instance, to be unimaginable. However, although the stable sea level of the last centuries has permitted people and other species, to develop extensively coastal areas, it is generally agreed that, as a result of global warming, sea levels will rise. By the year of 2030, the world will be 2º C warmer than today, and sea level will rise up to between 15 and 30cm. The impacts of such changes may increase the frequency of climatic extremes like floods, hurricanes, earthquakes or awakening volcanoes. Actually, periods of exceptional climate change in Earth history are associated with a dynamic response from the geosphere, involving enhanced levels of potentially hazardous geological and geo-morphological activity. The response is expressed through the adjustment, modulation or triggering of a broad range of surface and crustal phenomena, including volcanic and seismic activity, submarine and sub aerial landslides, tsunamis and landslide ‘splash’ waves, glacial outburst and rock-dam failure floods, debris flows and gas-hydrate destabilization. In relation to anthropogenic climate change, modeling studies and projection of current trends point towards increased risk in relation to a spectrum of geological and geomorphologic hazards in a warmer world, while observations suggest that the ongoing rise in global average temperatures may already be eliciting a hazardous response from the geosphere (. McGuire, B. 2010).

Lowlands, wet lands and coastal cities can be inundated, water supplies would become saltier, beaches can be dramatically flooded, Coral atolls, river Deltas, estuaries and Islands can be deeply uncharacterized.

In recent years, several natural disasters arrived unannounced at the four corners of the world, leaving trails of destruction and massive loss in tourism revenue. In December 2004, the Indian Ocean tsunami, one of the deadliest natural disasters in history was largely noticed. Many thousands of tourists were among the 275,000 people killed by the tsunami, which inundated coastal countries with waves with 30m high, including regions of Indonesia, Thailand, Myanmar, Sri Lanka and India. In Thailand, almost half of the 12,000 people who perished in that disaster which hit the Andaman Sea coast of Thailand were tourists based in popular resort destinations such as Phuket.

Within Australia, many of the country’s most popular tourist destinations are vulnerable to cyclones and floods. The Queensland floods earlier last year, followed by Cyclone Yasi created considerable disruption to tourism in Queensland. The worst cyclone in more than 30 years, impacted around 70% of the State and affected almost 60% of Queensland’s population. One month later, Japan's most powerful earthquake since records began has struck the north-east coast, triggering a massive tsunami. Cars, ships and buildings were swept away by a wall of water after the 9-magnitude tremor, which struck about 400km (250 miles) north-east of Tokyo. A state of emergency has been declared at a nuclear power plant,

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where pressure has exceeded normal levels. The Great East Japan Earthquake and resulting tsunami killed almost 16,000 people and destroyed the lives of thousands more. The double disaster, which in turn triggered a third crisis at the Fukushima nuclear plant, may have been a year ago, but for many of those in the worst-affected areas life remains in a state of turmoil. The quake was the fifth-largest in the world since 1900 and nearly 8,000 times stronger than the one which devastated Christchurch, New Zealand, the month before, said scientists (BBC-news online 11 March 2011).

Active volcanoes and earthquake risk are just a few of the very real natural disaster threats in Chile and visitors should be prepared ahead of time if they are to enjoy a safe trip. In March 2010 a massive earthquake, measuring 8.8 on the Richter scale hit approximately 300km south of the country's capital Santiago. Hundreds of people lost their lives and countless others were injured. In the same year, volcanic ash from an erupting volcano in Chile disrupted air travel throughout much of the southern hemisphere.

In the same year, the eruption of the volcano Eyjafjallajokull, Iceland also disrupted air travel to and from the United Kingdom, Ireland and Western Europe including the Portuguese Madeira and Azores Islands.

Many of the "pleasure periphery" destinations also happen to be located in regions subject to earthquake and volcanic activity (David Beirmen, 2012).

The Portuguese islands fit perfectly on the Beirman´s idea, as various on a different scale but no less dramatic for the size of the Atlantic islands, have happened over time, including earthquakes and volcanic activity, with huge economic and social losses. The geodynamic framework of the Azores combined with its geological, geochemical, geophysical and frequent manifestations of seismic and volcanic activity puts the Azores Islands at risk while on Madeira Island the historical records indicate several floods in villages based in or near beds of streams, numerous landslides, often with high material damage and human casualties. In the historical memory of Madeira these phenomena are defined as alluvium, which are registered with frequency since the seventeenth century. These dramatic negative events can threaten, weaken or destroy the competitive advantage of a tourist destination (Ritchie and Crouch, 2003).

The possibility of repeated or frequent events of possibly greater magnitude and power serve to put coastal tourism destinations in an almost constant state of alert. It is noted that although crises and disasters cannot be stopped, their impacts can be limited by both public and private sector managers (Machado, Luiz Pinto 2011).

Background

In the middle of the Atlantic Ocean, between Europe and North America, are the Portuguese Atlantic islands belonging to the Azores and Madeira archipelagos. It was with the Portuguese Maritime Discoveries, led by Prince Infante D. Henrique, that these volcanic islands were registered on the map of Europe.

The archipelago of Madeira, discovered by the Portuguese in 1418, comprises the islands of Madeira, Porto Santo and the uninhabited islands of Selvagens and Desertas. It is situated in the Atlantic Ocean 620 miles south-west of the coast of Portugal, and 310 miles west of the Atlantic coast of Morocco, North Africa.

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Regarding Azores, all the nine islands of the Archipelago, it is unknown whether the first navigator to reach the archipelago was Diogo de Silves in 1427 or Gonçalo Velho Cabral in 1431.

Situated 900 miles from west of Portuguese Mainland and 2400 miles from U.S. coast, the islands of the archipelago, are divided in three geographical groups: the Eastern Group, comprising Santa Maria and São Miguel, the Central Group, including Terceira, Graciosa, São Jorge, Pico and Faial, and the Western Group, composed by Corvo and Flores. The Azores, along with the archipelagos of Madeira, Canary Islands and Cape Verde, constitute the biogeographic region of Macaronesia, a name which means "fortunate islands" for those who live there and visit them.

Madeira benefits from a surprisingly mild climate due to its privileged geographical position. The rich volcanic soil, mountainous relief and abundant rainfall have created contrasting landscapes: Lush river valleys, terraced hillsides planted with vines and bananas and dense primeval forest. Madeira has a surface area of 459 square miles, (35 miles long and 13 miles wide), 260.000 habitants with its highest point being Pico Ruivo, at an altitude of 1861 meters. The mild average temperatures of 22ºC in the summer and 16ºC in the winter and a moderate level of humidity confer on the islands exceptional sub-tropical features. The sea temperature is also very mild, because of the influence of the warm Gulf Stream, presenting averages of 22ºC in the summer and 18º in the winter. The island´s high quality natural habitats have been classified as a Biogenetic Reserve, with flora and fauna species that are unique in the world, as well as sub-tropical and tropical fruits and vineyards that produce the famous Madeira wine. Madeira offers great trekking and walking opportunities to the many tourists who visit the island, in addition to mountaineering, game fishing, sailing and surfing, (Oliveira & Pereira, 2008). These are factors that contribute to Madeira being one of world's oldest tourist destinations. In the late nineteenth century, the first tourists were wealthy British visitors travelling aboard transatlantic liners and cargo ships that called into the harbour of Funchal, Madeira's capital city.

The island remained the exclusive reserve of well-to-do tourists until the opening of the Funchal airport in 1963, which was to lead to the development and expansion of infrastructure and the construction of more hotels. Hotel construction increased significantly after the Portuguese Revolution in 1974. Today, Madeira has approximately 31000 hotel beds in a wide range of accommodation options, with a high proportion of 5-star hotels, from the long-established traditional kind to the many new 21st century developments. Madeira's hotels are famed for their hospitality, personalised service, good taste and quality (Barros & Machado, 2010). While most tourists today arrive by air (about one million in 2011), Funchal is a port of call throughout the year on the itineraries of many European and transatlantic cruises. In 2011, a total of 303 ships and approximately 540,000 passengers visited Funchal.

The Azores, with their strikingly beautiful nature and sea, are a Portuguese region where tourism has grown rapidly in the last decade. Tourist nights spent in tourist accommodations increased from 407,000 in 1995 to over 1,200,000 in 2006. Despite the obvious tourist growth potential, the Azorean regional government did not promote tourism until the early 1990s, and the Azores was trapped in an inferior Nash equilibrium with virtually no hotels and no air connections. In the mid 1990s, a change in the Azorean regional government led to a change in tourism policy, with the adoption of tourism growth enhancing policies, such as the provision of air connections and the promotion of brand awareness, which led to a boom in

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hotel construction, with the total number of hotel beds growing from 3,000 in 1995 to 10000 in 2006 (Menezes, Moniz, Vieira, 2008) decreasing to 8870 in 2011.

The archipelago, have 244,780 people (2008 data) live in the 2,325 sq. of this island territory, which is part of the Portuguese state. In 2011, a total of 97 ships and approximately 85.900 passengers visited Azores Islands, while the 345.000 tourists produced 1.033.000 overnights.

The Azores are currently one of the world's largest whale sanctuaries. Among resident and migrant species, common or rare, more than 20 different types of cetaceans can be spotted in the Azores. It is an impressive figure and it corresponds to a third of the total number of existing species, this is an ecosystem with unique characteristics. With majestic whales and friendly dolphins, the blue Atlantic Ocean becomes a sea paradise around these nine islands. The walking trails are also an important spot for tourists and offer a variety of difficulty, as well as in terms of diving spots and types of diving. It offers adequate spots for various experience levels, from beginners to professionals, and the adventure may start with simple snorkeling in order to leisurely enjoy the abundant marine life of the archipelago's crystal clear waters. On the other hand, diving in an ocean bank is a guarantee for an adrenalin rush and for memories that enable the discovery of nine different worlds. Geotourism it´s also something that is growing in the last years. The genesis of the Azores is found upon 1766 volcanoes, nine of which are still dormant. Underground, almost three hundred volcanic cavities, including caves, ravines and cracks, have been surveyed. The landscape is filled with dry calderas, craters lakes, fumaroles and thermal water springs. In the sea, there are submarine geothermal springs. The mountain of Pico, majestic and with an intact cone appears to be protecting all this geological wealth. The volcanism of the archipelago impresses for its diversity and creates its own magnetism. It is a witness to the power of Nature, and the basis for very special experiences (www.visitazores.com).

The Azores have received several nominations, distinctions and recognitions by multiple organizations, entities and publications, by its natural heritage, being distinguished as a Nature Destination of excellence.

NATURAL DISASTERS AND PORTUGUESE ISLANDS

The enormous economic growth in the world in recent decades, globalization and technological progress has increased exponentially the number of tourists, allowing the multiplication of new tourist destinations, even in remote areas of the planet. For many of these areas, tourism has become a major revenue source and sometimes the basis for development of small local economies. This increased exposure to the risk of natural disasters, which amplifies the risk of the number of casualties and economic loss. This could have a huge impact on the development of the economics of tourism. In other words, tourism demand can fluctuate drastically, and economic losses are inevitable (Chung-Hung Tsai a, Cheng-Wu Chen, 2011). Portuguese Islands' special geographic environment and changeable climate combine to give it many unique and beautiful types of scenery, which are valuable natural sightseeing resources. However, according UNWTO-UNEP-WMO-2008, no destination should assume they will not be affected by climate change. There is high confidence that the most immediate and more significant consequences of climate change are

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likely to be changes in the nature of extreme wind event´s to its special geographic environment also makes the area prone to frequent natural disasters.

In April, 2010 Reuters wrote that one of the more disturbing possible results of anthropogenic global warming and one that scientists started to warn us about a number of years ago is the very real possibility that as the ice sheets and glaciers melt and transfer the weight of that water to the oceans, the Earth's crust will rebound and rise upward in formerly ice covered areas, causing stress on the tectonic boundaries of the crustal plates and producing more earthquakes and volcanic activity. Now scientists are pointing to the fact that melting ice can reduce the pressure on deep, hot layers of underlying rock causing it to turn molten and possibly producing a lot more volcanic activity in the years to come. Scientists have documented a 300% upsurge in volcanic activity in Europe which they feel was probably caused by the crustal rebound at the time, in the period about 10 to 12 thousand years ago when the huge glacial sheets melted off of Europe and North America.

Across the world, as sea levels climb remorselessly, the load-related bending of the crust around the margins of the ocean basins might – in time – act to sufficiently "unclamp" coastal faults, allowing them to move more easily; at the same time acting to squeeze magma out of susceptible volcanoes that are primed and ready to blow.

Volcanic blasts too can be added to the portfolio of postglacial geological pandemonium; the warming climate being greeted by an unprecedented fiery outburst that wracked Iceland as its frozen carapace dwindled, and against which the recent ashy ejaculation from the island's most unpronounceable volcano pales. The huge environmental changes that accompanied the rapid post-glacial warming of our world were not confined to the top and bottom of the planet. All that melted water had to go somewhere, and as the ice sheets dwindled, so the oceans grew. An astounding 52m cubic kilometers of water was sucked from the oceans to form the ice sheets, causing sea levels to plummet by about 130 meters – the height of the Wembley stadium arch. As the ice sheets melted, this gigantic volume of water returned, bending the crust around the margins of the ocean basins under the enormous added weight and provoking volcanoes in the vicinity to erupt and faults to rupture which brought geological mayhem to regions remote from the ice's polar fastnesses (McGuire, Bill. 2012).

The geodynamic framework of the Atlantic Islands combined with its geological, geochemical, geophysical and frequent manifestations of seismic and volcanic activity puts the Portuguese Islands at risk. Moreover, Portuguese islands, specially the Azores are exposed to events like Tsunami generated from different mechanisms, local or distant and associated with earthquakes and landslides.

Table 1 shows the numerous disasters that in recent years have affected the islands of Madeira and the Azores, causing enormous material and moral damages.

This could have a huge impact on the development of the economics of tourism. In other words, tourism demand can fluctuate drastically, and economic losses are inevitable (Chung-Hung Tsai a, Cheng-Wu Chen, 2011). The possibility of repeat or frequent events of possibly greater magnitude and power serve to put coastal tourism destinations in an almost constant state of alert. It is noted that although crises and disasters cannot be stopped their impacts can be limited by both public and private sector managers.

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Figure 1. Floods in Madeira Island Funchal Feb 2010 (Picture Duarte Gomes).

Table 2 shows that the Madeira tourism figures exhibit a decreasing trend during the period under recent year's analysis (with the exception of 2008, which was a magnificent year for tourism worldwide). This raises concerns over the long-term competitive position of Madeira. It is clear that issues related to the H1N1 and economic crisis had an effect on international breaks recorded in 2009, but political and strategic factors influenced the decline. While the tourist year of 2010 clearly shows a recovery of the sector, Madeira had one of the worst years ever, due particularly to the storm of February 2010. The torrents of water and mud in that month swept away people, houses, bridges and vehicles, burying some houses under tons of mud. About 120 people were injured, 48 died and 300 spent days in temporary shelters. Some 600 lost their homes. Locals said the storm was the worst in living memory. Meteorologists said the amount of rainfall that fell in one day exceeded the monthly average. Emergency crews in more than 400 vehicles including bulldozers worked through night and day to clear tons of caked mud, boulders and snapped trees that had piled up in the capital of Funchal and other coastal communities. Parts of downtown Funchal were cordoned off as crew's pumped rainwater and sludge out of a shopping centre's underground car park where officials feared more bodies would be found. Miguel Albuquerque, the mayor of Madeira's capital Funchal, said some areas above the city were particularly badly hit, likening the scene to Dante's Inferno. Many roads in Madeira were partially destroyed or blocked with rocks, trees and mud. It took civil protection services more than 24 hours to reach the village of Curral das Freiras, which had been cut off. Officials said one person had been killed and one was missing there (Machado, L.P. 2010).

The gravity of the crisis was reflected in hotel occupancy figures. On the same day of 20 February, almost all hotels received booking cancellations. In the following days, thousands of cancellations were received in succession, and reduced the arrival of new bookings. Cruise ships scheduled to call in at one of the most popular spots on their itinerary were urged to find alternative destinations because 90 per cent of excursions usually offered on the island were currently impossible and unlikely to be resumed for several weeks.

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Table 1. Natural Disasters in the last 100 years in the Portuguese Islands

Year/Island	Madeira	Azores
2012		Floods - S. Miguel
2010	Floods, Mudslides	
2005		earthquake5.6 on the Richter scale-Faial,Pico, São Jorge
2001,2007,2008	Floods	
1998		Earthquake devastated Faial and Pico Volvcano Eruption Seceta –Terceira / mudslides, floods and torrential downpours
1997		Mudslide in Ribeira Quente, São Miguel. Underwater eruption about 300 m in depth was located in Banco do Mónaco
1988/1989		Earthquake – S. Miguel, Graciosa
1980		Earthquake devastated Terceira São Jorge and Graciosa islands measuring 7 on the Richter Scale
1977/1979/1984	Floods	
1973	Floods	Earthquake -Pico and Faial
1964		Earthquake - São Jorge at 7/8 on the Wood-Neumann scale
1957		Earthquake Faial -submerged volcano dos Capelinhos
1926		Earthquake Faial

Source: Ferreira, Brum. A.Finisterra XL 79, 2005 pp 103-120 and www.cvarg.azores.gov.pt.

Table 2. Madeira island main tourism indicators, between 2000 and 2010

Tourism indicators	2000	2007	2008	2009	2010	2009/2010
Total beds available	21279	29661	30580	31213	31026	-0,6%
Total guests	740826	967134	1013281	1058410	974500	-7,9%
Total Overnights	4972470	5990015	6208144	5496926	5000351	-9%
Average length of stay	6.7	5.3	5.3	5,2	5,1	-1,9%
Bed occupancy	59.7	60.1	60,40	52,10	51,00	-6,8
Revpar	32.03378	35.57	36.76	30,62	28,6	-11,5%
British guests	168012	188843	238616	192232	179100	-6,8%
German guests	136835	174023	164570	182497	165500	-9,3%

Source: Portugal and Madeira Tourism Statistics Bureau, Regional Statistics Bureau.

An analysis of the results presented in Table 1 reveals a clear and worrying decline: Tourist arrivals, the Bed Occupancy Rate and REVPAR are 20% lower than at the beginning of the decade, revenues have fallen by 12,5%, and unemployment in that sector increased by 7% year on year in 2010 (Machado, L.P. 2010).

During the crisis, the media reports on the flooding served to damage the tourism image of Madeira Island. Isolated and localized events that occurred on the island were falsely assumed to have been widely distributed throughout the entire island. The problems were in

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fact contained to the immediate surrounds of the water courses that rose up from being dry or narrow channels bringing water off the mountains. In an attempt to mitigate the impact of the disaster the local government said there had been "no serious incident" involving the tourism sector on the island, but without effect. The withdrawal of tourists resulted in some tour operators immediately stopping the promotion and sale of holidays to Madeira Island, and led to the sudden halt of inbound tourism for the entire year. In some cases Tour Operators gave their clients the opportunity of changing their previously booked holiday to some other destination in their program, with no additional payment even if their choice was more expensive. Many of their clients favored this opportunity. The actions that tour operators are ready to take themselves in order to allow their clients to visit a destination at risk depend greatly on the interest in a particular country. The more important the destination is in their entire business program, the more attached to it they are (Nevenka Cavlek, 2002). This was the case of some tour operators in Madeira, like C&N-Thomas Cook and TUI who, as shareholders in some hotels in the Island, were incentivized to try to return more quickly than to another one without such business interests. Today Madeira Island depends heavily on foreign tour operators which control European tourism flows. These can significantly help the island to return more quickly to international markets. Although the largest European operators have returned, the accommodation capacities that they have taken are very small, and can hardly be compared with the period before the crisis.

Destination Marketing had to be constantly revised as the days went on. Efforts were directed at conveying the message that “Madeira was safe “. Even without experience of such a situation, the government took some measures to try to minimize the effects of a negative message, by providing updates on victims, the weather, the reestablishment or rehabilitation of roads and telecommunications, and the relocation of bases through press releases throughout the day; offering online videos and photos of real testimonies of tourists who were at that time in the Island, conveying an image of safety and return to normal; and immediate invitation to politicians, opinion leaders and tour operators following the idea of "come see for yourself ". These steps were then followed after some days or even weeks by a campaign using celebrities in small spots saying "this year I'm going to Madeira" and the slogan "Madeira- beautiful as ever ", a strengthening of fame and press trips, and the emergence of support groups on social network sites.

The Azores archipelago along its more than five centuries of history has been the scene of a set of natural phenomena with different origins that because of its magnitude and impacts were caused, in general, catastrophic for the population. In historical time, the earthquakes have been the natural factor of greatest danger, sometimes originated real tragedies: that's what happened in S. George in 1522, which killed 20% of the population of the island, and S.Miguel in 1522 that destroyed Miguel Vila Franca do Campo killing almost the entire population (Ferreira, Brum. A.,2005). Due to their geodynamic environment of the Azores Archipelago has unique characteristics in relation to volcanism, seismic and other geological hazards. The geodynamic framework of the Azores, combined with its geological, geochemical, geophysical and frequent manifestations of seismic and volcanic activity puts the Azores Islands at risk. Moreover, the Azores are exposed to events like Tsunami generated from different mechanisms, local or distant, associated with earthquakes and landslides. In this context, studies have identified 12 instances and six events associated with the flooding of coastal areas to rise in floods and / or extreme weather phenomena, which may hypothetically correspond to meteo-tsunamis. It should be noted that despite different

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mechanisms trigger both tsunamis generated by geological factors as the associated weather event may have similar consequences. Although not known reports of tsunamis associated with volcanic activity, the eruptive history of the active volcanoes of the Azores shows the existence of eruptions of high magnitude and high potential tsunamis (Universidade dos Azores-Repositorium).

More recently, in the XX Century, the main seismic crises that affected the Azores are reflected by the "peaks" of seismicity in the years 1927 (Faial), 1958 (Capelinhos, Faial), 1964 (St. George), 1973/74 (Pico), 1980 (Terceira), 1988/89 (São Miguel and Graciosa) and 1998 (Faial). On August 30th, 1926 Faial Island was struck by a strong earthquake, the local population had no memory of such catastrophe. This earthquake caused a large devastation in Horta city and surrounding villages; there are still stories that remember well that there was only one house standing in Flamengos village. Based on descriptions published in newspapers and other press, the intensities felt in each settlement were reclassified using the 1998 Macroseismic European Scale. Therefore, the maximum intensity attributed to the Flamengo village is X, here the percentage of house destruction was 80%, with a damage level degree of 5. To the following villages it was attributed an intensity of IX, Praia do Almoxarife, Angústias, Conceição Matriz, Feteira e Pedro Miguel with a damage level degree ranging from 4 to 5.

Also in Faial Island, the Capelinhos Volcano is one of the most paradigmatic of Volcanology in the world not only for the continuity of their observations but also the originality of its evolutionary processes. That is, the sample was Capelinhos sequential birth and development of the Azores, began as a submarine volcano and ended as a volcano on Earth.

Forjaz, Victor Hugo, 2007, volcanologist at the University of the Azores and the Observatory of the Azores volcanic and geothermal explains that in the morning of September 27, 1957, with the earth shaking continuously, the "whale watchers", a few meters above the Capelinhos Lighthouse, noted the stormy ocean half a mile from the coast, to the sides of West. Frightened, they went down to the lighthouse, lighthouse keepers and warned his fellow whaling in the port of Long. It was not whales, or any other animal - the sea came in and had boiling fetid smells! In early October the ashes were so voluminous that it generated a small island. At the end of this month the island disappeared but the activity is reactivated in early November by repeating the previous phenomenon, and formed a second island!

Until then scientists ignored that in this type eruption, there were large displacements of the seabed. It was the first lesson Capelinhos ...!

At the end of this year, to the astonishment of many onlookers, instead of the ashes, Capelinhos went on to launch lush fountains of molten basalt - an exciting show! In late December he returned to stage. The earth was shaking continuously - the tremor was volcanic phenomena explained by the scientists have since been coming from all over the world. Almost a year later, without warning, the ultimate explosions occurred strombolianas of reddish bagacinas: these began the process of degassing, cooling and erosion that lasted until present day.

After more than 50 years, the Capelinhos became a point of an obligatory visit in the Azores. What destroyed the lava is now a basis for new projects to boost tourism. The volcano is now the symbol of Faial said Victor Hugo Forjaz.

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During that time, the crushed houses and fields under a blanket of ash several feet thick, the only option for many families was emigration, having been generously welcomed in America. Today the volcano of Faial-Capelinhos continues the thought of all the Azores, where ever they are (Mota Amaral, 2007). It is estimated that before the Capelinhos resided on the island of Faial almost 30 thousand people, about double of that currently, existed.

The year 1980 could not have started worse for the Azorean, particularly for the inhabitants of the Terceira, S. Jorge and Graciosa Islands, when on the first day of the year, without notice received an earthquake of 7.2 on the Richter scale. The panic settled and catastrophe has befallen the city. 15,000 buildings were damaged and many other people were displaced. The scale of the disaster facing the balance of the victims was not as dramatic as expected. Still, 71 people lost their lives, and about 400 people were injured.

Figure 2. Vulcão dos Capelinhos – Faial Azores Picture : ATA- Azores.

Tourism is today the most important economic source for the Atlantic Islands, and it directly influences the sustainability of the destinations. This should increase the pressure on managers and planners concerned with tourism to consider the impact of crises and disasters on the industry and develop strategies to deal with the impacts to protect tourism business and society in general. There is a need to understand such incidents and examine strategies that can be used to stop or limit the impacts on a growing and important industry sector. Crisis and disaster management should be a core competency for tourism destination managers (Brent, W. Ritchie, 2004).While there was much discussion about post-crises strategies, the tourism industry, particularly in the Atlantic Islands, would require a recovery program implemented during, rather than after, the crisis. All parties involved needed to extract and retain the lessons learnt from the recent events of 2010 in Madeira Island and the recovery phase, as well as from crises that occurred in other destinations, to be able to develop the strategies and support systems to trigger such programs immediately (Machado L.P, 2010).

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Literature Review

The physical world we live in is subject to an inevitable threat from natural disasters (Brown, 1989). The global sea level (GSL) rise over the 20th century is 1.7 ± 0.5 mm a_1 [IPCC, 2007], which is a combination of ocean volume change associated with thermal expansion (thermosteric) and change in the mass of the ocean due to melting of continental ice and filling of continental reservoirs (eustatic). It is debated, however, which of the two causes: expansion of ocean waters due to warming, or freshwater input from the continents, dominated the GSL rise. Correlations between the regional sea level and regional heat content vary from 0.3 to 0.8, with largest correlation between the heat content and sea level in the Atlantic Ocean.

The sea level contributions calculated from continental glacier volume changes and ice sheet melting in Greenland and Antarctica make up the leading component (47%contribution to sea level trend) compared with 25% contribution from thermal expansion (S. Jevrejeva, J. C. Moore, and A. Grinsted, 2008). The North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) seems to play a role in managing the westerly wind intensity and direction of storm tracks as well as pressure distribution. This explains why the influence from the atmospheric circulation is more clearly seen along eastern coastal areas in the path of strong westerly winds. The results are consistent with modeling results from Wakelin et al. (2003), suggesting that during the winter seasons the wind stress is playing an important role, generating the storm surges, which contribute to the sea level variability

(Jevrejeva S., et al *2005).* High-frequency atmospheric forcing can lead to a low-frequency response in the coupled atmosphere–ocean system; moreover, feedbacks between the ocean and atmosphere may act in concert to amplify perturbations (Dijkstra and Ghil 2005).

If global warming is responsible for the rise in Sea Surface Temperature SST and decreasing Gulf Stream heat transport, then there is a direct link between anthropogenic warming and increasing hurricane risk (Moore et al 2008). Grinsted et al (2007), proposed that this hitherto-unappreciated sea level rise is caused by an imbalance in ocean mass fluxes due to a transient disturbance of the global water cycle, where the radiative forcing initially reduces ocean evaporation. This interpretation is supported by observations of large reductions in both land precipitation and continental discharge after major volcanic eruptions and modeled reductions in terrestrial storage caused by reductions in precipitation. The volcanic impact on the water cycle is comparable in magnitude to that of a large El Nino - La Nina cycle, amounting to ~ 5% of of global land precipitation. The respective roles that heat content, evaporation, and inter Oceanic redistribution of water play in the regional response of sea level need further study.

The nature of the tourism environment is often hazardous, where it is congruent with exotic scenery, unusual experiences or volatile natural settings. In such a landscape, inevitably in one locality or another, or across whole regions, there occur natural events that disrupt or destroy the physical base for tourism, and so threaten the existence of these regional enterprises. In short, the unexpected will at some stage become an eventuality that must affect business viability. Where the tourism environment is damaged, there can be far-reaching consequences, where tourism has evolved as an important contributor to local economic well-being (Leah Cioccio, Ewen J. Michael, 2007).

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The effects of disasters on tourism is an established research field (Beirman, 2002, 2003; Cioccioa and Michael, 2007; Robinson and Jarvie, 2008; Tsai and Chen, 2011). Although there is some research on the effects of natural disasters on tourism that focus on tsunamis (Henderson,Joan C., 2005) and earthquakes (Tsai & Chen, 2010), there is scarce research on floods and subsequent landslides, events that over the past 100 years have affected the Portuguese islands (Yeo & Blong, 2010; Jonkman & Kelman, 2005). Moreover, the research usually concentrates on the managerial strategies and procedures to recover from the effects (Beirman, 2003; Faulkner, 2001), disregarding the demand side, i.e., tourists' behaviour, which is of paramount importance for the future of the destination. It´s important to identify motivations that can assist in the development of post-crisis marketing strategies (Ritchie, 2004).

Beirman (2003), provides a detailed analysis of several major natural and man-made crises and their impact on tourism. For tourism organizations and destinations, these crises have become increasingly important, because of the intense media coverage, and the preparedness of tourism consumers to avoid destinations they perceive as unsafe (Grainger J. and Crouch I., 2006).

Perceived risk was seen as one of the costs of choice and since the concept of risk was introduced in economics in the 1920s (Knight, 1948), it has been successfully used in theories of decision making in economics, finance, and the decision sciences (Dowling and Staelin, 1994). Since 2005, there has been renewed interest in the construct in tourism studies as statistics from around the world show that higher perceived risk is associated with decreased visitation (Sonmez, Apostolopoulos and Tarlow, 1999). Indeed, Sonmez (1998) argued that destinations are evaluated according to their safety and risk factors with regard to terrorism and political problems. Hence media coverage of disasters or crisis are of particular concern to destinations in which the negative event occurs, as well as to other destinations that may be connected in some way in the publics' mind to the crisis elsewhere, and even to destinations which may benefit from the adversity.

In consequence of this situation, many destinations are seen as dangerous and unsafe, places to avoid. Sometimes, the authorities of origin countries recommend to tourists to not travel to certain places where problems occur, aggravating the negative image that the tourists may have of these destinations. Several studies analyze crisis dynamics and processes and propose planning and management models. Crisis can evolve at great speed in a chaotic manner, but are not always identifiable in advance. Recommendations on how to deal with these problems may be too general or too attached to one or to a particular case (Machado, L.P. 2011).

When a crisis erupts, hotels, flights and other services reserved are cancelled within a matter of hours, along with scheduled sporting events, cultural events and conferences; tourists and investors disappear and ask questions about the future of the place. While a place's positive image and reputation are built up over a period of years, it might take only a few moments to reach a state of crisis that could seriously damage the place's image, its tourism industry and the entire economy (Avraham E., Ketter E., 2008).

The underlying problem of predicting the unpredictable means that managers are not always fully prepared and must respond intuitively to unfamiliar and confused situations as they unfold in a random manner. Handling crisis is an especial challenge for those at work in tourism industry, which involves the movement and accommodation of people. Costumers face personal inconvenience when things go wrong and their physical well-being and lives, as

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well as those of staff, may be threatened in the most severe conditions of crisis (Henderson, Joan C. 2005).

Avraham and Ketter (2008) propose a holistic multi-step model to restore a place's positive image. The first step should be the preliminary analyses of the crisis, audience and place characteristics (CAP analysis), which include examining the crisis, the place where the crisis occurred and singling out the target audience for whom the place tries to alter its image. After that, place marketers should define the campaign's goals and the timing of the launch of the campaign. Next is the stage of choosing the most suitable marketing strategy or mix strategies, as indicated by the preliminary analysis and the campaign objectives and timing. The choice can be among three groups of media strategies —those that focus on the source of the message, those that focus on the message itself and those that focus on the target audience (SAM strategies: source, audience and message).The authors analyse also the use of SAM strategies adopted by various places in order to combat their unsafe images. Source strategies consist in trying to bypass the source of negative information by using two major strategies: "Come see for yourself" that the place is safe; and using celebrities as an alternative source of information. Message Strategies, rather than looking at the source, focuses on the message itself, following different ideas:

1. ignoring or limiting the crisis, pretending that nothing bad has happened or that the damage is minor;
2. "fencing off" the crisis, restricting the problems to certain areas;
3. Multiple facets and softening the "hard" image, adding new positive elements to their image;
4. Reducing the scale of the crisis, some places choose to acknowledge a crisis while reducing its scale to minimize the damage to their image;
5. Tackling the reasons for the place´s lack of safety, addressing and correcting the reasons that caused the negative image in the first place;
6. Hosting spotlight sport and cultural events, allowing the host place to promote certain chosen images that can be used to improve an unsafe image, and making available positive alternatives to draw the media away from the negative portrayal of a place.;
7. Promoting the place´s "safe" image by using films, helping to promote a place following the idea that " if actors are able to live and shoot movies in the place peacefully, it will bolster the efforts to promote a destination";
8. Delivering a counter-message to the unsafe image, by adopting advertising campaigns with opposite images to their current one;
9. Spinning the "unsafe" image into assets, recognizing a negative factor responsible for the unsafe image and spin it into a positive trait;
10. Ridicule the stereotype of "unsafe" place, showing how ridiculous it is and thereby nullify it.

Finally the Audience Strategies, that can be divided into two:

1. Patriotism and Nationalism, addressing residents directly and asking them to demonstrate those feelings and

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2. Changing the target audience, as usually the place image is formed by different actors whose impact could be negative for one target audience and positive for another.

The industry within the country can manage the crisis efficiently only by being prepared to take some actions in advance. Planning is an essential element of control. Without it, an organization is at the mercy of events (Barton 1994). The recovery of this industry from a crisis is far more complicated than for others. As proven in practice and stressed by Sonmez, Apostolopoulos and Tarlow (1999), although tourism is quite adept at using established marketing principles, setbacks due to negative occurrences call for something more than traditional efforts. The industry must conduct recovery marketing that is integrated fully with crisis management activities. Its complexity requires a proactive role from all tourism officials in the public and private management of marketing activities.

Very strong partnership and coordinated work among the government, national tourism organizations, foreign tour operators, local travel organizers, and local hospitality officials are essential. Each needs to participate to an important degree in order to secure the fulfillment of several important actions (Nevenka Cavlek,2002). These include successful rebuilding of the destination image, overcoming any adverse publicity resulting from the crisis, short-term restoration and long-term reconstruction of the damaged tourism facilities and infrastructure, and effective management of media coverage (Drabek, 2000).

Concerning, what happened on February 2010 in Madeira Island, Alberto Vieria (2010) wrote that some people said that was a flood, others speak in trunk water and meteorologists explain what happened as an exceptional situation and unpredictable with the means available on the island. But for us locals we are facing a phenomenon typical of alluvial, which unfortunately has been a constant in the historical process of Madeira.

History has revealed several situations similar to this, defined as alluvium, which are registered with frequency since the seventeenth century. Among the most disastrous signal the “Aluviões” of 1803 and this year 2010 where the most severe. In 1803, beyond the scene of destruction of Funchal and in almost all parishes of the island mark by about a thousand deadly victims, while at present the damage and destruction were also high, but hopefully, lower in the number of fatalities.

There is high confidence that the most immediate and more significant consequences of climate change are likely to be changes in the nature of extreme wind event´s to its special geographic environment also makes the area prone to frequent natural disasters.

Relatively to the Azores, João Luiz Gaspar (2011) said "The seismicity happens every day in all areas, especially on islands like ours, that does not mean we will have more or less derived from the intensity of earthquakes earthquake in Japan," he says. João Luís Gaspar considers that the Azorean should be drawn from this unfortunate experience just how to react to disasters such as Japan has responded, considering it necessary to rethink the model of planning for the Azores, "because it is that can save lives, all rest is speculation."

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CONCLUSION

Although the literature on tourism's sustainability often projects it as a process that demands professional management and planning, it has only recently addressed the issues of preparing for risks, crises and disasters (Faulkner, 2001; Miller & Ritchie, 2003). In recent years, analysts have focused on building a range of strategic responses to enhance the ability of communities and businesses to manage and recover from natural disasters. The experience from each new crisis adds further to the process of hazard management. The results in tourism research have expanded the community's collective capacity to respond to such circumstances, but little consideration has been given to how small firms, which are the mainstay of the industry, actually deal with the impacts of a regional catastrophe (Leah Cioccio, Ewen J. Michael, 2007). Looking at the small size of the Atlantic islands and the Portuguese Tourism Economy which is composed mainly of small and medium enterprises, is extremely important to ensure their survival to avoid bankruptcy resulting from a crisis caused by a natural disaster, because they represent more than 99% of the Portuguese business and are responsible for more than 2 million jobs (74.4%), and arguably the engine of national economy and the main source of our exports. Many countries, particularly the small islands, are currently ill-equipped to handle their existing environmental problems. If in 2010 the island of Madeira was equipped with meteorological forecasting tools technologically advanced, no one could stooped the floods, but could at least minimize its effects because it would be time to warn people that was expected. Many of the current problems will be exacerbated by the predicted impacts of global climatic change. It is there incumbent upon the industrial nations, which are largely responsible for the current global crisis, to assist, both financially and technically those small islands which may well suffer dramatic impacts as consequence of a problem to which they themselves have not contributed. Furthermore it is imperative that programmes of assistance should be individually tailored to the countries concerned and that they should be designed to enhance or establish general capabilities inthe field of environmental planning and management (Pernetta, J. C., 1989).

This chapter analysed the determinants of visiting a tourism destination following a natural disaster. We based our study on the floods and subsequent landslides that occurred in Madeira in February 2010, and Earthquake devastated Faial and Pico such as the Terceira / mudslides, floods and torrential downpours in 1998.

From our findings, it seems clear that tourism strategies in the wake of a disaster should focus on the rapid repair of the facilities damaged and the restoration of high-quality destination attributes, and on comfort and the positive image, assuaging tourists' doubts and fears by projecting the positive image and assets of the destination. Targeting nationalities that have a significant market impact should also be included in a policy to attract desired types of tourists. Thus, by embracing and acting on these results, there is a clear opportunity to refine policies to help increase post-disaster visitation, particularly among sympathetic and supportive potential consumers, since it is they who are also most disposed statistically to spending higher amounts during their stay.

In addition, it might be of potential value for tour operators to have a deeper insight into the variables that shape the decisions and actions of post-disaster tourists. With a greater awareness of what these consumers require from a vacation, operators and organisations can focus on those statistically significant variables determined in the model when targeting their

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potential customers. The variables that increase visitation should also be the focus of future promotional campaigns. Similarly, the variables that decrease the repeat visitation should be controlled and addressed in order to minimise their potential effect.

How does this chapter compare with previous research? While this chapter supports some traditional results such as familiarity, security (Hong et al., 2009) and satisfaction (Opperman, 2000), it does not validate the insignificance of price/expenditure (Alegre & Juaneda, 2006) and supports the idea that correlation exists among distinct types of tourists in a post-disaster context. This correlation has implications for the setting up of managerial practices to increase visitation, since it results in different managerial practices. In the present case, hospitality and satisfaction visitation are correlated and should be the focus of a targeting strategy, together with all the other exogenous variables that affect visitation in a post-disaster context. This result implies that each destination has its own specificity, which thus justifies the need for more studies on disaster-stricken tourist destinations and their recovery.

Perhaps most importantly, it may take decades for nations to decide how they intend to respond. Therefore small states or islands should begin today to identify implications and response strategies (Pernetta, J. C., 1989).

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Chapter 7

INFORMATION TECHNOLOGY AND SIMULATION IN DISASTER MANAGEMENT

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ABSTRACT

For the past century, information and computing technology has continued to evolve at an accelerating pace. Its applications to medicine, particularly disaster medicine, have increased dramatically in recent years. Its progress has advanced the way in which patient data are collected and disseminated, as well as how knowledge gained from experience in dealing with mass casualty events can be rapidly disseminated, critically evaluated, and applied to future events by healthcare providers. In this chapter, we provide a brief history of information technology (IT) and the related field of bioinformatics in the context of their applicability to disaster planning and response. We describe both "real-world" and virtual approaches to the problem of optimizing the smooth, practiced, and most efficient delivery of healthcare resources in times of crisis. Real-world approaches include drills and the use of advanced audiovisual and communications technology to extend the reach of the disaster practitioner's eyes, ears, and hands. Equally important are the *in silico* approaches including end user-friendly disaster scenario software packages, bioinformatics treatment of complex medical data sets to find and recognize patterns as early warning signs for poor patient outcomes, and queueing theory for the enhancement of delivery of limited resources to the disaster surge population. Overall, we will describe how these IT tools for disaster professionals can be incorporated into more conventional planning and response.

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I. INTRODUCTION

The development of the electronic computing machine, or computer, was undoubtedly one of the most significant events of the twentieth century. Its advent forever changed the way humans would deal with data and information in fields as broad-ranging as finance, transportation, entertainment, defense, science, engineering, and medicine. In the late 1950s, the concept of information technology (IT) emerged as a way of describing the use of computers for the management of complex systems. [1,2] The concept grew over the next five decades so that by the first decade of the 21st century, IT encompassed essentially all uses of computing technology. IT began to be integrated into healthcare delivery systems of the industrialized nations in the 1960s and 1970s, [3] and more recently, has been predicted to radically change the way biomedical research as well as patient care are conducted in the new millennium. [4] The purpose of this chapter is to present a concise overview of some of the relevant applications of information technology to disaster medicine. We will describe the integration of IT with real-world disaster drills, the applications of bioinformatics to disaster medicine, and the use of queueing theory and computer simulations to model patient flows and the response of the healthcare delivery system to them in the context of a mass casualty event occurring as a result of a disaster. An early definition of bioinformatics was the use of information technology to organize and analyze the extensive datasets available from modern biology research. [5] More recently, this definition has been extended to the application of computing technology to medicine in general, [6] and disaster medicine in particular. [7] For the latter, descriptions in the literature using the original spirit of the term have been limited to postmortem identification of nonsurvivors. [7,8] However, if a more inclusive definition is taken to include all uses of information technology as they pertain to disaster response, there is a significantly broader range of applications. IT has been described to have an incredible potential to integrate disaster response at the levels of information transfer to caregivers about the scope and details of the mass casualty event itself, logistics optimization for the efficient delivery of care and supporting resources, as well as patient identification and tracking, though this level of integration has yet to be realized. [9]

Despite this, a number of technologies that are already available, such as mobile phones and telemedicine, can contribute to mass casualty event response and disseminate information from specialty centers to more distant affected locales. [10] We shall review some of the applications of IT to disaster response in further detail below.

A related issue that bridges the real-world to the virtual one is the far-reaching domain of simulation. In this chapter, we shall consider both simulations that are set squarely in the real-world, as well as those that exist entirely in computer memory or even as a mathematical abstraction. These approaches can be thought of as forming a continuum spanning real-world drills, virtual reality simulations, and abstract models that nevertheless represent events in concrete reality.

In real-world drills, simulated survivors and disaster response personnel act out mock scenarios to test the response of the healthcare delivery system to a mass casualty event. [11] Virtual reality simulations employ interactive audiovisual immersion technology to bring the mass casualty event to the provider, and can also be employed for skills assessment. [12] Lastly, computer and mathematical simulations can predict the behavior of complicated

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systems in response to various conditions, such as the healthcare delivery system in response to a disaster. [13]

All these approaches can help to distribute information relevant to appropriate disaster response to the broader healthcare community. Modern technological civilization has connected humans around the globe and vastly expanded their awareness of and interdependence upon one another, so much so that the old maxim of a “small world” has been transformed into a field of rigorous academic inquiry. [14]

Therefore, though disasters are in some sense rare for any given locale, they have actually been observed to be increasing in incidence worldwide, [15] possibly due in part to the influence of more severe weather resulting from climate change. [16] The paradox of simultaneous rarity and increasing frequency of disasters therefore, confront the non-specialist healthcare provider with a problem of difficulty in maintaining readiness, given the scarcity of experience he or she likely has with them, combined with the need to respond adequately in the unlikely but always possible mass casualty event. The power of information technology can be harnessed toward this goal, in that the information needed in a disaster situation can be rapidly disseminated with modern communications methods. Moreover, the simulation and bioinformatics approaches alluded to above, and described in detail in this chapter, can bring the disaster to the provider in various degrees of virtual or true reality, thereby allowing him or her to be prepared to respond in an efficient and trained manner even in the absence of any previous real-world disaster experience.

II. Real-World Approaches

Disaster Exercises

Disaster planners are accountable for preparing their hospitals for disasters. Additionally, The Joint Commission (TJC) requires accredited hospitals to conduct two disaster drills each year, one of which needs to include people who act as “live” victims. [17]

Currently, an all-hazards approach is recommended and typically used to aid in understanding the types of resources that will be needed. Similarly, planners are responsible for supporting their staff’s awareness, knowledge, and training for how they will respond in the event of a disaster. The reason for conducting annual exercises to prepare hospitals for disasters is based on an understanding that organizations and people will learn through a process improvement cycle, e.g., plan, do, check, act, and thus be able to remedy issues that arise during a simulated event with the goal that those issues will be addressed prior to an actual event.

Process and Exercise Types

Identifying an appropriate exercise begins with an understanding of an organization’s environmental hazards, internal risks, and capabilities. There are several types of assessment tools that can be used in identifying greatest risks, but most are based on the probability of the event and the impact or severity of disruption. Those events that are likely to occur and are

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anticipated to create the greatest disruption are events for which organizations need to prepare and practice response. There are several types of exercises that can be used to support a coordinated response, and they can be categorized as discussion-based exercises or operations-based exercises. Discussion-based exercises are used to familiarize participants with plans, processes, policies, and agreements, and are used to orient participants, create dialog, or work to develop or assess plans, policies, or procedures. Operations-based exercises usually involve more resources and test the operation's environment to support identification of resource gaps, clarify roles and responsibilities, and validate theeffectiveness of plans, policies, and procedures. [18]

Operations-based exercises typically engage a larger number of participants and are increasingly being assessed for how participants will best be able to learn and acquire proper skills, knowledge, attitudes, and awareness.[19] One type of operations-based exercise is a drill. According to the California Hospital Association, a drill is a coordinated, supervised activity usually employed to test a single, specific operation or function within a single entity. [18] For hospitals, an exercise may include conducting a drill to test the facility's ability to respond to a sudden increase in the number of patients that overwhelms the current resources (surge). These types of exercises are sometimes tested with paper patients or simulated people arriving at a facility. A drill can also use "live" victims who are instructed on how to act based on their injury type and can be moulage*d* (disaster make-up) to simulate injuries. Another method is to include simulation manikins (Sim-Man®) that are designed to respond in the manner that a human would respond if a healthcare provider performed medical interventions.

It is arguable that a drill is more beneficial if a hospital uses live victims or undertakes a simulation. The effectiveness of live actors is questionable with factors including the amount of time invested in coaching actors and their own investment in the drill. [20] An important aspect to creating a more realistic environment for preparedness is to enlist actors to serve as victims and make them consistent with injuries that would result from the drill scenario. This requires a review of the epidemiology of injuries for different types of disasters.

Additionally, victims should be moulaged to create the appearance of realistic injuries. [21] Since children are not included in many preparedness plans and exercises, a drill becomes a good opportunity for hospitals to practice with children. Using children as live victims allows a hospital to test their clinical capabilities as well as their infrastructure and processes for the safety and security of children.

Drill Effectiveness

Although drills are required and theoretically can be argued to support improved disaster response, there is limited evidence on how drills actually support an improved response. A literature review in 2004 suggested that disaster drills were helpful in familiarization of staff with disaster procedures, identification of problems, and allowed lessons learned to be employed. [22] Additionally, individual studies are increasingly documenting that drills and simulation improve an individual's performance in specific disaster response tasks. [20,23-26]

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Table 1. Emergency Preparedness Exercises [18]

	Type	Description
Discussion-based exercises	Seminar	Informal discussion, designed to orient participants to new or updated plans, policies, or procedures (e.g., a seminar to review a new Evacuation Standard Operating Procedure).
	Workshop	A workshop resembles a seminar, but is employed to build specific products, such as a draft plan or policy (e.g., a Training and Exercise Plan Workshop is used to develop a Multi-year Training and Exercise Plan).
	Tabletop Exercise (TTX)	A tabletop exercise involves key personnel discussing simulated scenarios in an informal setting. TTXs can be used to assess plans, policies, and procedures.
	Games	A game is a simulation of operations that often involves two or more teams, usually in a competitive environment, using rules, data, and procedures designed to depict an actual or assumed real-life situation.
Operations-based Exercises	Drill	A drill is a coordinated, supervised activity usually employed to test a single, specific operation or function within a single entity (e.g., a fire department conducts a decontamination drill).
	Functional Exercise (FE)	A functional exercise examines and/or validates the coordination, command, and control between various multi-agency coordination centers (e.g., emergency operation center, joint field office, etc.). A functional exercise does not involve any “boots on the ground” (i.e., first responders or emergency officials responding to an incident in real time).
	Full-Scale exercise (FSE)	A full-scale exercise is a multi-agency, multi-jurisdictional, multi-discipline exercise involving functional (e.g., joint field office, emergency operation centers, etc.) and “boots on the ground” response (e.g., firefighters decontaminating mock victims).

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Virtual Reality

Simulated exercises involving virtual reality (VR) environments may provide different advantages compared to live victim and Sim-Man® drills. [24] As of 2005, VR environments were used in 6% of the 198 federal training courses on terrorism. [24] VR environments can alsodo provide an exercise and training opportunity for emergency and disaster preparedness. One study reviewing effectiveness of triage ability indicated that participants in a VR environment improved their ability to triage accurately. [24] Immersive simulation through a cave automatic virtual environment (CAVE) is another technique used to improve learner performance. This environment creates an illusion of a three-dimensional environment. [23] Simulation environments are more likely to be used in situations to train select groups of individuals since access to these environments remains limited.

Training

Another component of preparedness involves training healthcare workers (HCW) in disaster skills including triage (the ability to appropriately "sort" patients into level of medical response needed), structure of disaster response, and roles and communication during a disaster response. Awareness of the issues that arise during a disaster and how to respond effectively to them is a critical piece of understanding. However, there is mixed evidence regarding whether training interventions for HCW supports improved measures in knowledge and skills for disaster response and the evidence is insufficient. [22] Regardless, there are national, regional, and local efforts focused on training healthcare providers.

Technological Tools to Increase Ability to Respond

Technology enables an increasing ability to support training for high impact but infrequent events such as disasters. Additionally, technology supports the ability to expand a provider's reach into geographic areas that may not otherwise be feasible. Under normal conditions, there are areas that are geographically isolated and/or lack critical medical resources. In a disaster, areas that are typically integrated may become geographically isolated due to damaged roadway infrastructure. An essential resource in disasters is the appropriate medical sub-specialists required to treat traumatic injuries. These subspecialists may include general surgeons, plastic surgeons, neurosurgeons, and orthopedic surgeons and the associated pediatric surgical specialties. These physician resources are limited in everyday situations. A unique method of expanding the reach of these limited subspecialties includes use of the InTouch Health® RP-7 robot.

The RP-7® is a mobile robotic platform that includes two-way video, enhanced audio capabilities, and the ability to connect to medical devices such as electronic stethoscopes, otoscopes, and ultrasound. [27] The technology was created by InTouch Health, a Santa Barbara, CA-based company. In a situation where roadways may be disrupted, but an Internet connection is available, this technology can be employed to provide appropriate consultation. Initially developed to provide quick medical assessment and consultation for stroke and STEMI patients, Children's Hospital Los Angeles explored using this technology for disaster

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training and response efforts. The RP-7 requires that the robot be placed at the location of interest and that the lead medical specialist have the appropriate laptop and software to log into the robot to control the robot's movement and connect with the consultation-receiving organization. The robot can be physically moved by an operator in the field, but is also controllable by the subspecialist remotely via a joystick controller apparatus. In May 2008, the Trauma Program at Children's Hospital Los Angeles used these robots to provide remote tele-triage and consultation for pediatric disaster drill victims. It was demonstrated that the robots could function independently, but also could be controlled by the surgeon or other practitioner to go to the bedside of trauma patients in the field. The robots work wirelessly and are highly mobile, providing two-way audiovisual connectivity, the ability to assess patients, and speak with them. They could also perform stethoscopy and provide high-definition optical examination. Since not all hospitals are accustomed to caring for children, but may have children arrivingtoarriving at their facility, this type of technology provides an opportunity to ensure that children receive the appropriate care. Tele-triage was used in two disaster drill scenarios at two separate locations. The robots were deployed prior to the drill and technical connection and infrastructure were tested prior to the drill. Although successful in connecting and providing the ability to consult with outside providers, observers of the drill noted that the full potential use was not maximized. [28] Educating providers on the benefits of technology and ensuring that they are aware of and know how to use it is a critical aspect in effectively implementing new technology. Also, a significant caveat to this and related technologies is the potential loss of communications infrastructure after a significant mass casualty event. With this in mind, this technology nevertheless offers the medical subspecialist a way to see the patient and assess his/her appearance and vital signs remotely during a disaster.

III. MATHEMATICAL AND *IN SILICO* APPROACHES

Pediatric Emergency Decision Support Software (PEDSS)

The development of the PEDSS application was in response to current recommendations that advocated for a more comprehensive approach to hospital-based preparedness for pediatric disaster victims. The tool was developed by the University of Southern California Information Sciences Institute (ISI) and Children's Hospital Los Angeles Pediatric Disaster Resource and Training Center to help medical service providers more effectively plan for, train for, and respond to serious incidents and disasters affecting children. Currently, PEDSS addresses pediatric injuries resulting from an earthquake; however, there are plans to incorporate other types of natural disasters into the application. The software has previously been described in detail elsewhere. [29] We provide an overview here.

PEDSS Process

PEDSS was designed and implemented to support the tasks for a hospital or healthcare center emergency planner. PEDSS guides users at a facility through collecting and utilizing the critical information needed for a just-in-time disaster plan. PEDSS software is designed to embody best disaster preparation practice knowledge, gather information about the specifics

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of a medical facility's situation, and apply the knowledge to the situation to produce viable options.

PEDSS determines the number of children in each of the predefined seven age groups in the geographic area of interest. PEDSS then estimates the number of children that will be injured in an earthquake based on estimates produced by the Great California ShakeOut earthquake scenario. [30] PEDSS then determines the distribution of earthquake-related injuries and the number of children suffering from each injury type, based on previous research. [21]

Software

PEDSS presents a user with a set of tabs that enable the user to switch between different components, one at a time. Each tab encompasses a specific topic. The Context tab is the first tab and is used to collect contextual information, such as demographics, environmental context, regional situation, and type of event.

The Capabilities tab prompts a user to enter emergency department capabilities, such as facilities, personnel, and surge capacity per injury type. This information is necessary to ensure that the preparedness plan accurately reflects the number of personnel available to administer the required supplies and pharmaceuticals. The Load tab determines the expected health facility load by number of children per group per injury type. The Supplies tab determines the required medical supplies based on the estimated number of children per injury type and available resources. PEDSS also determines shortages. It identifies what needs to be restocked based on the current inventory and calculates the amount/dosage of each pharmaceutical. The Summary tab displays a summary of recommendations for supplies. Figure 1 provides an example of the information included in this tab. The software requires registration and can be accessed for free at http://pedss.isi.edu/pedss/. Overall, the current PEDSS software [29] allows hospital and emergency planners to determine needed supplies for pediatric victims of an earthquake. Future plans include expansion into the nature and specificity of demographic data as well as disaster event, thus allowing planners to more precisely adjust factors that determine patient load (Figure 1).

Queueing Theory

The discipline of queueing theory was inaugurated by a landmark paper in 1909 by Agner Krarup Erlang, a Danish engineer who developed a probabilistic means of estimating the customer loads on a telephone network. [31] Since its inception, the field has mushroomed into a multidisciplinary science that seeks in general to make predictions about the behavior of a system in which there are "customers" (which can include patients or disaster patients) who wait in line for a limited number of "servers" [32] (which in the context of disaster medicine, can entail emergency medical treatment, supplies, or transportation to a hospital, for example) by making some (often deceptively simple) assumptions and employing the tools of mathematical probability theory.

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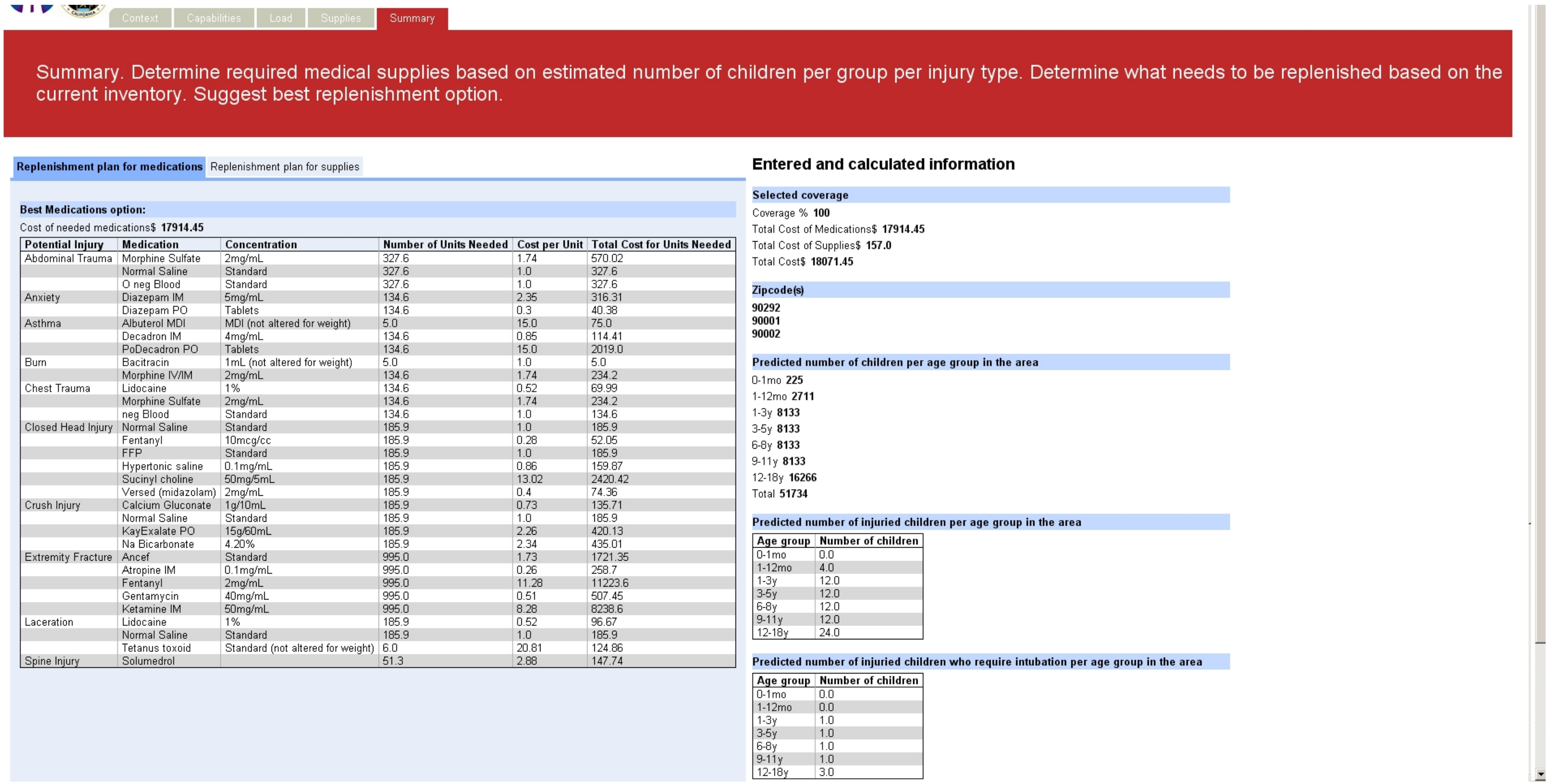

Context | Capabilities | Load | Supplies | Summary

Summary. Determine required medical supplies based on estimated number of children per group per injury type. Determine what needs to be replenished based on the current inventory. Suggest best replenishment option.

Replenishment plan for medications | Replenishment plan for supplies

Best Medications option:

Cost of needed medications$ **17914.45**

Potential Injury	Medication	Concentration	Number of Units Needed	Cost per Unit	Total Cost for Units Needed
Abdominal Trauma	Morphine Sulfate	2mg/mL	327.6	1.74	570.02
	Normal Saline	Standard	327.6	1.0	327.6
	O neg Blood	Standard	327.6	1.0	327.6
Anxiety	Diazepam IM	5mg/mL	134.6	2.35	316.31
	Diazepam PO	Tablets	134.6	0.3	40.38
Asthma	Albuterol MDI	MDI (not altered for weight)	5.0	15.0	75.0
	Decadron IM	4mg/mL	134.6	0.85	114.41
	PoDecadron PO	Tablets	134.6	15.0	2019.0
Burn	Bacitracin	1mL (not altered for weight)	5.0	1.0	5.0
	Morphine IV/IM	2mg/mL	134.6	1.74	234.2
Chest Trauma	Lidocaine	1%	134.6	0.52	69.99
	Morphine Sulfate	2mg/mL	134.6	1.74	234.2
	neg Blood	Standard	134.6	1.0	134.6
Closed Head Injury	Normal Saline	Standard	185.9	1.0	185.9
	Fentanyl	10mcg/cc	185.9	0.28	52.05
	FFP	Standard	185.9	1.0	185.9
	Hypertonic saline	0.1mg/mL	185.9	0.86	159.87
	Sucinyl choline	50mg/5mL	185.9	13.02	2420.42
	Versed (midazolam)	2mg/mL	185.9	0.4	74.36
Crush Injury	Calcium Gluconate	1g/10mL	185.9	0.73	135.71
	Normal Saline	Standard	185.9	1.0	185.9
	KayExalate PO	15g/60mL	185.9	2.26	420.13
	Na Bicarbonate	4.20%	185.9	2.34	435.01
Extremity Fracture	Ancef	Standard	995.0	1.73	1721.35
	Atropine IM	0.1mg/mL	995.0	0.26	258.7
	Fentanyl	2mg/mL	995.0	11.28	11223.6
	Gentamycin	40mg/mL	995.0	0.51	507.45
	Ketamine IM	50mg/mL	995.0	8.28	8238.6
Laceration	Lidocaine	1%	185.9	0.52	96.67
	Normal Saline	Standard	185.9	1.0	185.9
	Tetanus toxoid	Standard (not altered for weight)	6.0	20.81	124.86
Spine Injury	Solumedrol		51.3	2.88	147.74

Entered and calculated information

Selected coverage

Coverage % **100**
Total Cost of Medications$ **17914.45**
Total Cost of Supplies$ **157.0**
Total Cost$ **18071.45**

Zipcode(s)

90292
90001
90002

Predicted number of children per age group in the area

0-1mo **225**
1-12mo **2711**
1-3y **8133**
3-5y **8133**
6-8y **8133**
9-11y **8133**
12-18y **16266**
Total **51734**

Predicted number of injuried children per age group in the area

Age group	Number of children
0-1mo	0.0
1-12mo	4.0
1-3y	12.0
3-5y	12.0
6-8y	12.0
9-11y	12.0
12-18y	24.0

Predicted number of injuried children who require intubation per age group in the area

Age group	Number of children
0-1mo	0.0
1-12mo	0.0
1-3y	1.0
3-5y	1.0
6-8y	1.0
9-11y	1.0
12-18y	3.0

Figure 1. Summary tab display of PEDSS software.

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For a given mass casualty event, a queueing theory model can be used to investigate the allocation of resources or treatment to disaster survivors to find the optimal or maximally efficient means to do so. Depending on the complexity of the model, it can be solved analytically with pencil and paper, [33] or may require the use of numerical computer simulation for its implementation.

The occurrence of real-life disasters is random, in that it cannot be predicted even in principle when one will occur, regardless of the amount of data available. Moreover, because of this randomness, the fact that there were no disasters yesterday does not allow us to state that there is a greater probability of one happening today. In other words, the chance of a disaster happening is independent of when one looks, except when it happens, at which time its probability is unity. Disasters may therefore be said to have the Markov property: the present condition of disaster or no-disaster is independent of past events, or “memoryless.” [34]

Phenomena with this behavior can be well-described by stochastic simulations, which assume that a given event will occur over a set time interval with an associated probability per unit time. Note that this theoretical behavior can be used to describe not only the disaster itself, but also the frequency with which survivors will arrive or “join the queue” for triage and treatment by the healthcare delivery system after the mass casualty event.

Despite the random nature of disaster occurrences as well as the arrival of patients for evaluation and treatment in the aftermath, the behavior or flow of patients and healthcare resources can often be approximated in a non-random fashion. Specifically, one can construct deterministic models, or in queueing theory parlance, *fluid models*, that describe the flow of patients through the system as a continuous fluid, neglecting the fact that the number of patients waiting or being treated can only change in a discrete fashion of plus or minus one patient.

A classic description of this approach can be found in G. F. Newell’s book. [35] In fluid models, the system is represented by a system of ordinary [36] or partial differential equations [37] that take into account such factors as conservation laws (for disaster medicine, the total sum of patients in the system is constant, though some survivors may die during the simulation; the quantity of supplies available in the system is limited unless there is an external source of said supplies, etc.); average rates (of arrival, mortality, and treatment per unit time); transport and boundary conditions (patients may be evacuated from or brought to the system, geographical barriers may prevent egress, etc.); and other physical factors and limitations added to the model.

Both stochastic and deterministic approaches have been used to model disaster scenarios. For example, Hirshberg *et al*. employed Monte Carlo simulation to explore how total casualty load and how accurately patients are triaged after a bombing incident would affect how long it would take for trauma team capacity to become saturated, and found that this occurred more rapidly if survivors were inaccurately triaged (“overtriage”). [38] These authors had previously shown using a similar approach and disaster scenario that overtriage also decreases the surge capacity of a trauma center. [39]

On the other hand, a population kinetics or compartment model approach has also been employed successfully. Brandeau’s group applied a compartment model to the problem of a hypothetical anthrax bioterrorism attack, and found that while constructing large stores of medical supplies would not have much of an effect on mortality in a community, a targeted approach that focused upon maintenance of significant quantities of prophylactic oral

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antibiotics and the ability to dispense them to the exposed survivors could significantly reduce mortality from the event. [40]

We recently used a population kinetics approach to model a mass casualty event in the presence and absence of a pediatric trauma center (PTC) with varying efficiency in triage and treatment, and found that the pediatric mortality rate would be significantly decreased if the PTC were as efficient as an adult trauma center available to treat both pediatric and adult survivors (Figure 2). [41]

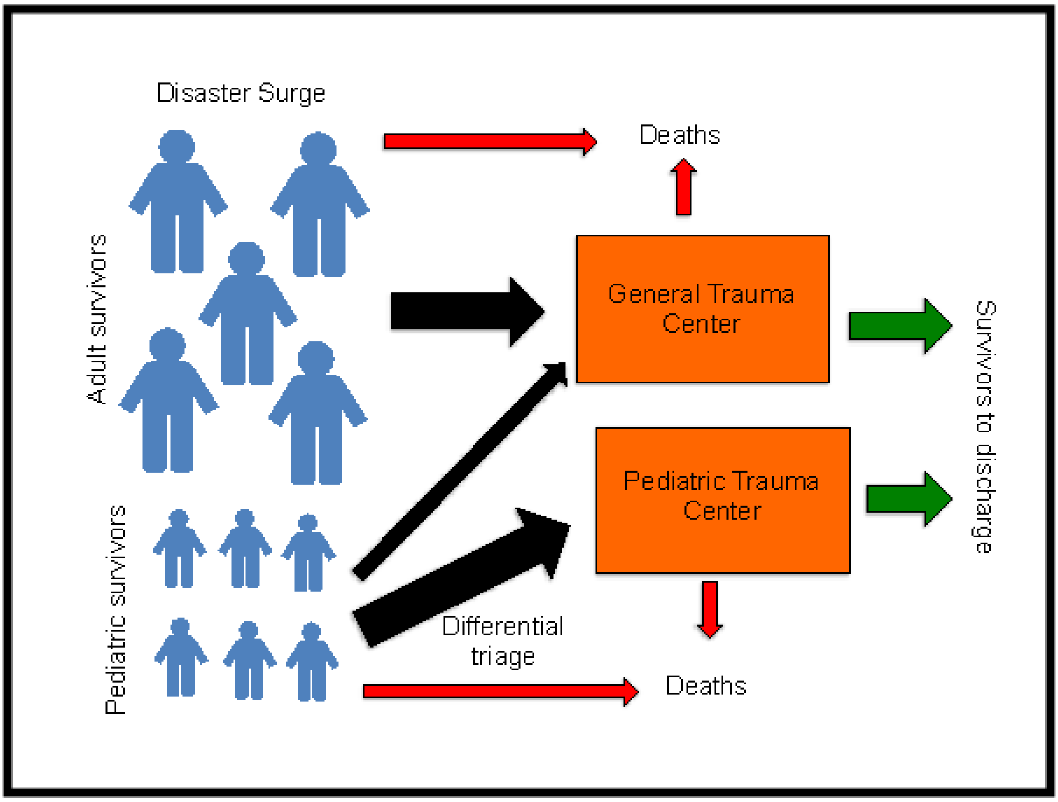

Figure 2. A pediatric trauma center can unload part of the disaster surge burden from a general center, resulting in decreased mortality and faster treatment of the entire survivor cohort.

Wu and Cowling recently reviewed the application of both stochastic and deterministic mathematical modeling approaches to the problem of influenza pandemics. [42] Taken together, these recent studies suggest that the application of queueing theory to disaster medicine can contribute significantly to planning and triage efforts.

Bioinformatics - The Virtual Pediatric Intensive Care Unit

Pediatric intensive care medicine combines aspects of the specialties of anesthesiology, pediatrics, pulmonology, pediatric surgery, cardiothoracic surgery, and cardiology into one integrated whole to provide care for the most severely ill children. Children who have

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suffered trauma, devastating medical illnesses, or are recovering from surgery all benefit from the practice of critical care medicine.

The urgency and the emotional environment of critical illness in children have made prospective data gathering and research in critical care difficult and mostly nonexistent. In addition, no single intensivist sees sufficiently large numbers of patients with any particular illness to prospectively determine the best medical practice. [43]

The Virtual Pediatric Intensive Care Unit (VPICU) was founded at Children's Hospital Los Angeles in 1997 by a committed group of pediatric intensivists dedicated to supporting and enhancing the care of critically ill children and their families by taking advantage of burgeoning information and communication technologies to further develop and share knowledge of pediatric critical care medicine.[[44] The vision of the VPICU is:

> We will create a common information space for the international community of care givers providing critical care for children. Every critically ill child will have access to the Virtual PICU, which will provide the essential information required to optimize their outcome.

The VPICU provides support for the practice of pediatric critical care by developing applications of such information technologies as telemedicine, distance learning, the development of data collection and analysis to improve quality, support research, and provide bedside decision support. [45,46] The VPICU has created a virtual community in which pediatric critical care practitioners work together to understand the way they practice and to identify and implement better ways to deliver pediatric critical care to more than one child at a time. [47] Ultimately, the goal is that we all practice together in one virtual community – constantly working together to improve the care we provide to critically ill children.

Team and Resources Involved in Creating VPICU

The VPICU has four main goals:

1 Development of Telemedicine;
2 Development of a common data repository to improve quality, support research, and provide benchmarking;
3 Development of a highly granular data repository to support research and clinical decision support; and
4 Foster a common information space: Social Media through websites, listserves, and research support via the Internet.

The VPICU has developed a Southern California telemedicine network to provide care for critically ill children and emergency support for them within the "Golden Hour". Additionally, the use of telemedicine robots, consultation in emergency departments and ICUs for critically ill children has been developed. Extending the use of telemedicine to care for children in mass casualty and trauma situations has also been explored.

The Virtual PICU Performance System (VPS) is a national, multi-institutional database that supports quality improvement, benchmarking, and research in pediatric critical care. In 1998, working with The National Association of Children's Hospitals and Related Institutions (NACHRI), the Laura P. and Leland K. Whittier Virtual Pediatric Intensive Care Unit

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(VPICU) developed a clinical database that was originally funded by the Whittier Foundation and directed by Randall Wetzel, MD, of Children's Hospital Los Angeles. The National Outcomes Center (NOC) of Children's Hospital and Health System in Milwaukee joined the group in 2001 to guide implementation of quality reports and manage quality control standards for the database. This collaboration produced the current VPS LLC system, which was incorporated as a separate partnership by the three not-for-profit entities that founded it. [48] VPS assists participating PICUs across the United States and internationally to share data for the purpose of clinical quality improvement and outcomes research. The VPS database has over 500,000 prospectively collected, complete cases from over 115 participating ICUs. It has supported scores of research projects and provides quarterly and annual quality reports for participating ICUs.

General Applications

The VPS dataset was developed by critical care professionals and contains many elements essential to analyze practices in pediatric critical care. The data are mostly captured through primary data collection efforts within each PICU. Extensive steps are taken to ensure reporting consistency internally and comparably across the sites. All patients are assessed for severity of illness by either PIM (pediatric index of mortality) methodology or PRISM (pediatric risk of mortality) methodology or both, thus enabling severity of illness adjustment for all reports. [49] VPS, LLC has undertaken to maintain the PRISM severity of illness system and keep it up to date. The result is a dataset with research-ready and publishable clinical data. The dataset can be used for studies of specific patient populations, customized blinded comparison groups based on site characteristics, and summary overviews of unit volume, severity, and outcomes. The shared data can also be used for multi-institutional studies. In addition VPS has worked with the National Quality Forum to develop and validate quality standards for pediatric critical care.

The data can be used for comprehensive reports to provide clinicians and administrators with valid and reliable measures of outcomes *to monitor clinical improvement modeled on evidence-based practice and the Donabedian approach of improving healthcare outcomes.* [50] These customized, annual and quarterly reports use a standardized presentation of key unit indicators arrayed against peers, interpreted by statisticians, and assessed through clinical consultation. The data can also be used for quality improvement by tracking current trends in quality indicators such as rates of delayed discharges, unplanned readmissions, length of stay, and severity of illness adjusted outcomes.

One of the major functions of VPS is to maintain the PRISM scoring system and other severity of illness adjustment tools. These can be recalibrated, and it is the stated goal of VPS to automate the process, based on hundreds of thousands of patients, of constantly updating methodologies for severity of illness adjusting. Tools are being developed that remain timely and are also adjusted towards specific diagnoses. For a further discussion of the importance of this effort and description of VPS please see the work of Wetzel, Sachedeva, and Rice. [51]

Apart from this national data service, the VPICU is also continuing research on providing collection, analysis, and decision support to and from complex clinical data flowing from the bedside of critically ill children. The goal is ultimately to capture 'every breath, every heart beat', the entire monitoring, laboratory, radiologic and even genomic data from every patient admitted to an ICU. Managing this 'big data' is extremely complex – and the VPICU has made significant strides in this area. [52] Once these data are captured and validated, analysis

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of these large heterogeneously distributed and complex data to derive meaningful information is a challenging new area. Using advanced computational techniques including machine learning, artificial intelligence, and advanced mathematical analysis, the VPICU is demonstrating the ability to cluster critically ill patients and explore effective therapies in thousands of ICU patients by analyzing hundreds of millions of individual data points. [53] Finally, presenting this meaningful information, derived dispassionately and mathematically from verified bedside data back to the care providers also provides an exciting challenge. The VPICU is exploring how to rapidly analyze clinical data and suggest effective management in near real-time throughout pediatric critical care, thus decreasing cycle time from data collection to application.

Applications Specific to Pediatric Disasters

The VPICU provides useful methodologies to support pediatric trauma care, especially those patients requiring critical care. The VPS data repository has a significant amount of information about the patterns of injury in children and the outcomes in children who have been admitted to the PICU with various forms of trauma. In addition, a trauma-specific severity of illness score has been developed. This data repository provides a rich source for understanding how critical illness caused by trauma happens to children and could reveal effective approaches for management. In addition the ability to provide information for treatment is also there.

One approach the VPS is taking in conjunction with the state of Ohio is the development of a catastrophe triage score for children requiring critical care in the event of an overwhelming catastrophe such as epidemic infectious disease, or mass trauma from intentional or unintentional catastrophic events from earthquakes to terrorist attacks. The goal of this work is to develop a triage score that relates outcomes to resource utilization and might guide triage of patients to match scarce resources with those most likely to benefit from them. Although somewhat controversial, the ability in an overwhelming event to determine where limited resources should be committed is a necessary function that is understood by all practitioners who have been involved in these types of episodes. Only dispassionate, effective, and validated analysis of objective data available from these patients can make this practice ethically possible.

The VPICU has also pioneered the application of telemedicine in pediatric trauma. Apart from providing telemedicine triage for critically ill patients, including those suffering from trauma, the VPICU has also developed the application of telemedicine robots, described above, to acute trauma care – again in the setting of catastrophic disasters. In addition, telemedicine may allow the trauma surgeon to rapidly contact distant disaster coordination centers and assess the overall scope and scale of the disaster, all while providing direct bedside consultation in the field. This can greatly extend the availability of expert consultation in the event of a widespread regional catastrophe.

Future Applications to Pediatric Disaster

Further development of telepresence, armed with comprehensive comparative effectiveness data for therapy in the trauma and disaster setting where children are involved, can be developed. The unique physical, developmental, and psychosocial characteristics of children make them particularly vulnerable during a disaster. [54] Thus, it is crucial that pediatric needs are incorporated into every stage of disaster planning. Education and training

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of the healthcare workforce can mitigate the effects of disasters on pediatric populations. The VPS can be used by national experts to develop and distribute protocols, curricula, lectures, courses, and demonstrations, all of which can be used as educational tools for hospital personnel. In turn, the VPS data can be used in pediatric disaster preparedness research studies. Research in this field could find timely and effective ways to treat, diagnose, and improve the outcomes of pediatric patients in mass casualty events. For example, information on interventions such as intubations, mechanical ventilation, venous/arterial lines, and catheters are collected. Because the dataset is available online, clinicians can quickly access it and apply it to the situation if needed. The VPS can also be used to distribute real-time information during a disaster, such as information on surge capacity venues, where the additional volume of patients may be triaged and treated. [55,56]

Given that the VPS listserv has over 400 critical care professionals and the program is available online, a potential application of VPS during a disaster would be telemedicine. This would particularly be essential for institutions that do not have pediatric intensivists available. In the acute phase, telemedicine would primarily play a supportive role, including assistance with triage, transportation, and medical logistics coordination. [57] In the sub-acute phase, telemedicine may play a broader role, including ambulatory/primary care and pediatric specialty consultation services, off-loading the less urgent patients from emergency medical facilities. [57]

In keeping with the vision of ‘creating a common information space’ the VPICU is currently developing extended social networking strategies to further facilitate communication, data sharing, and research among all of those interested in caring for critically ill children. The VPICU has recently received a grant from the Whittier Foundation to develop e-science around intensive care, and to develop a 'comprehensive health 2.0' strategy for pediatric critical care. The intent is to bring together practitioners of critical care medicine caring for children in all settings including trauma in an informed, interactive, and comprehensive virtual environment.

CONCLUSION

Information technology offers a unique and powerful set of resources and approaches to the problem of disaster medicine. Because it can be integrated into real-world drills, bioinformatics and computer simulation, it connects the virtual with the real and greatly expands the capability of the disaster healthcare provider to confront the challenge of a mass casualty event. Drills test the distribution of providers and resources “on the ground” in a potential disaster, but assessments of the effectiveness of drills will increasingly depend upon automated metrics and integration with virtual reality to increase the actuality of the experience for providers. These drills will allow the healthcare delivery system to identify gaps in performance and where performance must be improved. They will also permit individual providers to grade their own responses and improve them. The rapid advance of robotics and cybernetics combined with these approaches will allow for an effective virtual extension of the healthcare provider’s eyes, ears, and hands to a remote disaster site. Software for disaster healthcare providers will continue to evolve from the surge- and resource-focused PEDSS program discussed here, to more focused operations research or queueing theory

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applications and simulations to determine the optimal distribution of resources during a mass casualty event. The latter approaches will increasingly lend much-needed mathematical rigor to the problems of triage and treatment of large numbers of affected patients after a disaster. Lastly, the bioinformatics approach of the virtual PICU is a sophisticated methodology for the sampling and synthesis of large amounts of pediatric critical care data. Its specific applications to disaster medicine include a large database of pediatric trauma patient data that is being used to abstract the complex patterns of injury seen in children after such insults. The contributions of the VPICU system to disaster planning are likely to include the contribution of objective data for more accurate and precise injury scores for triage and resource allocation, as well as more seamless integration with telemedicine and telepresence in the future.

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Chapter 8

INSTABILITY, INVESTMENT AND NATURAL DISASTERS

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ABSTRACT

This chapter summarizes my previous work in Lin (2010), in which I expand upon the existing literature on population and the economy by examining whether natural disasters affect fertility – a topic little explored but of policy importance given relevance to policies regarding disaster insurance, foreign aid, and the environment. The identification strategy uses historic regional data to exploit natural variation within each of two countries: one European country—Italy (1820-1962)—and one Asian country—Japan (1671-1965). The choice of study settings allows consideration of Jones' (1981) theory that preindustrial differences in income and population between Asia and Europe resulted from the fertility response to different environmental risk profiles. According to the results, short-run instability, particularly that arising from the natural environment, appears to be associated with a decrease in fertility – thereby suggesting that environmental shocks and economic volatility are associated with a decrease in investment in the population size of future generations. The results also show that, contrary to Jones' (1981) theory, differences in fertility between Italy and Japan cannot be explained away by disaster proneness alone. Research on the effects of natural disasters may enable social scientists and environmentalists alike to better predict the potential effects of the increase in natural disasters that may result from global climate change.

INTRODUCTION

Dynamic demographic-economic relationships have been of interest to social scientists ever since Malthus proposed an economic theory of population growth in the late eighteenth century (see e.g. NBER, 1960; Schofield & Wrigley, 1985; Lindahl-Kiessling & Landberg, 1994; Galor, 2004). However, while it may describe long-run relationships between

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population and income in pre-industrial Western societies, the classical Malthusian theory fares less well in more general contexts. One possible reason is that, in focusing primarily on the extent to which wages and vital rates exert influence on each other in steady state over the long run of several generations, the classical theory has overlooked the possible effects of environmental shocks and other forms of short-run instability on the demographic-economic system that occur within a single generation.

Individuals behave differently under conditions of instability, risk and uncertainty than they do under conditions of perfect certitude. For example, ample empirical evidence suggests that household-level income volatility leads to lower investment in both physical and human capital at the micro level, and that country-level economic volatility leads to lower government spending and lower mean growth at the macro level (Blattman, Hwang & Williamson, 2007, & references therein). In a similar fashion, sources of instability are likely to affect fertility decisions as well. According to Cain (1983): "If people are motivated by a principle of safety-first, [their fertility behavior] may be influenced less by *average* mortality experience than by variance in that experience, and particularly the tail of the distribution that contains the worst records" (p. 698). Just as individuals in unstable economic environments may be less willing to invest in capital, individuals in volatile natural environments may be less willing to invest in bearing children.[1]

This chapter summarizes my previous work in Lin (2010), in which I expand upon the existing literature on population and the economy by examining whether natural disasters affect fertility. The identification strategy uses regional data to exploit the natural variation within each of two countries: one European country—Italy—and one Asian country—Japan. The time periods under consideration are 1820-1962 for Italy and 1671-1965 for Japan.

An analysis of the effects of environmental shocks on fertility is important for two reasons. First, because there are considerable differences in the stability of the natural environment across the world, studies of the effects of environmental shocks on demographic-economic relationships may enable economists to better understand the sources of cross-country differences in population growth and income.

There is an extensive literature that theoretically and conceptually discusses the consequences of population growth on a country's economy (see e.g., Lee & Edwards, 2001; Coale & Hoover, 1969; Spengler, 1969; Stavig, 1979, & references therein). In his empirical study of 94 countries over the period 1955-1971, Stavig (1979) finds that rapid population increase had a negative impact on changes in many crucial economic indicators—including change in per capita gross capital formation, government consumption, manufacturing, and exports—many of which are highly correlated to change in per capita GNP.

If population size affects the living standard, then an understanding of all the factors influencing population growth, including environmental ones, is essential for understanding global income inequality and past, current and future economic development. For instance, Jones (1981) makes the bold claim that differences in Asian and European population growth and income prior to the Industrial Revolution were due to the fertility response to different risk profiles; Asia's natural disaster-prone environment was to blame for its lower income.

A second reason research on environmental shocks is important is that it has implications for policies regarding disaster insurance, foreign aid, and the environment. For example, if

[1] In this chapter, the phrase "investing in children" is used to capture the bearing of new children rather than investments in the health and education of existing children.

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natural disasters cause a decrease in fertility because they make families reluctant to invest in having children, then risk-sharing policies such as disaster insurance can help mitigate these effects. Similarly, if economic volatility is associated with a decline in fertility, foreign aid policies that minimize the volatility can attenuate the impact on fertility.

In addition to the relationship between environmental shocks and fertility, my work in Lin (2010) also examines the relationship between economic volatility and fertility. Economic volatility is included as well because it is another form of short-run instability that may affect fertility, and because economic volatility has been found in other studies to lower investment in physical and human capital (Blattman et al., 2007, & references therein). This chapter summarizes my previous work in Lin (2010), in which I examine whether economic volatility, like environmental instability, may be associated with changes in fertility.

Italy and Japan were chosen for the empirical analysis based on the following factors: the availability of region-level data, the prevalence of natural disasters, and the need for a country each from Europe and Asia. The choice of two natural disaster-prone countries, one from Europe and one from Asia, enables one to build upon Jones' (1981) theory that differences in fertility behavior in Asia and Europe were a result of differences in the prevalence of natural disasters – not differences in culture, society, history, or politics – and therefore that any other society subjected to the volatility of the Asian environment would have responded in a similar manner. Lin (2010) is a first cut at comparing causes of historical fertility in Asia and Europe; a more thorough analysis will be the subject of future work.

According to the results of Lin (2010), natural disasters have a significant association with fertility in both countries. In Italy, earthquakes had a robust negative association with fertility, particularly marital fertility. In Japan, tsunamis had a robust negative association with fertility while earthquakes had a significant positive association with fertility in some specifications. Short-run economic volatility has a significant negative association with fertility in Italy but no association in Japan.

Previous Literature

My work in Lin (2010) relates to several existing branches of literature. First, it draws upon the literature on the effects of the environment on economic development (see e.g. Diamond, 1997; Gallup, Sachs & Mellinger, 1999; Sachs, 2001; Boserup, 1996; and Pebley, 1998), and the literature on the link between economic growth and population growth (Bloom & Sachs, 1998; Bloom & Williamson, 1998; Bloom, Canning & Sevilla, 2003).

My work in Lin (2010) relates most closely to the work of Portner (2006), who uses data on hurricanes in Guatemala over the last 120 years combined with a recent household survey to analyze how decisions on education and fertility respond to hurricane risk and shocks. By measuring risks and shocks separately, Portner is able to separate out the impact of shocks on fertility in the short-run from the impact of risk on fertility in the long-run. Portner uses the average percent chance of being hit by a hurricane in a year, as averaged over all the years in his data, as his measure of risk. Risk is therefore a time-invariant variable. By using county fixed effects that absorb the effect of all county-level time invariant variables, including risk, Lin (2010) similarly controls for risk in order to identify the short-run effect of an environmental shock.

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My work in Lin (2010) also relates to the work of Kalipeni (1996), whose analysis of the demographic response to environmental pressure in Malawi finds that areas that are experiencing intense environmental pressure are also beginning to go through a fertility transition. In particular, Kalipeni finds evidence of declining fertility rates in response to environmental pressure particularly in areas with high population densities. Lin (2010) similarly examines the association between the environment and fertility.

Previous studies have shown that instability in the environment in the form of famines and wars have a negative effect on fertility. In his analysis of South Asian famines, Dyson (1991) finds a reduction in conceptions prior to a famine even without a major rise in the death rate, perhaps due to conscious planning during the periods of mounting adversity preceding a famine. Boyle and Grada (1986) find that at the onset of the Great Irish Famine of 1845-1849, the fertility rate dropped to 75 percent of its pre-Famine level and remained at this level for the duration of the Famine. In their study of Angola, Agadjanian and Prata (2002) find evidence of a wartime drop in fertility. In their study of Cambodia, Heuveline and Poch (2007) find a one-third decline in fertility during the Khmer Rouge regime, under which 25 percent of the Cambodian population died.

The choice to examine both an Asian country and a European country relates to Jones' (1981) theory that preindustrial differences in income and population between Asia and Europe resulted from the fertility response to different environmental risk profiles.

According to Jones' theory, because Asians were faced with a more natural disaster-prone environment, they accumulated a population surplus as a form of demographic insurance against catastrophe; they therefore had a higher fertility rate, a higher marriage rate, and a lower age at marriage in steady state than their European counterparts did. This strategy of family size maximization resulted in lower consumption levels, lower savings rate, less investment in human capital, and larger disparities in income in Asia than in Europe. Thus, according to Jones, preindustrial differences in environmental risk had dire consequences on social and economic inequality both within and between the two regions. Natural disasters were to blame for Asia's relative poverty. Moreover, Jones claims, demographic choices were a result of the risk profile of the environment; if the risk profile were to change, then the steady-state choices would change as well.

My work in Lin (2010) expands upon Jones' work in two main ways. Jones uses measures of the incidence and effects of a natural disaster that are potentially endogenous to fertility. For example, one measure Jones uses is the death toll from a disaster, which is endogenous because it depends in part on the population density, which is in turn affected by fertility. In contrast, this paper instead uses measures that are exogenous: the number and geophysical magnitude of disasters, neither of which are affected by fertility.

The second innovation in Lin (2010) is that Lin (2010) focuses on the short-run behavioral effects of a disaster rather than its long-run steady-state implications. While the long-run steady state takes place over centuries and multiple generations, short-run behavioral effects take place over decades, within a single generation. Jones' theory describes the steady-state relationships among population growth, economic development and environmental instability. While greater environmental instability may lead to greater population growth in the long-run steady state, it is likely that the effect might be the opposite during short-run transitions. In the immediate aftermath of a disaster, one might expect risk-averse individuals to react by *decreasing*, rather than increasing, long-term investments in assets such as children. The latter short-run behavioral response is the focus of Lin (2010).

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My work in Lin (2010) also innovates upon the burgeoning literature linking economic volatility to lower investment. At the microeconomic level, empirical evidence suggests that households respond to income volatility by diversifying and skewing their income-generating activities towards low-risk alternatives with lower returns, thereby decreasing their investment in physical and human capital (Blattman et al., 2007, & references therein). For example, Rosenzweig and Wolpin (1993) find that risk-averse farmers faced with borrowing constraints and low and uncertain incomes underinvest in assets needed for agricultural production and consumption smoothing, thus leading to output losses, lower incomes, and greater income volatility. Similarly, income volatility causes parents to underinvest in the health and education of their children (Frankenberg, Beegle, Thomas, & Suriastini, 1999; Thomas et al., 2003).

Empirical evidence suggests that economic instability decreases investment at the macroeconomic level as well. For example, in their examination of 92 developed and developing economies between 1962 and 1985, Ramey and Ramey (1995) find that countries with high macroeconomic volatility have lower government spending and lower mean growth. Countries that face borrowing constraints and terms of trade shocks may have difficulty smoothing public investment and expenditure (Blattman et al., 2007).

In some ways, giving birth to a child is a form of investment just as investing in capital is. As noted by Becker (1960), children are a durable consumption and production good. The motives for having children may include both the direct satisfaction children are expected to provide their parents and the indirect satisfaction they may render by working in the household or family business or by remitting money income to their parents (Willis, 1973). In traditional societies, children are beneficial to parents from an early age as a source of labor; they represent an investment for support in old age, an insurance against risk in a hazardous environment, and enhance the physical security and political influence of the family unit (Cleland & Wilson, 1987). Childbirth requires huge up-front costs in terms of time and money, and the potential insurance benefits of having children accrue in the future. Economic uncertainty can therefore lead to lower levels of fertility (Kohler et al, 2002; Perelli-Harris, 2005). My work in Lin (2010) expands on the literature connecting income volatility with lower capital investment and depressed long-run economic performance by examining whether natural disasters and economic volatility affects investment in the future population size.

DETERMINANTS OF FERTILITY

What factors determine fertility? The classical Malthusian theory posits that fertility is affected by income and mortality; the hypothesis of my work in Lin (2010) is that short-run shocks should have an effect as well.

While the classical economic theory has focused primarily on income and mortality, Lin (2010) focuses instead on an additional determinant of fertility: environmental shocks, as measured by the number and magnitude of natural disasters. Income and mortality are used as controls. According to Jones (1981), who hypothesized that families living in a more natural disaster-prone environment would accumulate a population surplus as a form of demographic insurance against catastrophe, one would expect natural disasters to have a positive effect on

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fertility. However, it is also possible that short-run environmental shocks may decrease fertility, perhaps because the shock makes individuals less willing to make the long-term investments required to raise a family. Another reason individuals might have lower fertility in the short run after an environmental shock is that the disaster causes a disruption in family life and social organization, for example by causing the death and/or break-up of families, by destroying houses, or by causing individuals to lose their jobs. This paper investigates the effects of short-run environmental shocks, and therefore hypothesizes that environmental shocks are associated with a decrease in fertility.

In addition to natural disasters, a second form of short-run instability considered in Lin (2010) is economic volatility, as measured by the variance of the detrended wage. Economic theory predicts that greater economic volatility will lower investment in human and physical capital (Blattman et al., 2007). In this paper it is hypothesized that, like natural disasters, greater economic volatility will also lower the investment in the future population size, and is therefore associated with lower fertility.

Social factors influence fertility as well. Societal norms about reproduction affect fertility (Munshi & Myaux, 2006; Thomson & Goldman, 1987). Fertility decisions often occur in specified social contexts. For example, a woman's social network and social world may affect her fertility behavior (Madhavan, Adams & Simon, 2003). Social influences would affect the short-run and long-run responses to shocks. These social factors are addressed in several ways. First, analyzing Italy and Japan separately allows for country-level social differences between the two countries. Second, a region-level fixed effects model allows for region-level social factors. Third, a spatial model allows for social spillovers between neighboring regions, and therefore for social networks that may possibly spill over from one region to the next. [2]

DATA

Demographic, economic, and disaster data for Italy (1820-1962) and Japan (1671-1965) are used. Data from many countries were initially gathered, but Italy and Japan were chosen for the final analysis based on the following factors: the availability of region-level data, the prevalence of natural disasters, and the need for a country each from Europe and Asia. The choice of two natural disaster-prone countries, one from Europe and one from Asia, enables one to build upon Jones' (1981) theory that differences in fertility behavior in Asia and Europe were a result of differences in the prevalence of natural disasters – not differences in culture, society, history, or politics – and therefore that any other society subjected to the volatility of the Asian environment would have responded in a similar manner. The data sources used for Italy and Japan are detailed in Appendices A.1 and A.2 of Lin (2010), respectively.

Demographic data were compiled from various print sources or extracted from the Princeton European Fertility Project online demographic data set (Treadway, 1980). These variables include the following measures of fertility: crude birth rates, the index of total fertility (*If*), the index of marital fertility (*Ig*), and the index of non-marital fertility (*Ih*). They also include crude death rates. The print sources for Italy's demographic data are Livi-Bacci

[2] These models also address possible country-level or region-level biological influences as well.

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(1977) and del Panta (1979). The print sources for Japan's demographic data are Hanley and Yamamura (1977), Morris and Smith (1985), Smith (1977), and Jannetta and Preston (1988).

Annual real wage data were from Jeffrey Williamson: the Italian wage index (1900 = 100) was taken from Williamson (1995) while the Japanese wage index (1934-1936 = 100) was provided in digital form. This wage data was used to calculate, for each year, the variance of the detrended wage over the past 20 years prior to and including that year in the base case. Whenever possible, the variables for both the level and the variance of the wage were averaged over the same years over which observations for the demographic dependent variable spanned in any given regression. All averages were centered on the floor of the midpoint of the years covered in the average.

Daily natural disaster data on the number and magnitudes of earthquakes, tsunamis and volcanos were taken from the National Geophysical Data Center web site (Dunbar, Lockridge & Whiteside, 1999; Lockridge, 1999; and Whiteside, 1999). To measure the severity of the earthquake, either the Modified Mercalli Intensity Scale of 1931, which takes on integer values from 1 (least intense) to 12 (most intense); or the geophysical magnitude, where each increase in magnitude represents a ten-fold increase surface wave amplitude, is used. The magnitude of a tsunami is defined as the log of twice the maximum runup height of the wave; this value is incremented by 2, so that the minimum value is 1 instead of –1. For the volcano magnitude, the volcano explosivity index is incremented by 1, so that it takes on integer values from 1 (tephra volume = 1E4, column height < 0.1 km above crater) to 9 (tephra volume ≥ 1E12, column height > 25 km above sea level). For all types of disaster, a magnitude or intensity of 0 denotes no disaster.

From the raw natural disaster data, variables are constructed for each year in the data set for (1) the number of each type of disaster over the past 20 years prior to and including that year, and for (2) the sum of the geophysical magnitudes of all occurrences of earthquakes, tsunamis and volcanos over the past 20 years prior to and including that year. For example, for the 1880 observation, environmental shocks are aggregated over 1861-1880. When multiple observations existed for any given disaster, an average of the magnitudes reported was taken.

In the base case, both the measure of environmental shock and the measure of short-run economic volatility consider events that have occurred over the previous 20 years. This is because individuals who are making choices about marriage, childbearing and potential tradeoffs with their careers do so in their early twenties, and therefore have experienced the previous two decades of environmental disasters and economic instability. As a robustness check, the previous 10 years is also used to measure short-run instability.

The demographic, economic and natural disaster data are used to construct a panel data set for Italy and a panel data set for Japan.

For the Italian panel, the unit of observation is a region. There are 18 regions in Italy; following del Panta (1979), these regions can be grouped into 5 geographical areas: Northwest, Northeast, Center, South, and Islands. The panel covers all 18 regions and spans the years 1820 to 1962. While measures of fertility were available at the region level, the measures of mortality compiled were at the level of the geographical area. Thus, for each geographical area, the area's values for the crude death rates were used for all regions in the area. The same national Italian wage data, which reflects mainly the wage in Northern Italy, was applied to all regions. Volcano data were matched to the region in which the volcano was located. All other natural disaster data were matched to the region based on the location(s)

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named in the source, or, when the location name could not be located in any region, on the latitudes and longitudes given. Disasters that occur in areas larger than a region are assumed to strike all regions in that area; disasters that occur in areas smaller than a region are assumed to affect the entire region.

In the panel data set for Italy, the fertility variables generally each span 3 years per observation. For example, for the fertility indices, there are up to 11 observations of each fertility index for each region: (1) 1862-1866, (2) 1870-1872, (3) 1880-1882, (4) 1890-1892, (5) 1900-1902, (6) 1910-1912, (7) 1921-1926, (8) 1930-1932, (9) 1935-1937, (10) 1950-1952, and (11) 1960-1962. Of the 18 regions, 14 regions have observations during 1862-1866 and 16 regions have observations during 1870-1912; all 18 regions have observations from 1921-1962. For the crude birth rate data, there are several more observations over other 3-year intervals for some of the regions, so the crude birth rate data extends back to 1820.

Because the fertility data spans mostly 3 years per observation, the natural disaster variables, which represent the sum of either the number or intensity of natural disasters over the last 10 or 20 years, are averaged over 3 years. Similarly, the real wage and the variance of the wage (which is the variance in the detrended wage over the past 10 or 20 years, divided by 1000) are averaged over 3 years as well. Because the wage data begins in 1871, and because at least 10 prior years of wage data are needed to form the variance of the wage, the regressions that include the variance of the wage span the years 1880 to 1962. Geographical area-level crude death rates span 4-5 years per observation. All variables spanning multiple years are centered on the floor of the midpoint of the years covered in the average. For example, for each region in Italy, a birth rate that spans the three years 1880-1882 is coupled with the average of the natural disaster variable for the three 20-year ranges 1861-1880, 1862-1881 and 1863-1882, and the observation is centered on the floor of the midpoint of the years covered in the average, which in this case is the year 1881, the midpoint of 1880-1882.

The Japan panel consists of data from 13 *mura* (villages), one *shi* (city) and one *han* (domain), and spans the years 1671 to 1965. For lack of a better term, the level at which an observation applies—whether it be a village, city or domain—is called a "place". Observations are available for different years for each place, and each unit of observation covers from between 1 to 41 years depending on the place. For example, for the domain, Morioka, there are 15 one-year observations: one every 10 years from 1680 to 1790, and also the years 1803, 1828 and 1840. The observations for the other places cover different years. Each of the places can be matched to one of the 11 regions in Japan. Regressions include either place or region fixed effects.

The same national Japanese wage data were applied to all places; the data were constructed by Jeffrey Williamson from pre-1930 wage data for Kyoto and Kamikawarabayashi (near Osaka) and post-1930 wage data for Tokyo. The wage data span the years 1727 to 1938. Volcano data were matched to the prefecture in which the volcano was located. All other natural disaster data were matched to the prefecture based on the location(s) named in the source, or, when the location name could not be located in any prefecture, on the latitudes and longitudes given. Disasters that occur in areas larger than a prefecture are assumed to strike all prefectures in that area; disasters that occur in areas smaller than a prefecture are assumed to affect the entire prefecture. All the places are assumed to be affected by the disasters matched to the prefecture(s) in which they are located.

For the panel data set for Japan, crude birth rates span 1-41 years per observation, with an average span of approximately 10 years. Consequently, the natural disaster variables, which

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represent the sum of either the number or intensity of natural disasters over the last 20 years, are averaged over 10 years. Similarly, the real wage and the variance of the wage (which is the variance in the detrended wage over the past 10 years, divided by 1000) are averaged over 10 years as well. Because the wage data span the years 1727 to 1938, and because at least 10 prior years of wage data are needed to construct the variance of the wage variable, the regressions that include the variance of the wage span the years 1737 to 1935. Crude death rates span the same number of years as the crude birth rate for each observation. All variables spanning multiple years are centered on the floor of the midpoint of the years covered in the average.

According to the summary statistics in Lin (2010), the mean crude birth rate for the Italian regions over 1820-1962 was 30.31 births per 1000 people, while the mean crude birth rate for Japan over 1671-1965 was 28.79 births per 1000 people. On average, in any given 20-year period, there were 4.98 earthquakes and 0.69 volcano eruptions in the Italy regions over 1820-1962; and there were 0.65 earthquakes, 0.35 tsunamis, and 0.65 volcano eruptions in Japan over 1671-1965.

ECONOMETRIC METHODOLOGY

The identification strategy I employed in Lin (2010) uses regional data to exploit natural within-country variation for both Italy and Japan. With panel data, region fixed effects can be used to control for time-invariant, region-specific omitted variables such as local culture or local attitudes toward risk or mortality, or local economic factors; and the country-specific time trend (the coefficient on year) can be used to control for national trends including country-level changes in social attitudes, cultural values, network behavior, and/or people's fertility preferences. The fixed effects also control for the average long-run steady-state environmental risk faced by a particular region, thus enabling one to identify the effects of a short-run environmental shock. The fixed effects similarly control for steady-state differences in the economic volatility of different regions (e.g., their local economic risk profiles).

The primary innovation of Lin (2010) is to include measures of short-run instability in traditional regressions of fertility on income and mortality. The number and magnitudes of natural disasters are used to measure environmental shocks and the variance of the detrended wage is used to measure economic volatility. The joint significance of the natural disaster variables as well as the joint significance of the economic variables are tested.

All regressions are OLS. For the economic variables, it is therefore assumed that neither the real wage nor the variance of the wage is likely to be endogenous to the contemporaneous birth rate because babies are too young to have an effect on the labor market. For environmental shocks, exogenous measures are used: the number and geophysical magnitude of natural disasters, neither of which are affected by fertility.

For the crude death rate, one potential omitted variable that may cause the crude death rate to be endogenous to fertility is famine, which both elevates mortality and depresses fertility (Lee, 1985; Maharatna, 1996). Controlling for natural disasters addresses this problem at least in part, as natural disasters are often a cause of famine. Moreover, any endogeneity of mortality to fertility would operate through the number of births, not the birth rate. Fortunately, there does not appear to be any major documented famine either in Italy

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over the period 1820-1962 or Japan over the period 1671-1965.[3] Thus, it is assumed that, as with the other regressors, the crude death rate is exogenous as well.

In using historical data, one may worry that the data may be noisy measurements of the true values. Classical measurement error biases the coefficients towards zero (Wooldridge, 2002), which means that the effects may be underestimated. Thus, the results provide lower bounds to the magnitudes of the effects of natural disasters and economic volatility.

Because local economic data was not available for the time periods and regions analyzed, the fixed effects model does not pick up local short-run economic shocks unless they are correlated with national economic shocks. Therefore, to control for local short-run economic shocks, regressions are also run using regional fixed effects, year effects and variables interacting the regional area with year dummies. The spatial span for the regional variables to be interacted with year is at the level of a geographical area for Italy, since its natural disaster variables are at the level of a region; and at the level of a region for Japan, since its natural disaster variables are at the level of a place. For both countries, these regressions cannot include the wage or the variance of the wage, which are at a national level and thus only have one value each per year, because they include year effects. For Italy only, these regressions cannot include the crude death rate, which is at the geographical area level, because they include geographical area fixed effects. Because they include variables interacting regional area and year, these regressions control for all other factors other than natural disasters (and mortality for Japan) that vary by locality and time, including local economic shocks (and mortality for Italy).

To account for possible spatial spillovers, for example due to social influences that may spill over across regional borders, a spatial lag model is run for Italy, where the crude birth rate *z* is given by:

$$z = \rho W z + X\beta_1 + WX\beta_2 + \varepsilon, \tag{1}$$

where *W* is a weight matrix, *X* is a matrix of explanatory variables including natural disasters, and ε is i.i.d. normal. The weight matrix *W* assigns a “1” to all contiguous neighboring regions and a “0” to all other regions. Because they have no neighbors, the regions of Sardegna and Sicilia are dropped from the spatial analysis. The parameter ρ indicates the extent of spatial interaction between neighboring observations.

CONCLUSION

The research in Lin (2010) presents a detailed investigation of the effects of environmental and economic instability on fertility and its components in both Italy and Japan. For identification, regional data are used to exploit the natural variation within each of these two countries.

Three results in Lin (2010) deserve special mention. First, environmental shocks have a significant association with fertility behavior in both countries, even after controlling for year,

[3] See e.g., the list of famines in Walford (1970).

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the death rate, the wage, short-run economic volatility, and steady-state risk. The sign of the association varies by country and disaster type. In Italy, earthquakes had a robust negative association with fertility, particularly marital fertility. In Japan, tsunamis had a robust negative association with fertility while earthquakes had a significant positive association with fertility in some specifications.

A second important result is that short-run economic volatility, as measured by the variance of the detrended wage, has a significant negative association with fertility in Italy. Taken together, the significant negative association between short-run instability and fertility behavior in Italy suggest that, just as economic instability decreases investment in physical and human capital, environmental shocks and economic volatility are associated with a decrease in investment in the population size of future generations.

These results have many important implications. First, the results have implications for understanding differences in income and population growth both within and between countries and both throughout the past and in the present. Second, they have implications for policies regarding disaster insurance, foreign aid, and the environment. Third, these results have important implications for the development of models of behavior under uncertainty. Fourth, the results have implications for the design of policies for risk-sharing. If natural disasters cause a decrease in fertility because they make families reluctant to invest in having children, then risk-sharing policies such as disaster insurance can help mitigate these effects. Moreover, in countries such as Italy where economic volatility is associated with a decline in fertility, policies such as foreign aid or prohibitions against cutting wages that minimize the volatility can attenuate the impact on fertility. These policies can be the subject of future research.

The third important result is that, just as there are differences in how fertility rates in Italy and Japan respond to natural disasters, there are systematic differences in how fertility rates in these two countries respond economic volatility. The variance in the detrended wage has a negative association on the crude birth rate, total fertility and marital fertility in Italy, but an insignificant effect on the crude birth rate in Japan. One possible reason why the fertility choices of the Japanese respond less to economic volatility than do those of the Italians is that there may be some institutions in Japan, such as cultural norms, that already provide the Japanese with insurance against economic volatility. Another possible reason is that the Japanese wage appears less volatile than the Italian wage, and thus may be too stable to have much of an effect of fertility.

The different effects of natural disasters and economic volatility on Italy versus Japan highlights the importance of country-specific factors such as social attitudes, cultural values, network behavior, history, politics, and people's fertility preferences. Contrary to Jones' (1981) theory, differences in fertility between Italy and Japan cannot be explained away by disaster proneness alone. These other factors vary by country, and are likely to be different for other countries in Asia and Europe as well.

The main results of Lin (2010) are therefore that natural disasters have a significant association with fertility in both countries. In Italy, earthquakes had a robust negative association with fertility, particularly marital fertility. In Japan, tsunamis had a robust negative association with fertility while earthquakes had a significant positive association with fertility in some specifications. Short-run economic volatility has a significant negative association with fertility in Italy but no association in Japan. These results should be of interest to economists, historians, environmentalists, and policymakers alike.

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Chapter 9

COPING WITH DISASTER TRAUMA: OBSERVATIONS FROM AROUND THE WORLD

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ABSTRACT

Disasters have multitude of effects on the victims; as the direct loss and damage during disasters and the indirect consequences continue for years. In the developing world disasters have colossal impact where the resources are scarce, disaster relief systems are inadequate and post-disaster long-term care is abysmally poor. Psychiatric morbidities are observed in a large majority of affected population and these often become chronic. It is imperative to study how the victims cope following the catastrophic disasters, the relation between various coping strategies and manifest morbidities and variations across disasters and cultures. This article reviews the available literature regarding coping following various disasters and summarizes the coping strategies employed by disaster victims around the world. Variations in coping across cultures are highlighted and areas for therapeutic intervention are suggested. These understandings in coping may help in facilitating positive coping and developing culture specific and appropriate intervention programmes.

INTRODUCTION

Disaster is defined as 'a severe disruption, ecological and psychosocial, which greatly exceeds the coping capacity of the affected community' [1]. It is well known that while most of the disaster victims could cope and move on in their lives following traumatic disaster experience, many victims struggle and suffer long term for the psycho-socio-economical

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consequences of the disaster. It is intriguing to see this difference about how some are able to cope and others do not. As inability to cope is often associated with physical and mental ill health, it becomes imperative to study these aspects.

The importance of coping in traumatic disaster situations can not be overemphasized. Primary goals of psychiatric interventions after a disaster include reducing psychobiological distress, reducing the effects of secondary stressors and facilitating successful coping. Successful coping is defined as one's ability to continue task-oriented activity, regulate self-emotion, sustain a positive self-value, and maintain and enjoy interpersonal contacts [2].

COPING DISASTERS IN DEVELOPING COUNTRIES

Coping the trauma of disasters in middle or low income countries is particularly challenging because of various reasons. Natural disasters are not only more common in developing countries, but also have greater devastating impact. There are various reasons for this, viz, poor warning systems, inadequate emergency response during disaster, poor preparedness and mitigation measures for the disasters. Besides, disasters in developing countries usually affect comparatively large number of people. Poor connectivity to affected areas and deficit in resources for acute relief appear as important determinants of morbidity. Pre-disaster factors like lower economic status, poor housing quality and poor communication systems add to the misery [3]. Besides all these, even before the victims recover from the impact of one natural disaster there comes more in their way, as these are particularly frequent in the vulnerable zones.

In the above context this article tries to review the coping strategies used by the victims for dealing with the traumatic experience of disasters; and their effectiveness. The information has been gathered from extensive literature search and qualitatively from the experience in working with disaster victims.

SIGNS OF INEFFECTIVE COPING

While no one who sees a disaster is untouched by it; most people pull together and function during and after disasters, but their effectiveness is diminished [4]. Secondary stresses resulting from the original disaster continue and complicate the scenario prolonging the distress. The signs of ineffective coping are observable easily every where in the post disaster scenario.

Depending upon the nature of disaster, traumatic experience, the meaning of trauma for the individual victims and their personal and societal coping capabilities, various outcomes are observed in the aftermath. In other words, several background, dispositional, coping style and exposure-related factors characterise those who developed psychological morbidity [5].

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Coping and Psychiatric Disorders

Catastrophic trauma of the disasters overwhelms the coping capabilities of the victims; and often this manifests in stress related psychiatric disorders in a proportion of victims. A range of psychiatric disorders have been observed namely: acute stress reaction, adjustment disorders, anxiety disorders, depressive disorders, posttraumatic stress disorder (PTSD), dissociative disorders, psychoses etc [6,7,8]. Some victims have personality change in the long term following catastrophic traumatic experience. It is known that individual vulnerability and coping capacity play a role in the occurrence and severity of acute stress reaction [9]. Severity of psychological reaction in behaviour and cognitions may lead to psychotic presentations which are often transient. However what often appears as psychotic features can be dissociative in nature, or even culturally sanctioned behaviour of coping the extreme degree of stress [10]. This suggests that there is complex interplay of various factors influencing the final outcome following traumatic disaster experience.

Other Psychological Sequel

Besides the syndromal psychiatric disorders there are other indicators of psychological problems secondary to ineffective coping. It is a common observation that many victims initiate substance use or increase their previous level of use. Most of the victims give the explanation that it is a way of coping. It has been reported that prevalence of substance use increases following disasters which in many cases lead to disorders of harmful use or dependence. Alcohol and cannabis are the commonly used substances although other illicit drugs are also used. This results in substance related mental and physical health problems adding to the burden of posttraumatic stress. A survey after World Trade Centre (WTC) disaster found a significant increase in tobacco, alcohol, and marijuana use, but primarily among adults already using these substances [11].

Disasters are often associated with death of near and dear ones. After sudden, unexpected death, bereavement reactions are extraordinarily intense. Customary coping strategies become ineffectual to mitigate anxiety and withdrawal is frequent. In these circumstances hypertrophic grief are observed in the victims [10]. Complicated bereavement issues continue for many victims long after the disaster. It is known that the loss of an attachment to a loved person or of some other significant attachment leads to a prolonged period of distress and disability. The upset feelings are usually associated with reduction in cognitive effectiveness and problem-solving capacity. These factors may lead to poor mental health in the form of an acute adjustment disorder, or of a chronic psychopathology if the individual uses maladaptive ways of trying to escape the burdens through alienation from reality [12].

Some of the disaster survivors resort to self-harm behaviour, without the intention to kill themselves. A proportion of victims suggest this as a method of coping. These behaviours may include cutting, scratching, neglecting self etc.; however sometime there can be more serious self-injurious behaviour and suicide attempts [10]. It is well established that in post-disaster period inability to cope the consequences of the disaster leads to increase in suicide attempts and completed suicide [13,14,15].

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Coping Styles and Psychiatric Symptoms: Associations

Use of specific coping strategies shortly after an event is associated with symptoms over time. It has been found that more frequent use of cognitive and avoidance coping strategies to be significant predictors of PTSD symptoms one year after an earthquake disaster [16]. In another study, symptoms of depression, anxiety, and PTSD were associated with avoidant coping strategies [17]. Both emotion-focused and problem-focused coping strategies predicted traumatic stress in community residents who lived on both sides of a rail track where a train collision occurred [18]. In another study the role of coping in the onset of PTSD in a non-patient population following exposure to a natural disaster was examined. The use of coping strategies was found to be associated with the presence of PTSD rather than the absence of symptoms. The results suggested that coping (in this sense) represented a psychological process used to contain the distress caused by symptoms as well as to manage environmental adversity [19].

In contrast to above, disengaging from coping efforts early can signal the likelihood of psychological difficulties up to 6 months after a trauma [20]. Giving up, denial and self-distraction were associated with high levels of posttraumatic stress symptoms following the 9/11 attacks. Global distress was observed to increase with denial and giving up, and to decrease with active coping [20].

Coping Strategies: Observations Following Various Disasters

It is essential to learn about various coping strategies employed by the victims following disasters around the world. It may be possible to glean about their effectiveness; and such information can be helpful in supporting victims elsewhere. Available literature on this subject is being discussed here. Summary of observations related to coping is given in table 1.

Coping at Individual Level

Victims of 2004 Asian tsunami in Sri Lanka reported various culturally-relevant coping activities. The majority of respondents in a study found their own strength, family and friends, Western-style hospital and their religious practices to be the most helpful coping aids [21]. Another study following the Southeast Asian earthquake-tsunami found best predictors for positive psychological adjustment were frequent support seeking, along with pre-disaster employment. Infrequent support seeking and increased intrusion were the best predictors for the negative psychological adjustment [22].

Floods in Bangladesh generate socioeconomic misery and cause damage to the environment, health and infrastructure frequently; however, people's indigenous coping strategies have helped them to reduce their vulnerability significantly. A study reported that the people in an area with low flooding and with better socioeconomic circumstances were more likely to cope with impacts compared to people in areas with high and sudden flooding.

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Similarly, households' ability to cope varied depending on people's socioeconomic conditions, such as education, income and occupation [23].

Table 1. Observations on disaster related coping

• Activities: undertaking and remaining engaged • Adaptation to social assets • Adaptive coping • Avoidance of negative social influences • Avoidant coping • Behavioral disengagement • Clinical exposure • Cognitive coping • Cognitive dissonance • Cognitive restructuring • Communal coping • Community activities • Confrontive coping • Coping self-efficacy • Culturally-relevant coping • Debriefing: emotional/educational • Denial • Distancing • Emotion-focused coping • Escape-avoidance • Extra-familial social support • Family coping strategy • Family support • Feeling responsible • Flight • Freezing • Giving up • Group-meetings • Hope • Humour • Indigenous coping • Information seeking • Making new friends • Meaning-focused coping	• Medical training • Self monitoring • Open discussion • Optimism • Over-protectiveness • Perceived helpfulness/support • Physical exercise • Positive appraisal • Positive self-talk • Practical help • Problem-focused coping • Problem-solving, • Professional support • Psychological integration of the event • Reaching and protecting significant others • Relaxation • Religious activities • Reuniting with family members • Safe and secure environment • Seeking support: social/financial • Self-blaming • Self-distraction • Self-help group • Social withdrawal • Spirituality • Staying in touch or turning to with family and friends • Supportive coworkers • Taking shelter • Timely warning • Trying to keep a realistic perspective on the situation • Ventilation • Vigilant coping

Many victims of 1999 Orissa super-cyclone reported of using various coping methods e.g. seeking help from others; seeking financial assistance; ventilation; having someone empathetic to talk to; avoiding to think about cyclone and damages; believing in self and in

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God; hoping that things will be fine; accepting nothing could have been possibly be done. A majority had tried to view the trauma in a different perspective (cognitive coping). Methods like accepting that nothing is possible, avoiding thinking on the trauma or ventilation were not helpful [24].

Earthquake victims in Fabriano, Italy identified their coping responses during the earthquake as taking flight, freezing, taking shelter, failing to realize what was happening, reaching and protecting significant others, seeking information from the social environment, and recovering personal belongings. In the aftermath of the earthquake the coping behaviour were reuniting with family members, undertaking activities, observing the scene, recovering personal belongings, meeting in groups and continuing activities [25]. There are reports of existence of positive emotions and positive coping as well after the disasters. In the refugees at the shelters after the 2001 earthquakes of El Salvador, most of the people affected by the earthquake revealed a consistent pattern of positive reactions, cognitions and emotions. In the individual sphere, these acted as buffering elements to protect people from the effects of the traumatic experience [26].

More frequent use of cognitive and avoidance coping strategies has been reported following Northridge Earthquake, Los Angeles [16]. Avoidance coping has also been reported following 1989 Earthquake in New Castle where one of the factors that contributed to post earthquake morbidity was trait vulnerability [27]; which suggest that people with particular personality profile may not be able to cope well. An avoidance coping style following the 1989 Newcastle earthquake contributed substantially to psychological distress [28]. In another study, avoidance as a coping strategy by earthquake survivors has been observed to have significant positive correlations with PTSD and depression outcomes [29]. Following 1999 earthquake in Taiwan confrontive coping were significant predictors of psychiatric morbidity, while distancing, escape-avoidance, and positive reappraisal were significant predictors of posttraumatic morbidity [30].

After the WTC and Pentagon attacks, reported coping behaviors included turning to open discussion (98%), religion (90%), and community activities (60%) in order to cope with their reactions [11]. In a paradoxical way, problems of ‘re-living’ a train accident were observed to be important for the coping process which included psychological integration of the accident as an important life event. This new coping strategy was observed to minimize emotional pain in the victims. However "re-living" of the accident through nightmares and intrusive thoughts was responsible for problems in carrying out ordinary tasks [31]. Relative to those with stable incomes, victims with oil spill-related income loss had significantly worse scores on tension/anxiety, depression, fatigue, confusion, and total mood disturbance scales; had higher rates of depression; were less resilient; and were more likely to use behavioral disengagement as a coping strategy [32].

Variations of coping across different age groups have been studied. Following exposure to technological disasters, young, middle-aged and elderly community residents were observed to employ similar coping strategies; and displayed similar post-traumatic responses, which contradicted the vulnerability hypothesis and the inoculation hypothesis. One significant interaction effect was that residents exposed to the aircraft crash used significantly more confrontive coping than those exposed to the train collision, in all three age groups [33].

It is known that many emotional situations of disaster survivors stem from problems of living brought about by the disaster. Concerns regarding living start immediately after the disaster and continue long term; e.g. locating missing ones, housing, clothing, food,

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transportation, medical care, demolition, digging out and clean up, relocating etc. These concerns may be too difficult to cope in those times without external help [4]. These problems are especially difficult for victims with preexisting problems, inadequate support and those who are compromised because of various issues. After the Niigata-Chuetsu Earthquake the elderly were more affected by matters relating to coping with daily problems [34]. At the time of the Hurricane Katrina, more elderly died than any other group during and in the first year after the storm. However, those who did survive beyond the first year reported coping with the long-term disaster aftermath better than the generation below them [35].

Mentally ill people cope negatively in the post disaster situations. A study found that the schizophrenia group reported lower approach coping, self-esteem, and social support than controls, with the bipolar group reporting intermediate levels. Within the schizophrenia group, higher levels of avoidance coping predicted higher residual stress symptoms at follow-up [36].

The role of religious beliefs and religion in general in strengthening coping skills is well known [37]. Finding refuge in religious activities is very much a part of coping behaviour of victims in disastrous situations. Religious coping have been reported in many studies from all over the world, West and the East [38-42]. Religious coping strategies have been reported following the tsunami disaster in Sri Lanka with special reference to Buddhism, which is the majority religion in the island. Religious observations were the usual coping methods of the community following 1999 Orissa super-cyclone; wherein most of the victims had elaborate involvement in religious activities to cope with the tragedy [6]. Religious beliefs and religious coping were also observed following Hurricanes Katrina and Rita. They were negatively correlated with physical function, implying that stronger reliance on religiosity as a coping mechanism may be more likely among those who were less physically capable. Gender differences were noted in religious beliefs and religious coping, favouring women [43].

There is solid documentation for the positive relationship between spirituality and health, but there are only a few examples of how this link may be used in projects of rehabilitation after the disasters. It has been observed that the Tibetan torture survivors use Tibetan Buddhism as an important coping mechanism [44]. Following 2004 tsunami, survivors in India valued their unique individual, social and spiritual coping strategies more than the formal mental health services [45].

Coping self-efficacy (CSE) is defined as a person's subjective appraisal of his/her ability to cope with the environmental demands of the stressful situation [46]. More than half of the victims in 1999 Orissa super-cyclone did not have the hope that they will ever be able to succeed in coping with the disaster [24]; and it may be highlighted that a majority of victims had psychiatric morbidity. Personal resources (i.e. self-esteem, optimism, and perceived control) and CSE have been observed to have direct effects on intrusion and general distress following an earthquake disaster. Personal resources had also an indirect effect on general distress mediated by CSE [47]. These observations highlight the implication for concepts of conservation of resources model and social cognitive theory for interventions following natural disasters. After Hurricane Katrina CSE was greater among men, the most educated and those with the highest income. Hurricane CSE scores were highly correlated with perceived stress and posttraumatic stress symptoms; and significantly lower scores were observed among participants who sought counselling after the storm [48].

Meaning-focused coping (MFC) can contribute to individuals' adjustment in the face of uncontrollable situations such as natural disasters. A study examined the role of MFC in post-

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traumatic growth and to explore how three different types of coping (problem-focused coping, emotion-focused coping, and MFC affected the mental health of earthquake victims following the 2008 Sichuan Earthquake. It was found that MFC had a significantly incremental value in predicting positive affect and well-being, above and beyond problem-focused coping and emotion-focused coping [49].

Children and Adolescents

Children's responses to disasters and other traumatic events are based on developmental stage, the specific threat, injury and loss, and the child's coping skills as well as previous traumatic experiences [50,51,52]. Like adults, coping patterns in children following disasters are also relevant in relation to psychiatric manifestations. In a study five months following a hurricane the number of coping strategies employed by children was positively related to depression scores, whereas coping efficacy was negatively related to depression scores. Social withdrawal, self-blaming, and emotional regulation were associated with more severe depressive symptoms. Lower levels of symptomatology were found among children who sought social support and engaged in cognitive restructuring [53].

Negative coping has been found to be one of the risk factors that predicted PTSD frequency and severity in school students following a snowstorm disaster in China [54]. A study in the post-Hurricane Katrina recovery environment (i.e. discrimination, social support) and coping behaviours on children's posttraumatic stress reactions (symptoms of PTSD, anxiety, and depression) revealed that greater helpfulness from extra-familial sources of social support predicted lower levels of child-rated symptoms of PTSD, anxiety, and depression. A positive predictive relation was found between helpfulness from professional support sources and PTSD, perhaps suggesting that parents whose children were experiencing higher PTSD symptom levels sought professional support and reported it to be helpful. Youths' avoidant coping behaviours predicted both PTSD and anxiety symptoms. Discrimination, active coping, and familial support did not predict any of the posttraumatic stress reactions assessed [55].

It was reported that hurricane-related trauma experiences and greater psychological distress of adolescents might be mediated in part by the family coping strategy [56]. A family mobilizing strategy that reflected an increased reliance and seeking of extra-familial, community-based support but lower self-esteem and more symptoms of distress and depression has been observed among adolescent survivors of Hurricane Katrina [56].

There are difference in coping following disasters and other common stresses. Adolescent victims of an earthquake reported more use of secondary control engagement coping, in contrast to adolescents with examination stress who reported more use of primary control engagement coping. Coping in earthquake group was more strongly associated with neuroticism; and coping strategies explained the relationship between neuroticism and depression. In contrary, perceived social support was more strongly associated with coping in examination group; and coping strategies explained the relationship between perceived social support and depression to a large part [57].

Perceived helpfulness of parents, siblings, relatives, friends, classmates, classroom teachers, guidance counsellors, psychologists can influence stress experience. In a study of seventh graders grieving the death of fellow students in a traffic accident, perceived

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helpfulness of various support person categories mentioned above was related to current stress levels, context of the disaster, and prior helping relationships. Their confronting behaviour and stress reaction levels were affected by personal loss and situational variables [58].

Excessive parental control, over-protection and infantalization of children for a long time after a disaster are harmful for adolescents' health and could be an obstacle in the recovery process. Researches highlight the importance of studying parental ways of coping in order to predict how adolescents cope with a traumatic event [59,60].

Community Coping

Community coping has increasingly received attention as a potential buffer of the negative effects of stressors but that literature is also limited in its application to disasters [61]. It is reported that there are considerable differences regarding perception of stress, resilience and coping among different cultural groups exposed to disasters [62]. This makes it interesting to study the coping patterns in communities in different cultures.

At the heart of community's dealing with disasters is the coping by family units. There have been few studies which have highlighted the methods employed by families. In the survivors of hurricane Katrina a relationship between family coping and hope, family hardiness and spirituality have been observed [63]. A study reported a strong buffering role for communal coping among those who evacuated from wildfires [61]. Self help groups in the community helped the victims to cope well following 1999 Orissa super-cyclone [6].

A wide range of coping strategies were being utilized by the drought-hit families in Australia from problem-focussed coping, optimism and positive appraisal to less adaptive strategies such as cognitive dissonance, denial and avoidance of negative social influences. A significant finding was the discovery of a range of collective coping strategies used by the families in this study and the reliance on social capital as an adaptive resource. Providing financial assistance to support current community initiatives and collective coping strategies may prove more beneficial to farmers than allocating inadequate amounts of funding to individual farming families. There were signs, however, that social cohesion of this community had become compromised due to competition for resources [64].

It is known that victims who are financially poor are particularly susceptible to climate-related natural hazards. As a result of their limited access to capital, adaptation based on social assets constitutes an effective coping strategy. Evidence from Bolivia and Belize illustrates the importance of social assets in protecting the most vulnerable against natural disasters [65].

Better preparedness for disasters can be presumed to have better coping in the post-disaster period in the community. However a study regarding the identification of coping mechanisms to deal with flood events, found somewhat paradoxically that the people that faced the highest risk of flooding were the least well prepared, both at the household-level and community-level flood relief [66]. Similarly, poor coping behavior was positively associated with risk perception, and knowledge of preparedness in the victims of typhoon disaster on coastal inhabitants in China [67].

Ethno-cultural coping mechanisms of affected communities in the face of incomprehensible adversity have been discussed. It was observed that the survivors of

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tsunami reconstructed meaning for the causes and the aftermath of the disaster in their cultural idiom. There were qualitative changes in their social structure, processes and attitudes towards different aspects of life. Survivors valued their unique individual, social and spiritual coping strategies more than formal mental health services. Their stories confirmed the assertion that the collective response to massive trauma need not necessarily result in social collapse but can include positive effects [45].

Coping by Disaster Workers

Varieties of coping strategies have been reported by the professionals working in the post-disaster situations [68]. A descriptive study on the emotional and coping responses following an explosion 52% of the multidisciplinary disaster workers reported that family members and coworkers were supportive in meeting their emotional needs following the disaster; 36% noted that support networks were not helpful. The coping behaviors most frequently used were to remind oneself that things could be worse (57%) and to try to keep a realistic perspective on the situation (53%). Eleven percent reported seeking emotional support from others or looking to others for direction [69]. Following 1995 Oklahoma bombing, most spouses and significant others of firefighters who participated in the bombing rescue effort coped by turning to friends or relatives, with less than 10% seeking professional help [70].

Coping strategies such as confrontive coping, distancing, seeking social support, accepting responsibility, escape-avoidance, planful problem solving, and positive appraisal were reported by fire fighters after the Taiwan Chi-Chi earthquake. These strategies significantly modified the effect of exposure to dead bodies on general psychiatric morbidity. Furthermore, confrontive coping, distancing, and planned problem solving significantly modified the effect of exposure to direct rescue involvement on general psychiatric morbidity. However, coping strategies were not observed to buffer the effect of rescue involvement or contact with dead bodies on post-traumatic morbidity. More frequent use of coping strategies could reduce the effect that exposure to rescue efforts has on the incidence of general psychiatric morbidity in rescue workers. However, coping strategies do not seem to reduce the influence of such exposure on trauma-related morbidities. This suggests that coping strategies can be used to prevent general psychiatric morbidity but not trauma-related morbidities [71].

Medical training and clinical exposure are believed to be somewhat protective for health care professionals; but these do not seem to prevent vulnerability to the emotional impact of their experiences [68].

Assessment of Post-disaster Coping

Coping in disaster situations has been assessed using various measures (table 2). It is essential to note that the coping strategies differ amongst cultures and these may be so varied that the scales may not assess all the coping strategies. It may be essential to have scope for

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open ended, exploratory assessment of coping strategies that are employed by the victims and their effectiveness.

Table 2. Scales used to measure coping in disaster situations

• Coping Resources Inventory from the Health and Daily Living Form (CRI-HDL)	[16]
• Coping Strategies Scale (CSS)	[29]
• Coping Style Questionnaire (CSQ-30)	[72,73,74]
• How I Coped Under Pressure Scale (HICUPS)	[75]
• Modified Coping Strategies Scales	[17]
• The Hurricane Coping Self-Efficacy (HCSE)	[48,76]
• Ways of Coping Checklists (WOC)	[18]
• Ways of Coping Questionnaire (WCQ)	[30]
• Youth Coping In Traumatic Times (YCITT)	[75]
• Simple Scale to Measure Coping Styles	[77]
• Ways of Coping	[78]

References are the representative studies utilizing the scale. List is not exhaustive.

The Hurricane Coping Self-Efficacy (HCSE) measure is a validated tool for assessing self-efficacy appraisals after hurricanes. The HCSE measure exhibits excellent internal consistency, external validity and repeatability after Hurricane Katrina [48]. In another study HCSE was positively associated with optimism and social support, but negatively associated with general psychological distress, trauma related distress, and resource loss [76].

Simple Scale to Measure Coping Styles covers different ways the persons try to cope with the stress. It has items on social, emotional, behavioral and cognitive coping and spiritual methods for coping [77].

Youth Coping in Traumatic Times (YCITT) is a brief measure of coping strategies administered to children and adolescents after a mass traumatic event. The YCITT was developed for the New York City - Board of Education WTC Study, conducted 6 months after 9/11. It has an acceptable fit of a four-factor solution based on the HICUPS (distraction, active coping, support seeking and avoidance) [75]. How I Coped Under Pressure Scale (HICUPS) is a lengthier, widely used scale [75].

Coping Style Questionnaire (CSQ-30) it is a 30 item scale which relates to subject's general coping style, and not coping of a specific event. The questionnaire rates coping style from 1 (never) to 4 (very often) on the following three dimensions: A: Task-focused coping; B: emotion-focused coping and C: Avoidance-focused coping [72].

How to Facilitate Coping?

It is clear that in a proportion of the disaster victims signs of inability to cope become manifest in psycho-socio-occupational dysfunction and impaired quality of life, those persist a great length of time [6,10]. On the other hand, victims those who master their problems by

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working out ways of effective coping, they may emerge from the experience with increased competence and resilience [12].

Community Focus

Programmes to support the victims to effectively cope the disaster trauma should preferably focus on the affected communities; while the individual victims can be helped for their specific needs. Individual oriented stress reducing interventions that use coping as starting point could be more effective by taking into account the subjective experience of the social context in terms of trust and feelings of mutual support and reciprocity in a community. Observations indicate that affected people may especially benefit from a combination of individual stress reducing interventions and psychosocial interventions that foster cognitive social capital [79]. In addition, it is relevant that the post-disaster interventions should be grounded in the ethno-cultural beliefs and practices and should be aimed at strengthening prevailing community coping strategies [45].

Culture appropriate coping strategies should be facilitated. As it is known that the responses to catastrophic stresses like disasters and coping strategies used by individuals are strongly influenced by cultural factors as well as social support and other factors [80]. The cultural differences in coping should be understood and given due importance while supporting the victims to come to the terms of the loss and rebuild their lives. For example, in cultures which are kinship-based, the help may be available within kinship, and the services may rely on such systems [80].

From the perspective of external disaster worker, culture sensitivity regarding the affected communities is extremely important to be able to help the victims. Lack of understanding about the cultural differences of perception of trauma, coping strategies, indigenous sources of support and healing, religious life, may come as a hurdle in the way of supporting the victims for effective coping.

Being Vigilant and Prepared

Effective coping starts from the pre-disaster warning phase. Remaining informed and prepared, gives better chance to cope well, if the disaster could be anticipated even for a brief period. A theoretical analysis of responses to disaster warnings suggests that effective emergency decisions are most likely to be made, when a vigilant coping pattern is dominant. This requires that the following four mediating conditions are met: i- awareness of serious risks if no protective action is taken; ii- awareness of serious risks if any of the salient protective actions is taken; iii- moderate or high degree of hope that a search for information and advice will lead to a better (i.e. less risky) solution; and iv- belief that there is sufficient time to search and deliberate before any serious threat will materialize. When one or another of these conditions is not met, a defective coping pattern, such as defensive avoidance or hypervigilance, will be dominant, which generally leads to maladaptive actions [81]. This highlights the role of pre-disaster preparedness, having adequate, accurate and timely information, taking protective actions, and having hope in supporting measures. Effective measures in the pre-disaster period may decrease the impact of the trauma. However for many

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kinds of disasters which are less predictable the scope to remain prepared may be very limited.

Coping in the Post-disaster Phases

In the post-disaster phases various supportive measures can help the victims to cope better [6]. These might help in preventing various morbidities that are seen. Outline of some of the methods are discussed.

Practical Help

In the immediate aftermath of disasters, practical help from others supports the victims to cope with the trauma. Psychosocial input by the disaster workers should be characterized mainly by practical help and emotional support and by 'being there' [6]. Disaster mental health assistance is usually more "practical" than "psychological" in nature. Disaster worker may assist problem-solving and decision-making. They should identify specific concerns, set priorities, explore alternatives, seek out resources, and choose a plan of action. They should also inform about resources available, relief measures and agencies, and health care [4]. These measures will help the victims to cope with the emerging and constantly changing situations.

The victim's own attempts to cope with the problem should also be analysed. In the process, many adaptive or maladaptive strategies may come to the fore. Avoidance of the problem is least adaptive. In contrast distraction and attempts at relaxation are adaptive coping strategies which can be encouraged.

Group Interventions

Later, support from self-help groups may be all that is required to facilitate coping. Such groups are both cost and clinically effective. It provides members with personal contact, information, an opportunity to share coping techniques, a sense of universality and belonging, increased self worth, reinforcement for positive change and opportunity to help others. Group processes have a very important role in supporting positive coping, shaping the behaviour and alleviating personal and social handicap of the individual. Responses to the situation change in a positive direction following social learning in a group situation. The group dynamics are utilized to correct the individual's distorted perception to the situation and enhance individual coping for greater adaptation to the changed circumstances [10].

The ability to conduct such groups with trauma survivors and professionals during and post disasters is a vital skill and serve to provide immediate relief and constructive coping [82]. Group interventions can include counseling for grief, encouraging coping through various culturally appropriate group activities, community measures e.g. observing religious activities and rituals [6].

Social skill training also helps the victims to acquire skills in different areas to meet the demands of coping stressful situations, interpersonal relationship, and self care. A major area

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of social skill training is assertiveness training. Training to downplay anxiety, modelling, desensitization of threatening stimuli, positive feedbacks and rewards are used to enhance assertiveness in different situations.

A study examined the effectiveness of a psychoeducation intervention based on Peplau's approach, including problem-solving compared with intervention with medication on PTSD symptoms and coping of earthquake survivors. There was a significant difference between the psychoeducation with medication group and the 'medication only' group with the first group showing greater relief of symptoms. Generally, there were no differences between the 'medication only' and 'psychoeducation only' groups [29].

Supportive psychotherapy tries to bring back the emotional equilibrium of the victims so that they can function almost according to their previous level of functioning. It aims to relieve the person's distress by ameliorating the pathological condition of symptoms and helps to strengthen the healthy coping mechanisms of an individual to enable him to recover from the effects of the stressful situations.

Some of the victims decompensate so much under the pressure of the traumatic experience that their inability of cope leads to risk of suicidal behaviour. It is essential to assess the suicide counters i.e. the factors for which the person will not attempt suicide, and strengthen these. Usually the suicide counters are: children in house, sense of responsibility to family, pregnancy, religiosity, reality-testing ability, and problem-solving skills, positive social support and positive therapeutic relationships. These factors can be good coping resources and need to be highlighted to augur positive coping.

Perceived CSE has emerged in recent years as a focal mediator of posttraumatic recovery and provides a possible intervention target [83]. Verification of its independent contribution to posttraumatic recovery across a wide range of traumas lends support to the centrality of the enabling and protective function of belief in one's capability to exercise some measure of control over traumatic adversity [84].

Eventual mastery of the disaster experience involves reorganization of the individual victims's inner intra-psychic world and the post-disaster external reality which have been disorganized by the loss of their anchorage. This reorganization can be helped by the various methods. The maintenance of hope of eventual personal mastery is essential which provides a basis for continued striving. Regular activity through adhering to a daily schedule of work and social interaction is important even though this initially provides little emotional satisfaction and seems empty and meaningless. Seeking support from other people in compensating for current deficits is helpful [12].

Supporting Children and Adolescents

Coping in children can be facilitated, through various methods [85]. Facilitating adaptive coping strategies has the potential to decrease the long-term behavioural health consequences and help children positively adjust to a stressful life experience [86]. There are few studies which suggest various methods of encouraging coping in children.

At the outset it is essential to provide a safe and secure environment for children and adolescents in such devastating times. In the post disaster period, schools and communities can serve as a sanctuary for children and their families [50].

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Children can be supported emotionally through the engagement processes, explained about difficult situations, bereavement, and can be suggested coping methods through the play content. Interaction with an empathic, objective, neither judgmental nor over-indulgent therapist enables the child to reintegrate, reorganize, and proceed with recovery. Potentially the child may internalize and identify with those qualities in the therapist [87]. Play therapy for children has been used in post-disaster situations [6,51] facilitating expression, ventilation and eventually better coping with the trauma.

Following a faith-based intervention for children affected by natural disaster, parents reported increased coping skills related to weather among some children [88]. Building coping skills without the structured trauma narrative may be a viable intervention to achieve symptom relief in children experiencing trauma-related distress. However, it may be that highly distressed children experience more symptom relief with coping skills plus narrative processing than with coping skills alone [89]. It has been suggested that the caregivers of children and adolescents who suffer from PTSD should be encouraged to convey belief of and empathy for their children, provide a forum for children to discuss the trauma if they choose, and promote coping skills that have been helpful following other stressful events [90].

Supporting Disaster Workers to Cope

Working in disaster situations is stressful. Stress of the situation, scarcity of support, individual vulnerability and being away from one's usual supportive network makes the situation more difficult. It is essential to discuss ways to facilitate coping by the disaster workers/volunteers.

Preparation before going to the disaster situation is essential. Information on what to expect, other supporting resources available in the ground help in building the confidence. Depending upon the nature of disaster and relief work it may be days or weeks to months for which volunteers may have to stay in the ground. The volunteers should develop a 'buddy' system with a co-volunteer to keep eye on each other's health or stress reactions. They should encourage and support the co-workers. Activities like physical exercise, listening music, reading books help. Volunteers should eat regularly and sleep adequately. Use of humour, positive self-talk and relaxation are important [91]. One should take breaks if effectiveness diminishes. Alcohol or tobacco should be avoided. Monitoring self through writing diaries, staying in touch with own family and friends and making new friends helps reducing stress [10].

Optimism amongst health care workers in disasters was found to be helpful both in daily medical work and in cases of medical emergencies. Optimism was also revealed as one of the key components of resilience and self-efficacy. Strengthening the optimism through initiative programs with appropriate information, social support, professional trust, and leaders' modelling behaviour, will raise the well-being and enhance coping skills of the health care workers during and in the aftermath of disaster scenarios [92].

An organized approach to management of stress response in the volunteers is known as debriefing. Debriefing has been understood to influence coping. The focus is on the emotional aspects of the experience. In educational debriefing, disaster workers are acquainted with possible personal reactions. Normal stress responses, specific skills for coping with stress and how to provide support for each other are taught. In this regard, 'outside teams' in contrast to

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'own debriefing teams of affected organization' may be helpful as interim measures to demonstrate the universality of the process of coping with traumatic stress and grief management [93]. In an illustrative study rescue workers who participated in a structured 2.5 hour group psychological debriefing in addition to the operational debriefing and received brief stress management counseling after a fatal traffic accident had lower frequency of symptoms compared to the non-debriefed group [73].

Characteristics of a Disaster Worker for Effective Coping

Certain traits and attitude towards life in general are found to be helpful in constituting the so called 'survivor personality' [94]. Characteristics of individuals opting to volunteer for disaster work would ideally comprise of strong commitments, a sense of involvement in life and clear values. They should possess paradoxical traits of gentleness and strength; trust and caution; self confidence and self criticism; dependence and independence; and, toughness and sensitivity. A feeling of control of their circumstances and willingness to admit what can not be controlled are important. Ability to see change as challenge (not just a threat), commitment to meet the challenge in a way that will make them stronger persons, ability to see both positive and negative sides of any situations, liking to challenge themselves are other required assets. Personnel trained to absorb painful, emotional, angry expressions of distress without reacting personally or becoming defensive; or without promising immediate solutions, are most valuable in lowering effects of stressors and mitigating victim's reactions. Most persons interested in disaster work can cultivate such qualities and can improve through training [10] which will help them in coping the disaster experience more effectively.

Conclusion

Ability to cope is the key to surpass the catastrophic trauma of the disasters. Coping is an important element relevant for post-disaster psychosocial and occupational effectiveness. Inadequate, ineffective coping leads to many psychiatric manifestations. Various inhibiting factors are known which influence the process of coping. Coping can be facilitated and strengthened by various methods. Outcome of a traumatic experience is not always bitter. If the victims turn to resourcefulness, use inner strength, and endure the crisis as a challenge; they may get new understandings, insights and may gain increased self-esteem and coping repertoire. In a post-disaster situation it is essential to emphasize and strengthen the existing community coping strategies that will support its individual members in a culture-appropriate way. Greater understanding in coping mechanisms will help supporting the disaster victims in a better way; and effective use of these is expected to prevent various morbidities.

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Chapter 10

PECULIARITY OF THE FLIGHT AND THE DESTRUCTION OF THE TUNGUSKA COSMIC BODY

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ABSTRACT

The Tunguska disaster, which occurred at about 7 a.m. on June 30, 1908 over Eastern Siberia, has no equivalent in the Earth's recent past. The interaction of the Tunguska cosmic body with the Earth's atmosphere was witnessed by thousands of inhabitants of Eastern Siberia, who noted unique characteristics of this event. The visual size of the flying object was >2 km, which is considerably, (>10 times) greater than the real size of the Tunguska body. The body's substance was visibly breaking into pieces. The flying object resembled something aflame: both in its colour and form, i.e. the substance that separated from the object was undergoing a reaction of burning with atmospheric oxygen. The duration of the flight of the cosmic body was more than 1 min. The object became visible at heights of >500 km. The dispersion ellipse of the Tunguska cosmic body, the longer and shorter axis of which are ~4000 and ~2000 km, respectively, was determined. The southern part of the dispersion ellipse was found on the base of the form of the area covered by noctilucent clouds, which appeared as a result of the Tunguska disaster. The northern part of this ellipse corresponds to an area with an intense growth of trees, located to the north of the epicenter of the disaster. To form a similar dispersion ellipse, the object had to explode at a height of more than 1,000 km over the Earth's surface. The final destruction of the Tunguska body took place at a height of ~6 km above the ground. In spite of the liberation of energy in 5 10^{23} erg during this explosion, several hundred trees survived the disaster, located at a distance of <7 km from the epicenter. According to researchers, the explosion of the Tunguska cosmic body was of the sort of volume detonation explosion which is most widespread in nature. The explosive destruction of the object over the epicenter lasted several minutes and was represented by a series of strokes, which were more than 10 in number. As a result, over the explosion area there appeared an atmospheric discharge, which reached a height of 80–90 km above the Earth's surface. According to estimates, the Tunguska disaster was

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accompanied by the transfer of charges in ~10^5 C and the generation of magnetic fields 50–60 times greater than the Earth's magnetic field.

1. Introduction

The Tunguska disaster occurred on June 30, 1908, at 7 a. m. local (Krasnoyarsk) time. The explosion of a cosmic object took place in the atmosphere above the Siberian taiga near the Podkamennaya Tunguska river – 65 kilometers to the north-west of the Vanavara trading station. This explosion was accompanied by an unprecedented release of energy ~10^{23} erg. As a result of this explosion, the forest was flattened over an area of more than 2,000 km^2; seismic and air waves were registered as well. Window panels in the houses were found broken at a distance of 300–400 km. One thousand kilometers from the epicenter some appreciable vibrations of ground as well as reeling of different objects were widely recorded.

The Tunguska phenomenon is one of the most important manifestations of an intrusion of a cosmic object into the Earth's atmosphere. It differs from all similar preceding catastrophes considerably, since the effects that accompanied the end of this space stranger were registered by plenty of geophysical instruments. Another information source is numerous eyewitnesses of this disaster. More then 700 stories of inhabitants were collected in the archive [Vasil'ev et al. 1981]. Among the eyewitnesses were people with a university education including political exiles, who had taken part in the revolutionary movement of 1905.

A considerable number of stories was collected on the trail. Many messages with a description of this phenomenon were independently sent by eyewitnesses to different organizations. It is reasonable to believe that the very first descriptions contained more authentic information. It is well known that in stress situations such as the Tunguska disaster the human memory stores details and keeps them all during one's life. That is why the results of eyewitness interrogations carried out 50 years after the event also contain unique information.

2. The Flight of the Object

Many thousands of people who lived in the territory between the rivers Yenisei and Lena and Lake Baikal become eyewitnesses of the Tunguska disaster.

2.1. The Size of the Object

According to Astapovich [1951], the flying object was seen on a sunny morning inside a circle with a radius of > 700 km. The flying object was described in more than 250 reports, and the visual size of this object (D_{viz}) was compared with that of the Sun (D_{sun}) and the Moon in 38 reports. Whichever trajectory of the flight of the Tunguska body we might draw (Figure 1), we always can find points at a distance >250 km from this trajectory for which an inequality D_{vis}>D_{sun} is possible. Accounts show that in this case D_{vis}>2 km [Gladysheva 2011]. According to all estimations, the size of the Tunguska cosmic body was D_{obj} ~100 m.

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Therefore, the flying object had a visual size which exceeded its veritable size many times $D_{viz} >> D_{obj}$. According to evidences from eyewitnesses, the flying object represented an inflammation both in color and in form, i.e. the substance which had separated from the object entered into the reaction and burned with the oxygen in the air. Thus we suppose that the flying object represented a comet nucleus with the size D_{obj}, which had a luminous shell around it with a size of D_{viz}.

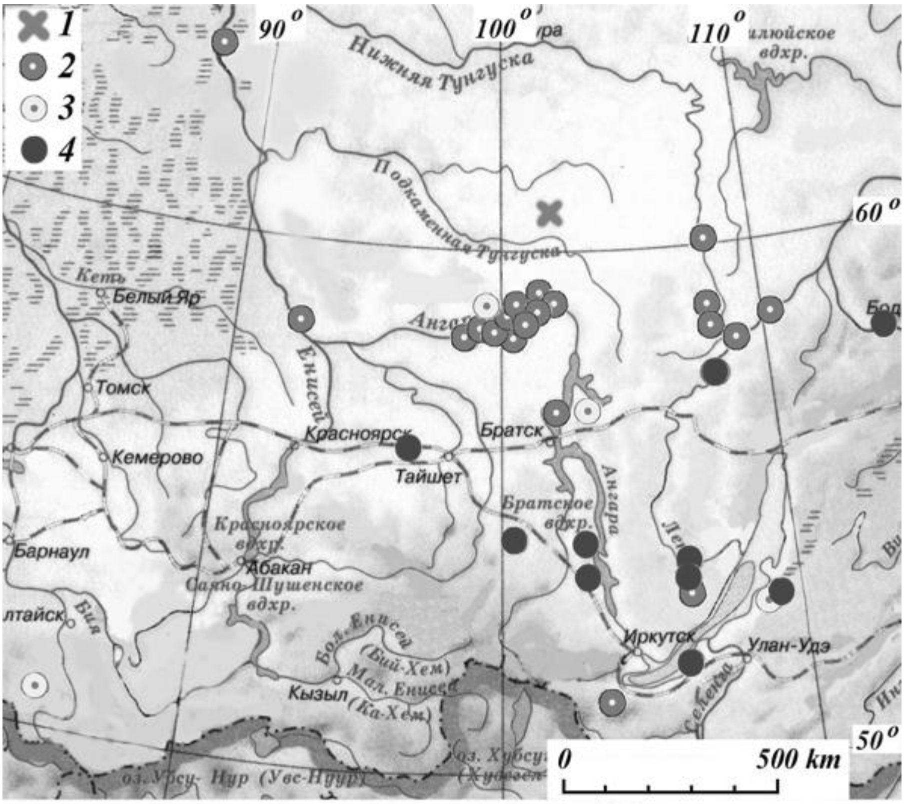

Figure 1. The visual size of the Tunguska cosmic body as it was observed in different settlements (according to reports of inhabitants of the Eastern Siberia). Sign: 1 – the epicenter of the explosion of the Tunguska body; 2 – the size of the flying object exceeds that of the Sun; 3 – the size of the flying object was similar to the visual size of the Sun; 4 – the size of the flying object was smaller than the visual size of the Sun.

2.2. The Duration of the Tunguska Cosmic Body's Flight

The period of time when the cosmic body was observed, as well as its speed in comparison with other flying objects, is estimated in 102 observations. Having an analysis of all reports, it is possible to offer the following division (Table 1).

The perception of time in a stressful situation is very relative. Therefore it is necessary to give special attention to reports in which eyewitnesses were doing something at the moment when the object flew by. It is noted that people had enough time to approach a window and watch the phenomenon. In some cases eyewitnesses left houses responding to the call of

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people from the outside and observed the flying object. Here is, for example, the story of an eyewitness from the village Klimino (~300 km from the epicenter): ‘My father rushed out of the house suddenly and cried: ‘Maybe the chimney has fallen?’ My father ran out of the house, ran along the street. I followed him. He passed one street and then turned into an alleyway. I ran after him as well and saw the fire, which was already descending. I saw it low over the mountain … Bigger than the Sun, oblong …’ [Vasil’ev et al. 1981]. On the assumption, that eyewitnesses observed only a fragment of the trajectory of the celestial body, it is possible to conclude that the time of the Tunguska body’s flight was more than 1 minute. The duration of the observation of the flying body (>1 minute) calls into question the meteoric origin of this object. Large meteorites practically do not interact with the Earth's atmosphere and are not slowed down by it; therefore, the time of their flight is <10 seconds.

Table 1. The duration of the observation of the Tunguska cosmic body

Time of flight	Number of reports
< 10 s (As a falling star)	14
10 – 30 s (More quickly than a plane, more slowly than a falling star)	18
30 s – 1 min (Similar to a plane’s speed and more slowly)	23
1 – 10 min	8
> 10 min	5

2.3. Height of Body’s Appearamce

The Tunguska cosmic body became visible and started discharging some matter at an altitude of >500 km [Epiktetova 2008; Gladysheva 2011]. It is assumed that the cosmic body’s disintegration was explosive at these altitudes. This follows from the evidence of witnesses from the Aleksandrovka village (Altai Side), who observed the Tunguska body from the gorge bottom: “At seven o’clock in the morning, sunrise had already taken place, but the Sun had not yet appeared from behind Mt. Glyaden. Then, a ball of light suddenly appeared in the sky, and its dimension and brightness rapidly increased… When this ball appeared, the entire locality was unnaturally illuminated, and this illumination was oscillating and came in wave-like flashes… The unnatural oscillating light was terrible…” The increase in the object’s dimensions, as well as the change in its brightness, can be explained by explosive matter discharges. Sparks that escaped from the body and burned with a cracking noise, according to numerous witnesses, indicate that the interaction between the Tunguska cosmic body matter and the atmosphere was explosive during the entire flight [Gladysheva 2011].

3. Matter Dispersion Trail

During some days after the explosion, an anomalous atmospheric luminosity was observed in the northern hemisphere from latitude 40^{o} to 60^{o} from Yeniseisk to London, covering more than 6 thousand kilometers. In Asia and Europe, it was light enough to take

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photos or read newspapers at night. An exceptional development of noctilucent clouds resulted in White Nights not only in the Baltic lands but also in middle latitudes and even in the Black Sea region. On the first night after the explosion, astronomers could not carry out their observations because no stars could be seen in the sky. In addition, there were optical anomalies in the day-side sky: various kinds of halos around the sun were observed; there were changes of sky polarization and atmospheric transparency, etc.

3.1. Solar Halos

Different solar halos in the form of rings and columns were observed after the Tunguska disaster in Oxford, Oslo, Yekaterinburg and other cities in Europe and Asia. An anomalous state of the dayside atmosphere in England and Norway was observed ~12 h after the Tunguska cosmic body explosion. According to the information of Nadein [1908], the beacon keeper at the Gulf of Riga observed numerous rings near the sun on July 2, 1908 from 8.45 a.m. till 10 a.m. This unique phenomenon took place in a layer of clouds that had covered the sky in the morning.

The anomalous state of the dayside atmosphere lasted for several months in some areas. In Grossfolk near Hamburg, false suns and halos of extremely rare configurations were observed in July and August 1908. It is important to note that halos and coronas around the Sun were even observed at several points in the United States (Utah and Washington states). In Washington solar halos were observed on July 1 and 2 [Vasil'ev et al. 1965].

Halos are atmospheric optical phenomena related to refraction and reflection of the Sun's light in ice crystals suspended or falling in the air. To explain these anomalous phenomena, it is necessary to assume that a large quantity of water was carried into the atmosphere, which indicates that the Tunguska cosmic body was of a comet origin [Gladysheva 2011].

3.2. Noctilucent Clouds

A gigantic field of luminous clouds extending over more than 10 million km^2 was formed after the Tunguska catastrophe. The region of "White Nights' extended from Eniseisk and Krasnoyarsk, which is located slightly west of the crash site of the TCB, to England; and its southern boundary reached the Black Sea and Tashkent. The anomalous luminosity observed in the summer of 1908 almost everywhere in Central Russia and Europe. Rudnev [1909], who was at that moment near the village Muratovo (~53^o N, ~36^o E), remarked the following: "on the night of June 30 – July 1, 1908, soon after sunset (8.24 pm) a greenish luminescence, gradually increasing, became visible. By 11 pm it was as light as during White Nights, which at this latitude never occur. The sky was practically clear, with only some clouds situated in a thin layer along the horizon. Stars grew dim, only the most sizeable – Vega, Arcturus, etc. – were seen. The brightest light seemed to originate from thin, slightly parallel – ribbed clouds (a bit sloping to the horizon); the center of the greatest light intensity was moving gradually from the west (W) to the east (E) and at midnight was exactly at the north (N). The luminous clouds themselves seemed to not change their position. The color of the clouds went from pure white near the luminous ones; it turned golden orange and then to red (to E and W). Upwards it changed through greenish and blue to dark-violet at its zenith." Rudnev [1909]

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noted that in the course of previous years in the period close to the summer solstice the appearance of luminous noctilucent clouds was quite often observed. As a rule, the luminescence set in 4–5 minutes after sunset and continued for about 30–35 minutes. But on June 30 it continued, with extraordinary intensity, up to sunrise, melting into it. In many places in Russia this phenomenon was repeated with lesser but still considerable intensity on July 2, 1908.

Similar reports also came from other places in Russia. Rossin [1941] noted that on June 30, 1908 at the town of Narovchat (53°53` N, 43°44` E) the night was totally absent or, one could say, it was a White Night in spite of this day being "the third day after the new moon with sunrise at 2.42 a.m. and sunset at 9.25 p.m. according to the loose-leaf calendar." Rossin, who was keen on photography, made the photo of this phenomenon. He set his camera and began shooting a view of the town at 11.30 p.m. and finished punctually at 12 p.m. During the process Rossin was reading a newspaper very easily without any artificial light. Light of the evening glow during the shooting illumined objects from the north – west side. Thus, on the photo one can see opacity on the southern side of temple buildings and the south-west wall of the corner house. In normal conditions it is impossible to get similar illumination. This confirms the fact that the shooting might be held only in the time interval between sunrise and sunset [Rossin 1941]. Just like the above-mentioned observation, the source of light in this case also was the Sun, though the latter was considerably below the line of the horizon.

In the majority of cases, light nights over Russia and Europe appeared twice. Daytime, twilight, and nighttime phenomena relate to noctilucent clouds and light refraction by ice crystals. The field of noctilucent clouds was formed as a result of crystallization of water vapors which was released when the matter of the TCB reached altitudes of 70–90 km. The time of observation of light nights depended on the ice crystal settlement rate at these altitudes. Descending under the action of gravity into the mesosphere, where temperature rises with decreasing altitude, the ice crystals had to lose water up to their complete disappearance. This explains the fact that White Nights over Europe and Asia were only detected during two days. According to rough estimations, the quantity of water that was released into the atmosphere as a result of the cosmic body's destruction was $10^{10}\div10^{11}$ kg [Gladysheva 2011], therefore, we can conclude that the TCB had a comet nature.

3.3. Hypothesis of Frank-Lebedinets

It is assumed that comets explode in the Earth's atmosphere at altitudes of ~1700 km [Frank et al. 1986]. This hypothesis was proposed in order to explain the observed short-term "atmospheric holes" in the UV range. The Dynamics Explorer 1 satellite registered a 5–20% decrease in the intensity of natural dayglow in the UV range at the atomic oxygen wavelength (103.4 nm). This UV radiation weakening lasts several minutes. It is assumed that a small comet with a mass of ~10^5 kg transforms into a particle swarm and flies in an expanding cone. Water vapor which absorbs UV radiation, is most probably released when this comet breaks down [Frank et al. 1986; Gladysheva 2011].

Only this hypothesis concerning explosive interactions between comets and the atmosphere makes it possible to explain the following data. First, according to balloon and rocket twilight atmospheric sounding, the dust content of the atmosphere is considerable at

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altitudes higher than 100 km and rapidly increases with increasing altitude. The particles of an exploded comet should decelerate precisely at these altitudes. Second, short-term (shorter than 40 min) and very considerable increases in the dust particle impact registration frequency were recorded on the Prospero and GEOS-2 satellites. It is assumed that the satellites crossed dust jets caused by explosions of the nuclei of small comets at those instants. Third, one only fails to explain the quantity of water in the thermosphere, mesosphere, and upper stratosphere due to the diffusion of water vapor and methane (with subsequent decomposition) from the near-surface atmosphere. Water should flow in from space [Lebedinets 1991; Gladysheva 2011].

3.4. Form of Dispersion Trail

Discharged matter (even with an organic component) can reach the Earth's surface if it loses its cosmic velocity as a result of an explosive discharge from the corresponding cosmic body's surface. Particles that retain cosmic velocity start burning or melting at altitudes ~100 km. In this case, only the refractory components of discharged matter can reach the Earth's surface.

According to the evidence of numerous eyewitnesses, obscuration took place on the day of the Tunguska catastrophe. "It was noisy. Night fell and was subsequently replaced by day. When it was noisy, it was daytime, which was replaced by night and day again" [Epictetova 2008]. In this quotation, noise means sound effects that accompanied the TCB destruction. The obscuration was mostly similar to twilight and lasted ~1 h. This obscuration was observed several hours after the catastrophe and coincided with the audible the sound effects and even with the body flight instant in several cases. For the majority of eyewitnesses, the TCB flew between them and the Sun. Therefore, the discharged matter, which moved toward the Earth in the form of a cloud, could cause the effect of temporary obscuration [Gladysheva 2011].

A considerable part of a cosmic body's discharged matter would evidently continue moving along the trajectory of this body. When a cosmic body's matter can reach the Earth's surface, the precipitation area of this matter can be determined based on the effect of this matter on vegetation. Several facts indicate that biomass gain is related to the matter of the TCB. First, it was reported that trees grew much more intensely at the epicenter of the Tunguska catastrophe and along the TCB trajectory. This indicates that a certain new factor stimulated tree growth when the TCB matter was added to soil. Second, a series of experiments was devoted to the effect of fertilizers on growth of crops, the composition of which was similar to that of the ash from the peat layers sampled at the TCB explosion epicenter and corresponding to the time of the Tunguska disaster [Golenetsky et al. 1977]. As a result, it was detected that the crop capacity of meadow grass, potato and flax was substantially increased [Zhuravlev and Zigel' 1998]. Thus, it was proved that the TCB matter promoted an increased biomass gain [Gladysheva 2011].

Kasatkina and Shumilov [2007] plotted the region with increased annual tree growth related to the Tunuguska disaster (Figure 2). This region (about 2 million km^2) is located north of the explosion epicenter and slightly shifted westward. It extends up to the Arctic Ocean. If the cosmic body was mostly moving northward when the matter was discharged at

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altitudes >100 km, we can superpose the northern segment of the TCB matter dispersion ellipse with the zone of accelerated tree growth, taking particle dispersion into account.

The southern segment of the TCB matter dispersion ellipse could be determined from the field of noctilucent clouds (Figure 2). Taking into account the location of the Sun during the Tunguska disaster, we can assume that the shape of the eastern, southern, and western edges of the region with atmospheric anomalies depends on the transfer of the matter under the action of solar radiation. During the Tunguska disaster, the Sun was east of southeast. Under the action of solar radiation, small fragments and water vapor within the TCB matter dispersion ellipse first had to be carried almost westward and northward near noon until they decelerated at an altitude of ~100 km [Gladysheva 2011].

In that way, we have the dispersion ellipse of the Tunguska cosmic body, the longer and shorter axis of which are ~4000 and ~2000 km, respectively (Figure 2). Only the hypothesis of Frank-Lebedinets could explain the very large size of the matter dispersion trail of the TCB.

4. Destruction of the Tunguska Body over the Epicenter

The explosion energy has been estimated from analysis of barograms and seismograms, ballistic waves from the TCB and the taiga destruction. The most likely value of the energy, which was liberated during the explosion over the epicenter was found to be 5 10^{23} erg [Bronshten and Zotkin 1995]. The height of the explosion zone was determined (i) over the area of the forest standing upright, (ii) as the location of the lighting zone which was found from burns on tree branches, (iii) as well as barograms and seismograms. The evaluated height of the explosion zone was ~6 km [Vasil'ev 2004].

4.1. Radiation of the Tunguska Disaster

One more characteristic of explosions is their radiation. It represents a flow of radiant energy, covering infrared, visible and ultraviolet parts of the spectrum. The influence of the radiation of explosions is characterized by the light pulse Q (cal/cm^2). Radiation during the Tunguska disaster was so powerful that a feeling of scorched human skin was noted at a distance of 65 km from the epicenter [Krinov 1963]. According to medical data, in order to reach this effect, a light pulse of ~3 cal/cm^2 is required (Figure 3a). Dry trees, brushwood on the ground and reindeer moss caught fire at a distance of ~50 km from the epicenter and living needles on the trees fell down at ~30 and ~40 km, according to Evenk's stories [Suslov 1927, 1967]. To undergo combustion, dry branches and growing needles need ~8 and ~21 cal/cm^2 (Figure 3a), correspondingly [The effects… 1962]. Based on these data (Figure 3a, line 1), the energy of the light flash was calculated as $10^{22}\div10^{23}$ erg [Zolotov 1961; Zhuravlev 1967]. This value is comparable with the full energy dissipated during the TCB's destruction. Such powerful radiation should have resulted in total devastation of vegetation at the epicenter. However this didn't happen.

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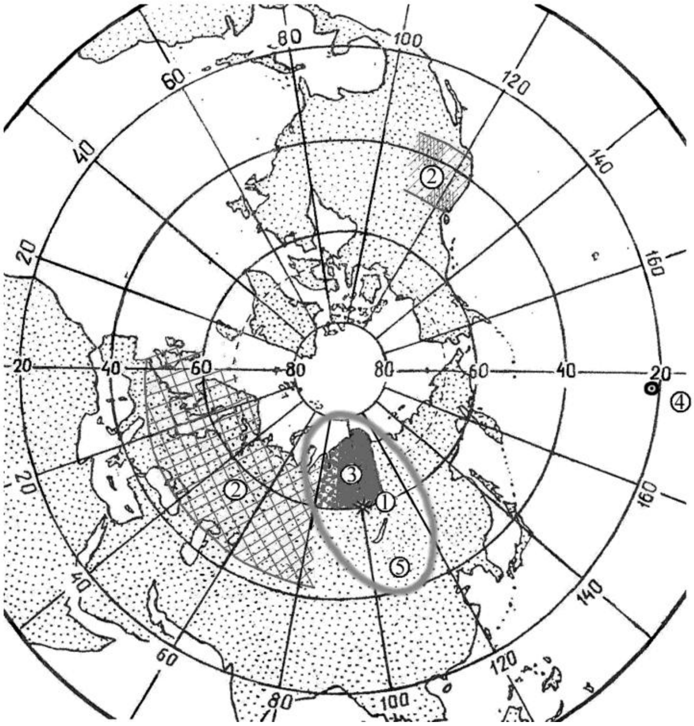

Figure 2. The Earth's Northern Hemisphere: (1) the explosion epicenter (~61° N, ~102° E); (2) the regions with noctilucent clouds [Gladysheva 2011] where optical anomalies were observed in summer of 1908; (3) the region where trees grew intensely after the Tunguska catastrophe [Kasatkina and Shumilov 2007]; (4) the point where the Sun reached its zenith at the instant of the disaster [Bronshten 1991]; and (5) the TCB matter dispersion ellipse.

Field investigations of the devastated area showed that several hundred trees which survived the disaster were located practically at the epicenter. More than 80 groups of living trees, mainly larches, cedars and pine-trees were found around the Northern and the Southern swamps at a distance of less than 7 km from the epicenter [Zenkin et al. 1963].

According to Kulik [Kulik 1927; Vasil'ev et al. 1981] – the first investigator of the disaster site – the trees in the epicenter of windfall and around it were not carbonized, but only scorched. The burn of the vegetation was exceptionally homogeneous and invariable everywhere, including the parts of the dry land isolated by water and separate trees in the middle of swamps. Investigating the influence of light radiation on different vegetable samples, the experimenters determined that carbonization of the bark of living trees, such as fir- and pine-trees, occurs at Q>15 cal/cm^2 [Tsynbal and Shnitke 1988]. Since Kulik didn't discover carbonization of the tree bark near the epicenter, we can conclude that the light pulse at the epicenter was ~15 cal/cm^2 (Figure 3a).

One more detailed study of living trees located at the epicenter of the explosion was made in the seventies. 120 larches were investigated in the following way [Vasil'ev 2004]. When trees which survived the disaster were chosen, the steeplejack climbed up on them to a height of 15–20 m, discovered branches that been growing before the disaster, determined their height above the ground, their azimuth, the inclination to the horizon and then sawed them down. Subsequent study of these brunches was conducted in the laboratory.

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It turned out that not all trees which survived the disaster have burns but only the ones which were young and at the same time reached an upper deck of the forest. Their thin and flexible branches were not broken by the shock wave similar to crowns of older trees with thick branches, which were broken and destroyed [L'vov and Vasil'ev 1976]. The affected surface stretches as a stripe mainly along its upper side (Figure 4). Nearer to the trunk with increasing branch diameter it got narrow and came to naught. On branches ends where the diameter is little and crust is very thin, the affected area sometimes exceeded half of the branch perimeter. Within one tree, one can see lesions of different intensity (Figure 4) from hardly visible "staples" (suberized and getting dark, probably on account of overheating cambium part, the layer of 1908) up to strong lesions of the damaged and destroyed more deep-seated layers [L'vov and Vasil'ev 1976].

As a result of an investigation, the area with the burns to branches was determined. Variations in the maximal diameters of affected branches depending on the distance from the epicenter are shown in Figure 3b. The burn effect was found up to about 6÷9 km around the epicenter of the explosion. Outside this area, burns to the branches are absent, therefore, we take Q~0 cal/cm^2 at a distance R~10 km from the epicenter (Figure 3a). Inside this area, both the trees with evident traces of thermal effects and the trees without these traces were found. According to estimates, for the appearance of a physiological burn and the mortifying of the cambium on the branch in 10 mm thick it is necessary to have a light pulse of 10±5 cal/cm^2 [Florensky 1963]. Trees with maximal diameter of affected branches D~10 mm are located at a distance ~5 km from the epicenter (Figure 6b); therefore, we take Q~10 cal/cm^2 at this distance (Figure 3a).

Considering Figure 3a, one can infer the presence of two regions with different levels of radiation. How can this be explained? Investigations of the disaster site have shown that the burning took place within a few minutes after the shock wave propagation. On the grounds of this observation, it has been suggested that the explosion of the cosmic body, and the liberation of radiation energy, have a different nature [Gladysheva 2009]. In Vanavara (65 km from the epicenter), the feeling of scorching on human skin was caused by a short-term flame which was thrown up to 50^o over the horizon [Astapovich 1951]. The TCB exploded at a height of ~ 6 km and in this case the radiation source had to be located at a height of <5^o over the horizon. Therefore, powerful radiation was emitted by the object, which was located considerably above the zone of destruction of the TCB (see below Chapter 5). The level of burn of vegetation near the epicenter turned out to be essentially smaller than the value calculated, because the area around the epicenter was partially shielded from the action of powerful radiation by the dispersed cosmic body and by dust that was lifted from the ground by shock waves. In that way, the very burn damage to branches in the epicenter can give information about the temperature in the explosion zone. According to available estimate [Zhuravlev 1967], to cause thermal damage similar to that found at the epicenter, it is necessary to heat the bark to 600 K, or, if we deal with a momentary pulse, – to 1000 K. Tsynbal and Shnitke [1988] calculated that the explosion destruction of the TCB took place at a temperature of less than 3000 K. This value is substantially less than the temperature needed for absolute evaporation of a cosmic body in the end of its way.

On the basis of the aforesaid, we can conclude that the upper limit of the temperature of the explosion destruction of the TCB is close to 3000 K. This value is comparable with the temperature of chemical explosions and essentially lower than the temperature of the

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explosion zone in nuclear tests and the explosion zone during full evaporation of cosmic objects.

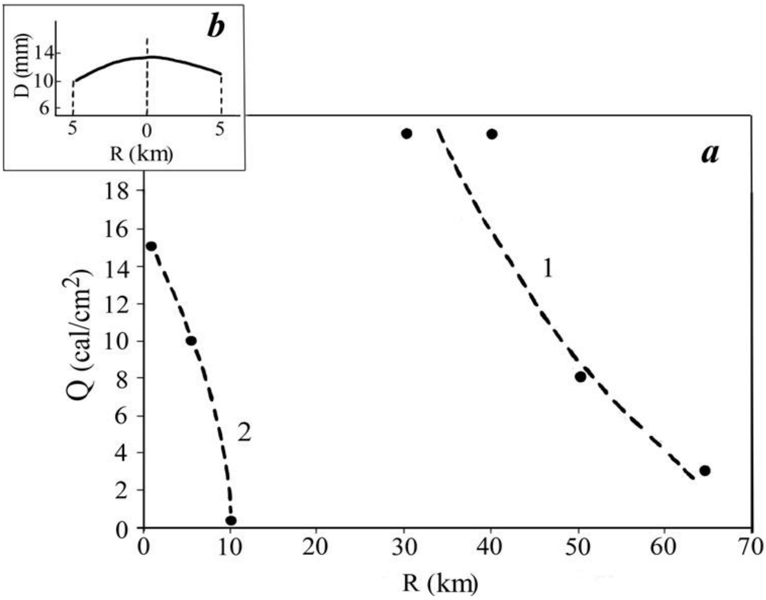

Figure 3. An influence of the radiation on vegetation. (a) – Approximate values of light pulses Q vs distance from the epicenter of the TCB's destruction; (b) – The maximal diameter D of affected branches, depending on the distance from the epicenter [L'vov and Vasil'ev 1976].

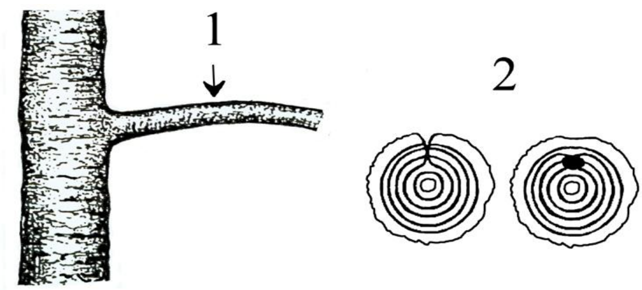

Figure 4. The burns on branches of trees which survived the Tunguska disaster. Signs: 1 – the place of burn affections, 2 – the cuts of affected branches.

4.2. Shock Waves

The Tunguska disaster led to formation of an exclusively powerful shock wave. The total area of destroyed forest was 2150±25 km^2 [Fast 1967], including continuous windfall ~600 km^2. An Evenk who was 30 km from the epicenter was thrown back by the shock wave to at a distance ~40 m [Suslov 1967]. Another man (at a distance of 65 km) was thrown ~6.5 m [Krinov 1949]. The swinging of objects stimulated by the air wave was noted at a distance of more than 1000 km from the epicenter [Astapovich 1951].

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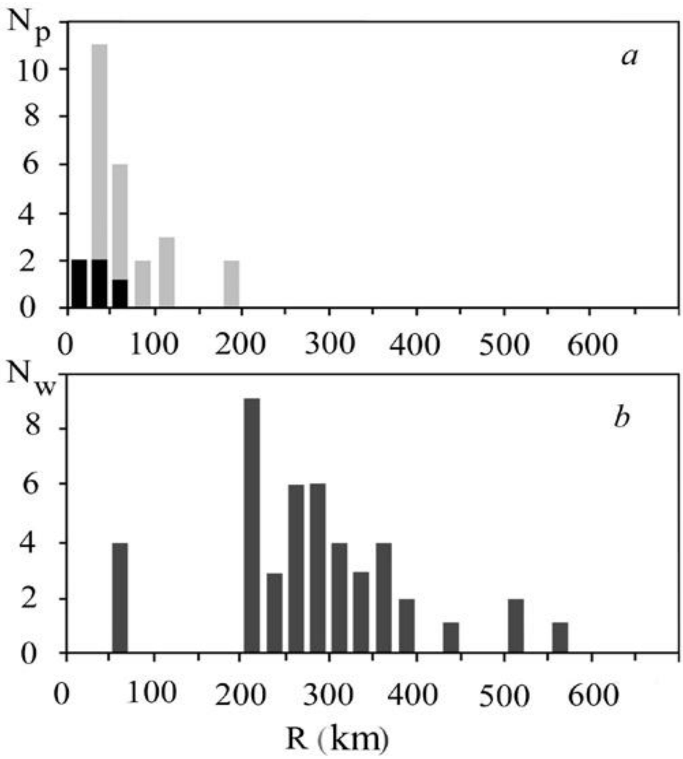

Figure 5. Effects of the shock wave vs distance from the epicenter on people and buildings (using data from Vasil'ev et al. [1981]). (a) Number of reported casualties (black) and losses of consciousness (grey). (b) Number of reported broken windows and glass.

The destroying action of the shock wave on people and dwelling buildings is shown in Figure 5. Human losses due to the Tunguska disaster were noted in 5 reports from the catalog [Vasil'ev et al. 1981]. Killing action of the shock wave took place at a distance of less than 30 km from the epicenter, and at a greater distance people perished from fright or in absence of medical care. Cases of unconscious states and stunning action of the shock wave were noted by eyewitnesses up to 200 km from the epicenter. In several cases people were unconscious for 2–3 days.

The boundary around the epicenter where the forest was 90% struck down depends on the direction, and is situated at a distance from 15 to 25 km [Boyarkina et al. 1964; Tsynbal and Shnitke 1988]. According to estimates [Zolotov 1969], at a distance of 25 km from the epicenter an overpressure ΔP on the shock front was ~60 kPa. Chooms (wigwams) of the Evenks were pulled down by the shock wave at a distance more than 100 km, but wooden houses in Vanavara (65 km from the epicenter) resisted, only many glass window panes were broken. Therefore, ΔP in Vanavara was ~9 kPa [The effects… 1962]. Glass fractures were reported mainly at a distance from 200 to 400 km, but isolated cases were registered up to 570 km away (Figure 5). To fracture a glass, an overpressure ΔP of 2–7 kPa is required [The effects… 1962]; thus, we could assume a ΔP equal to ~2 kPa at a distance of 500 km from the epicenter. Proceeding from the aforesaid it was calculated that attenuation of the overpressure ΔP with the distance R occurred slowly enough $\Delta P \sim 1/R$.

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4.3. Microbarograms

Comparing the microbarogram of the Tunguska explosion [Whipple 1930] with those of nuclear [Wexler and Hass 1962] and chemical explosions, one can note the following. The microbarogram of a nuclear test is practically symmetrical with regard to undisturbed condition values of the compression and rarefaction waves, i.e., on the wave front the pressure rises up to 162 μbar and then decreases to -169 μbar. The same picture, similar to a fading sinusoid is observed for a chemical explosion. The microbarogram of the Tunguska explosion [Whipple 1930] differs essentially from them. The compression front of the Tunguska explosion is slightly sloping (reaching 42 μbar), and the subsequent rarefaction wave is very deep (up to -161 μbar). This difference in the microbarograms of the Tunguska explosion from those of nuclear and chemical explosions is in agreement with the hypothesis by Tsynbal and Shnitke [1988] that in the Tungusla disaster we are dealing with a volume detonation explosion.

A volume explosion is a detonation of a combustible substance dispersed in air which occupies a large volume. The size of the explosion area in the Tunguska disaster can be estimated starting from the area of forest characterized by the presence of the so called “telegraph poles”, i.e. trees stripped of their branches standing upright close to the epicenter, where the shock wave came from above. The horizon size of the explosion area for the TCB can be >5 km. Ignition of the mixture in the explosion area spreads at a terminal velocity, and this could explain why the compression wave of the microbarogram of the Tunguska explosion grew gradually. A deep rarefaction wave is also characteristic of an explosion in a large volume. It is known that a volume explosion in comparison with other is characterized by a deeper rarefaction, which comes after the shock front’s passing over and a larger duration of attenuation of the overpressure at the shock wave front.

The explosion that took place during the destruction of the TCB, both in the form of microbarogram and the duration of attenuation of the breaking force, as well as in the level of burn of vegetation in the epicenter, resembles a volume explosion which is widely distributed in the environment.

5. Ionospheric Discharge

According to the evidence of eyewitnesses, the explosion destruction of the object lasted several minutes and was represented by a series of strokes, of which there were more than 10 [Voznesensky 1925]. The plurality of explosions is also confirmed by the seismogram from Irkutsk (965 km from the epicenter), that shows 3 waves at the end of the earthquake record. It was determined that these waves moved through the air at the speed of sound [Voznesensky 1925].

The TCB was a comet, i.e. it contained enough inflammable material which was liberated in the process of heating and crushing of the object. A dust cloud that consisted of fragments of the cosmic body was formed during the explosion of the TCB. The explosion destruction of the TCB in this cloud lasted for 2÷6 min. According to eyewitnesses reports, explosions followed one after another for about 5–6 min, with an equal time interval (10 explosions in 1 min). It is possible that explosions were initiated by lightning strikes. Separation of charges

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took place in the explosion zone of the cloud. It is supposed that large fragments of the TCB with positive charge moved to the ground under the influence of gravitation, whereas negative charges were lifted up with aerosols by powerful convective current since the temperature in the explosion zone was 2000–3000 K. When the positive charge flies on the ground, a condition can arise where the electric field strength in the entire atmospheric interval will exceed the threshold value. This takes place if a charge of ~10^4 C is removed from a dust cloud. If charges of ~10^5 C were formed as a result of Tunguska body destruction, the field strength corresponding to the breakdown strength can quite probably exist at altitudes of 10–100 km for several seconds. Since electrons in strong fields are produced in the form of avalanche, the discharge intensity should increase with increasing lifetime of such fields. Energy release accompanied by displacements of a charge of ~10^5 C should be comparable with the total energy of the Earth – ionosphere condenser (~ 10^{10} J). An upward propagating discharge over the dust cloud was observed as a bright light near the horizon from a distance more than 500 km and lasted 2÷5 c [Gladysheva 2009].

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Chapter 11

When Flood Invades the Village …

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Abstract

This project aims to clarify the mechanism which determines community cohesion alteration following natural disaster. Data were collected from residents in a flood effected community (Carlisle, UK) using an anonymous questionnaire survey. This project revealed that, contrary to the findings of previous hazard studies, community cohesion was not predicted by the length of residence, or any other demographic characteristics of residents.

Community cohesion was actually predicted by sense of community, community cognition, and degree of community participations. Cohesion alteration was not uniform, but varied along levels of hazard severity (i.e., flood invasion). Specifically, community cohesion increased in line with hazard severity at the initial flood stage, as residents recognized of the importance of community entity and therefore were brought closer together to cope with the losses they suffer. However, when the severity aggravated, residents transferred their focus to individual interests rather than community interests, which resulted in decreased community cohesion. The present project distinguishes itself in examining community cohesion in the wake of a natural disaster in the real world. Implication of the findings towards community reconstruction and suggestions to hazard researchers are discussed accordingly.

Keywords: Flood Invasion, hazard studies, community cohesions

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INTRODUCTION

One of the long held goals of hazard studies has been to establish a model that can conveniently describe the impact of hazard (e.g., volcano, flood, and earthquake) on community and residents. Since 1980s, for instance, first-line researchers were keen to explore how the community responds to hazard information, and how the governments and community leaders can help reconstruct the suffered community and victims more efficiently (Lindell and Perry, 1993; McKay, 1984; Varela, Koustouki, Davos and Eleni, 2008). Among these studies, researchers endeavoured to scrutinize the impact of hazards using different perspectives; however, only limited studies focused on the influences of such impact on group cohesion (see exception on: Speller, 2005).

Group cohesion is a crucial but invisible force, sticking individuals together as a group. The cohesion itself can be regarded as a dynamic process reflected in the tendency for a group to stick together and remain united in pursuit of its goals and objectives.

Although group cohesion is a meaningful topic, contemporary research paid little attention to the impact of disasters on real group cohesion (see exceptions on Chang and Chen, 2006; Van Vugt, 2001). This project believes that this is, at least in part, due to the tradition of cohesion research which has been conducted primarily in the laboratory. Such tradition may also restrict the ecological validity of cohesion studies.

Therefore, this project aimed to analyse how real groups cope with a natural disaster and examine the association between natural disaster and community cohesion, via a field study (i.e., the flood invasion in Carlisle, United Kingdom). The results will first and foremost increase the understanding of hazard impact on community cohesion, then enrich the theoretical framework of hazard studies, and, finally, benefit to the community reconstruction policies.

The Nature of Group Cohesion – Group Affect, Cognition and Behaviour

Before analyzing the nature of group cohesion, there is a need to explain why people prefer to live in groups. Kruglanski and Higgins (2003) indicated that one of the key characteristics of humans as a species is their sociability and an important expression of human sociability is their membership in groups. For example, people may belong to diverse groups through different stages of their life, bound together under the auspices of external structures, such as school, business organization, religious worship or other professional affiliations. When people join the group, they are newcomers and are treated accordingly. Gradually, their involvement with the group’s activities and its objectives may deepen and their status in the group may improve. From the perspective of psychodynamics, people move from the periphery of the group to its centre, and their commitment to the group as well as the group’s dependence on them increases proportionately (Levine and Moreland, 1990). Over time, people form a psychological link (e.g., attachment, a sense of belonging) to the group and work with other members in pursuit of its goals and objectives; then, the foundation of group cohesion is formed.

Interestingly, the mechanism of group cohesion is not fully understood and there may be no single definition or model that is unanimously accepted by researchers interested in this

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construct. Group cohesion was first theoretically defined by Festinger, Schachter and Back (1950), and they claimed that a field of forces, deriving from the attractiveness of the group and its members and the degree to which the group satisfies individual goals, acts upon the individual. The resultant valence of these forces of attraction produces cohesion, which is responsible for group membership continuity and adherence to group standards. Broadly speaking, cohesion captures the very essence of being a group – the psychological process that transforms an aggregate of individuals into a group. In group dynamic studies, researchers have developed different ways of analyzing group cohesion, including group affect, cognition, and behaviour. To begin with, group cohesion was associated with aspects of group affect, e.g., group membership (Perkins et al., 1990) and attachment to the group (Van Vugt, 2001; Van Vugt, 2003).

Secondly, field studies suggest that group cohesion is associated with group cognition. For example, Roy (2001) indicated that groups comprising individuals with similar cognitive processes outperform diverse thinking groups. Compared to their counterparts, groups comprising individuals with similar cognitive processes were better in task cooperation and had a better communication competence. Thirdly, recent laboratory studies have provided preliminary evidence to support that group cohesion is related to group behaviours. Chang and Chen (2006) found that, compared to their counterparts (i.e., lower cohesion teams), members from higher cohesion teams were more likely to cooperate with each other and showed superior group performance. People from higher cohesion groups also had lower intention of leaving the group and lower occurrence of actual departures. Similarly, Van Vugt and Hart (2004) claimed that social identity helps foster group loyalty behaviours. In their series of lab experiments, data showed that group members who identified strongly with their groups are more loyal to their groups when facing external challenges.

Overall, the aforementioned studies have conveyed a message that group cohesion is associated with a series of group factors, such as group membership (group affect), perception of group identity (group cognition) and involvement of group activities (group behaviour). However, as these prior findings were discovered on laboratory-based experiments, implications of these findings may be limited. In order to test the generalisability of these findings, this project proposed:

> Hypothesis 1: Group cohesion in the community is predicted by community affect, cognition, and behaviour.

The Impact of Disaster on Community Cohesion – The Perspectives of Individual Interests

From a sociological perspective, cohesion is often treated as a measure of social integration. Social integration reflects the degree to which individuals are psychologically linked to others in the group and are attracted to the group (Levine and Moreland, 1990). The strength of such a link depends on a variety of variables, both intangible (e.g., commitment to the group and perception of group identity) and substantive (e.g., financial incentives and learning opportunities). The characteristics of this link can be further clarified applying social dilemma theory (Dawes, 1980).

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A social dilemma is a paradox that arises from a social decision situation in which contributions are needed to attain some common and shared goal, and where the rational choice of the individual is to free-ride. Moreland (1999) found that individuals may stop cooperating with other group members and may even exit their groups if they can not receive sufficient interests from the group or the benefits received do not meet their expectations.

Following the logic of social dilemma theory, natural disasters such as floods and earthquakes should impact on community dynamics and destroy its cohesion, as individual interest has suddenly become more salient and community residents are looking after their own interests. Also, due to the free-rider concerns and anxiety of being exploited (Van Vugt, 2001), community residents may become reluctant to cooperate with each other during and after natural disasters. Plausibly, if no one is willing to contribute to their community, the community dynamics and consensus may break down, and, gradually, the community disintegrates. In a similar vein, hazard studies discovered that, due to the unawareness and under-estimation of flood risk, community residents often adopted a passive attitude toward flood invasion (Burningham et al, 2008; Speller, 2005). Once the flood invasion commenced, it was usually too late to stop the damages and residents were keen to protect their own interests (e.g., safety and food) rather than community interests. Under such circumstances, community cohesion inevitably degrades.

The Impact of Disaster on Community Cohesion – The Perspectives of Community Identity

From a different perspective, however, social identity theory (Tajfel and Turner, 1986) offers a completely different prediction pertaining to cohesion alteration after a natural disaster. According to Tajfel and Turner, people need to belong to groups to protect their self-esteem, feel being part of the group, and feel being involved within the group. Group consensus, that is, an opinion or position reached by a group as a whole, is a key concept here. Empirical studies indicated that, once the consensus is formed, individuals will be more willing to contribute to their group goals (Pruitt and Kimmel, 1977). Following the logic of social identity theory and group consensus, natural disasters (e.g., floods and earthquakes) should strengthen community cooperation and cohesion, as individual members realize the importance of cooperating together to achieve mutually desired goals, that is, protecting community property and private assets concurrently. Due to the needs to belong to a group and heightened awareness of collective survival (e.g., group consensus), community residents will be keen to cooperate with each other and protect their common goods during the hard times following a natural disaster.

In addition, hazard studies highlight that, due to the devastating impact on the community and individuals, victims were keen to unite to fight with the loss they had suffered. In February 2000, for example, Mozambique suffered its worst flooding in their history. 699 residents died and countless residences and farmlands were submerged in water. Moore, Eng and Daniel (2003) indicated that, under calamitous conditions, victims were pull together and worked with humanitarian aid organizations (e.g., Red Cross and other NGOs) to reconstruct their community. In September 1999, the Athens earthquake in Greece resulted in a series of psychological disorders and health problems among the residents. Varela et al. (2003) discovered that residents in the earthquake zone helped each other to cope with the

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catastrophe, although they suffered from the same symptoms, such as safety concerns, stress, and sleep disturbance. Other hazard studies also revealed similar findings that victims were willing to help each during the natural disasters, e.g., urban flooding in Australia (McKay, 1984; Smith and Handmer, 1984). In view of these findings, when the flood invasion commences, the community cohesion shall enhance.

The Impact of Disaster on Community Cohesion – Overview

To our knowledge, very little research has paid attention to the impact of natural disasters on group cohesion. The majority of prior group cohesion studies were either threat-incentive oriented (Perkins et al., 1990; Van Vugt, 2001), scenario-manipulation oriented (Chang and Chen, 2006; Hart and Van Vugt, 2006), or performance-assessment oriented (Bahli and Buyukkurt, 2005; MacCoun, Kier, and Belkin, 2005). In these prior studies, as threats were artificial, the ecological validity of subsequent analyses was thus compromised. In addition, social dilemma theory and social identity theory have provided valuable information and contributed to the understanding of group cohesion in the face of threat. These theories may be all partially correct, each explaining the mechanism of group cohesion under different circumstances. Yet, these inconclusive interpretations actually hinder the amalgamation of findings, and hold back the development of the group cohesion theories. For this concern, it would be valuable to clarify the direction of group cohesion alteration under the real threat of a natural disaster, pitting social dilemma theory against social identity theory. Two competing predictions were then proposed: *First*, disastrous conditions such as a flood invasion are expected to strengthen group cohesion, as community members realize the importance of cooperating together to achieve mutually desired goals, for example, building sand bags to block water or reconstructing the community in the wake of a disaster (as predicted by social identity theory); *Second*, it may be that a flood can destroy community cohesion as individual interests become more salient and people look after their own interests, whilst hoping to exploit the collective efforts of other members of the community, thereby negating the needs of the community in favour of servicing their own individual needs (as predicted by social dilemma theory). Finally, as aforementioned perspectives were against each other, this project proposed a non-directional hypothesis: *Hypothesis 2 – Community cohesion is variegated following the flood invasion* (Direction will be further examined in Results).

METHOD

Design and Procedure

In 2005 a severe and prolonged downpour flooded hundred residences in a small community (Carlisle, UK), paralyzed the public transportation system for four successive days, disrupted power supplies and caused widespread distress across the community. Residents in the community were relatively acquainted with each other, which served a baseline for community cohesion. For this reason, this community was selected for the survey and data were collected after the event using an anonymous questionnaire.

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Due to the limited budget and research staff, however, only residents from *easy-access* areas were enquired, including: Brampton Road, Melbourne Street, Orton Road, Silloth Street, and Warwick Road. Participants were initially contacted via the community centre and local leaders. Questionnaires were then sent to the respondents who agreed to partake in the survey, either by post or research assistants. Questionnaires were distributed in booklet form, along with a covering letter assuring research aims, data anonymity and voluntary participation. The letter also ensured that the survey *per se* is a pure collection of general ideas re: flood, survey data are only analyzed for academic purpose, and the data do not have any implication on the welfare and benefits of respondents. Overall, 106 questionnaires were distributed, 101 returned, and 96 of them were completed, giving an overall corresponding rate of 90.57%. In addition, due to two reasons, this survey did not investigate which street/area respondents came come. First, the community leaders had some ethical concerns re: identification of residence, as it may evoke some negative emotions during such disastrous event. Second, this survey did not intend to compare the heterogeneity between areas, as the analytic focus was the whole community rather than individual areas.

Sample

Respondents are all from Carlisle community, which is situated on the western coast and on the Scotland-England border (being bounded on the west by the Irish sea, on the north by Scotland, on the east by Northumberland, and on the south by Cumberland). The majority of 96 respondents are British and only four of them are European. Demographic characteristics of the respondents follow: Gender (*Female = 61.46%*; *Male = 38.54%*), age (*M = 39.52, SD = 15.76*), marital status (*Married = 53.13%*; *single = 20.83%*; *cohabited = 15.63%*; *divorced/separated = 6.25%*; *widowed = 4.17%*), residence ownership (*owned = 70.83%*; *rented = 15.63%*; *others = 11.46%*), length of time living in the community prior to the flood (*M = 13.5 years, SD = 13.69*), moved out after the flood (*37.50%*), moved back again of those who moved out after the flood (91.90%; only 3.04% of the entire sample moved out for good), duration of moving out, *i.e.*, outside the original community caused by the flood (*M = 3.14 months, SD = 4.65*) and number of dependents (*M = .62, SD = 1.10*).

Measures

The questionnaire survey is comprised of six scales. Details follow:

Community affect was measured using the Sense of Community Index (Perkins, Florin, Rich, Wandersman, and Chavis, 1990). There are totally twelve items in the scale and participants' responses to these items were recorded using 6-point *Likert* scale (*1 = completely disagree, 6 = completely agree*). Sample items include: *I think my community is a good place for me to live*; *My neighbours and I want the same things from the community*; and, *I can recognize most of the people who live in my community*. Internal consistency of these items was measured using the *Cronbach* formula (*α = .83*).

Community cognition was measured using the Social Life Feeling Scale (Qureshi, 1996). There are totally eight items in the scale and participants' responses to these items were recorded using 6-point *Likert* scale (*1 = completely disagree, 6 = completely agree*). Sample

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items include: *People in this community help each other out*; *The different ethnic groups in the community get on well with each other*; and, *Social relations between the different ethnic groups in this community have improved*. Internal consistency of these items was measured using the *Cronbach* formula ($\alpha = .74$).

Community behaviour was measured using the Community Participation Scale (Rapley and Beyer, 1996). There are totally nine items in the scale. Participants' responses to these items were recorded using 6-point *Likert* scale (*1 = very unlikely, 6 = very likely*). All items were preceded by the stem: *With reference to the questions below, please indicate how likely you are to do the following*. Sample items include: *Get involved in any local clubs, organizations or schemes*; *Contact my local council about local services*; and, *Contribute either money or time to a scheme to improve the community*. Internal consistency of these items was measured using the *Cronbach* formula ($\alpha = .77$).

Flood severity was measured using the Flood Severity Scale (Chang, 2007). There are totally ten items in the scale. Participants' responses to these items were recorded using 6-point *Likert* scale (*1 = not affected, 6 = severely affected*). All items were preceded by the stem: *Resulting from the flood of Carlisle, to what extent were you affected by*. Sample items include: *Problems with gas and electricity supply*; *The flooding of your residence*; and, *Delays in repairing of damage*. Internal consistency of these items was measured using the *Cronbach* formula ($\alpha = .86$).

In addition, as natural disasters can not be predicted precisely or manipulated, community cohesion alteration was assessed via self perceived changes between *pre*- and *post*- flood periods. That is, through retrospection, this project tried to obtain a proximal baseline for comparison across the time. For this purpose, participants were asked to rate five items preceded by the stem: *Compared to the pre-flood invasion period, how do you feel about the community after the Flood*. Sample items were: *Residents in the community more trust each other*, *Residents on the street more get on well with other*, *Neighbours more care what happens to each other*, *Social relations in this community have been better*, and *People get more involved in any local clubs, organizations or schemes*. All responses were anchored on a 6-point *Likert* scale (*1 = Completely disagree; 6 = Completely agree.*). As these five items showed a high internal consistency, all were regarded as a single scale (*Cronbach* $\alpha = .87$).

FINDINGS AND ANALYSIS

As shown in Table 1, multiple correlation analysis indicated that community cohesion was positively correlated with community affect ($r = .71$, $p < .001$), community cognition ($r = .67$, $p < .001$) and community behaviour ($r = .58$, $p < .001$). Flood Severity was negatively correlated with community cognition ($r = -.22$, $p < .05$). Community affect, cognition and behaviour were co-variables, sharing positive significant correlation ($r = .54$, $p < .001$; $r = .50$, $p < .001$; $r = .46$, $p < .001$, respectively). That is to say, when one of the three variables increases, the other two variables concurrently increase, and vice versa. Community cohesion was positively correlated with community affect, cognition, and behaviour ($r = .71$, $p < .001$; $r = .67$, $p < .001$; $r = .58$, $p < .001$, respectively). These figures explained that community cohesion increased in line with community affect, cognition, and behaviour, and vice versa.

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Table 1. Multiple correlation analysis

	α	1	2	3	4
1. Community affect	.83				
2. Community cognition	.74	.54***			
3. Community behaviour	.77	.50***	.46***		
4. Flood severity	.86	.01	-.22*	-.01	
5. Community cohesion	.87	.71***	.67***	.58***	-.06

***. p < .001; **. p < .01; *. p < .05.

Examination of Hypothesis 1

Multiple regression analysis revealed that community cohesion was predicted by a number of variables, and such prediction efficacy is apparent ($R = .80$). To be exact, community affect, community cognition, and community behaviour jointly accounted for 65% of the variation in community cohesion (ΔR^2). Statistical figures also show that community affect ($ß = .42, p < .001$), community cognition ($ß = .35, p < .001$), and community behaviour ($ß = .20, p < .01$) significantly predicted community cohesion ($F (3, 95) = 56.73, p < .001$). As shown in Table 2, community affect ($ß = .42$) had the highest prediction significance, followed by community cognition ($ß = .35$) and community behaviour ($ß = .20$). The results of collinearity diagnostics are satisfactory, indicating that multi-collinearity is not severe between predictors ($CI = 14.99$). In view of the aforementioned findings, Hypothesis 1 was supported. In addition, non-significant predictors included: flood severity ($ß = .02, p = .74$), gender ($ß =.05, p = .78$), age ($ß = -.08, p = .33$), marital status ($ß = -.13, p = .11$), residence ownership ($ß = .06, p = .43$), length of time living in the community prior to the flood ($ß = -.04, p = .64$), moved out after the flood ($ß = -.10, p = .15$), and number of dependents ($ß = -.05, p = -.64$).

Table 2. Multiple regression analysis

	B	*Std. Error*	*Beta* (*ß*)	*R*	ΔR^2
(Constant)	-.91	.39			
1. Community affect	.53	.10	.42***		
2. Community cognition	.45	.10	.35***		
3. Community behaviour	.23	.08	.20**		
				.80	.65

***. p < .001; **. p < .01. (F (3, 95) = 56.73, p < .001).

Examination of Hypothesis 2

For the sake of analytic validity, a univariate analysis of variance was conducted to examine whether residents perceived community cohesion differently (i.e., whether the

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heterogeneity exists). As the univariate analysis was conducted after the survey, administrative biases during the stage of data collection were efficiently precluded. The outcome of analysis reveals that residents' perceptions of community cohesion were quite varied ($F\ (1, 95) = 1430.67, p < .001$). That is to say, respondents (i.e., residents) possessed different viewpoints regarding: levels of community cohesion after the flood invasion. As the severity raw scores were ranging from 0.00 to 5.40, for the sake of analytic expedience, it is more sensible to categorize the sample into several sub groups on the basis of their perceived flood severity. This gave researchers a closer look to analyze the heterogeneity.

Table 3. Severity and cohesion

	Low Group	Middle Group	High Group	F/p
No of residents	31	33	32	
Severity raw score	0.00-1.49	1.50-2.89	2.90-5.40	
Community cohesion (μ)	$M = 3.81^{b}$	$M = 4.45^{a}$	$M = 3.86^{ab}$	F (2, 93) = 3.98, p < .02
	SD = 1.02	SD = 0.92	SD = 1.11	Levene = .12, n.s.

Note: Means share the same superscript are not significant ($Mdiff^{a\text{-}b} = 0.64, p < .05$).

In terms of categorization procedure, as too many sub groups may actually increase the complexity of data interpretation, this project therefore categorized the sample into three groups with similar size (i.e., equal number sampling). The rationale underlying such categorization is to help observe the different levels of perceived cohesion across groups more easily and to analyse why such heterogeneity exists. Details are shown in Table 3.

As shown in Table 3, three groups are manifested, including: Low group (residents who perceived not affected or only slightly affected; μ: 0.00-1.49, n = 31), Middle group (residents who perceived moderately affected; μ: 1.50-2.89, n = 33), and High group (residents who perceived severely affected; μ: 2.90-5.40, n = 32). In addition, subsequent analyses revealed that residents in the community felt their community cohesion was strengthened after the flood (t (95) = 37.82, p < .001). However, the extent of cohesion enhancement (i.e., levels of perceived enhancement) was not universal across levels of flood severity (F (2,93) = 3.98, p < .02; Levene = .12, n.s.). To be exact, the Middle group felt their community cohesion was greatly strengthened (M = 4.45, SD = .92), followed by the High group (M = 3.86, SD = 1.11) and the Low group (M = 3.81, SD = 1.02). The difference between Middle group and Low group was also significant (Mdiff = 0.64, p < .05). All three groups though reported higher-than-scale-midpoint (3.5) means for community cohesion. In view of these statistical findings, Hypothesis 2 was verified. Community cohesion was indeed variegated following the flood invasion and the enhancement (i.e., levels of perceived increment) varied along levels of flood severity.

Conclusion and Discussion

Being the first study to examine the impact of disasters in a natural setting on community cohesion, this project revealed two interesting aspects: a). community members felt their community cohesion was strengthened after the flood invasion but their degrees differed

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depending on their exposure to flood damage; b). community cohesion was predicted by community affect, cognition, and behaviour, but not any demographic characteristics. Prior studies of group dynamics suggested that the formation of cohesion was associated with stability (Van Vugt et al., 2005), structure of group boundary (Chang and Chen, 2006), length of living in the community (Gardner and Stern, 1996), or other demographic variables (Roy, 2001). Contrary to previous findings, this project revealed that community cohesion was not associated with the length of residence or other demographic characteristics (e.g., marital status, ownership of the residence, or number of dependents); instead, community cohesion was predicted by sense of community, community cognition, and degree of community participation. These findings are meaningful in several respects.

To begin with, although stability and structure of group boundary are important to group cohesion, especially for those artificially formed or manipulated groups in *lab* situations, they are not necessarily important to the community cohesion in natural settings. The heterogeneity of community members is much bigger than that of general group (e.g., business organizations and social clubs) members. Unlike general groups, community members usually do not have definite collective goals and their community does not embed a hierarchical management system. If one tries to use stability (or group boundary) to control community cohesion, such endeavours will very likely fail.

Second, the results indicated that the length of residence and demographics were not predictive of community cohesion. Instead, cohesion was linked to the sense of community (community affect), social life feeling (community cognition), and degree of participation (community behaviour). Different from prior studies, which focused on residence length and demographic variables (Roy, 2001; Van Vugt et al., 2005), this project developed an alternative method to index community cohesion, *i.e.*, community cohesion is a function of people's community affect, cognition and behaviour. This index focused on individuals' sense of belonging and perception of their group memberships. Adopting standardized scales, this method not only ensures measurement reliability but also improves ecological validity.

Third, all community members felt their community cohesion was strengthened after the flood. This seemed to imply that community members (at least in this project) were keen to repair any damage to their community after the flood. Specifically, residents in the flooded areas were willing to partake in community activities and devoted more attention to the community as a whole. These findings confirmed that disastrous conditions like flood invasion can strengthen group cohesion, as community members realize the importance of cooperating to achieve mutually desired goals, e.g., building sand bags to block water or reconstruct the community. On the other hand, however, results also indicated that, although all community members felt their community cohesion was strengthened after the flood, their perceived degree of increment differed as a function of flood severity they suffered. Statistical analysis revealed that the Middle group (moderately affected) felt their community cohesion was extremely strengthened, the High (severely affected) group felt their community cohesion was moderately strengthened, whereas the Low group (slightly or not affected) felt their community cohesion was slightly strengthened. This phenomenon can be further interpreted using an inverted curve (Figure 1).

These statistics revealed that social identity theory (Tajfel and Turner, 1986) works well for people encountering low to mediate levels of disasters: the flood actually helps to strengthen community cohesion by sharpening the need for cooperation to ensure collective survival (Points A to B). Yet, when the disaster becomes greater, social dilemma principles

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(Dawes, 1980) starts to work: people may have to shift their focus from collective goals to protecting individual interests (Points B to C). Figure 1 seems to provide a legitimate answer to explain the heterogeneity across a number of hazard studies.

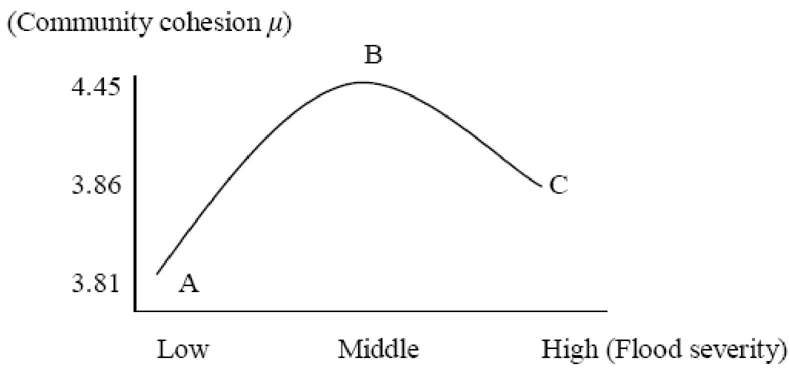

Figure 1. The impact of flood on community cohesion.

To be exact, when the flood invasion commences, a group of researchers proposed that community cohesion should decrease (Burningham et al, 2008; Speller, 2005), whereas the other group possessed an opposite viewpoint (Moore et al., 2003; McKay, 1984; Smith and Handmer, 1984; Varela et al., 2003). Nevertheless, this project believes that both groups were reasonable in their own views and their analytic rationales were righteous in their specific circumstances. As shown in Figure 1, the findings extracted from the survey have cunningly bridged the viewpoints from two opposite research groups and explained the mechanism of cohesion improvement (or deterioration) using an inverted curve.

Implications and Limitations

This project discovers that community cohesion is predicted by group members' cognition (sense of community), affect (social life feeling), and behaviour (degree of participation). In view of these findings, both local government and counsellors shall adopt appropriate psychological interventions to strengthen the psychological commitment to community, for instance, by establishing a community consensus of collective goals and corresponding action plans.

To assist a community after the wake of a natural disaster (e.g., flood and earthquakes), both community leaders and residents should always give priority to community cohesion maintenance and management during the reconstruction process. As flood severity also significantly impacted on perceiving community cohesion, there is a need to adopt different reconstruction policies for groups of people that have been affected to varying degrees of severity, to achieve maximum efficiency. To be exact, the severely-affected groups may need immediate assistance such as food and sheltering service, whereas the slightly-affected groups may need some psychological interventions to rebuild their confidence in living in the post-flood zone.

This project must concede though that the aforementioned analyses suffered from several limitations which compromise the generalizability of the findings. To begin with, some

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residents (about 5.20% of the population) permanently moved out of the community after flood invasion, so that their perception toward the community cohesion was not available and couldn't be further analyzed. Future research could target this population to probe reasons for their departure. Second, this project did not measure the community cohesion before the flood invasion, as the occurrence of natural disasters was rarely predictable. However, if such baseline data were available, a *pre*- and *post*- flood comparison analysis could then be attempted to obtain more convincing evidence of community cohesion changes attributable to the natural disaster.

Preferably, the data should have been collected right after the event. Nevertheless, as the field survey required permission from the research ethics committee and local community leaders, the actually survey was not commenced until 2.5 months later, which may affect the accuracy of people's recollection regarding the impact of flood invasion. Specifically, Lindell and Perry (1993) indicate that residents have different perceptions of volcano severity during different periods. Residents of at-risk areas may also have inaccurate beliefs about the hazard agent and its impacts, are unaware of available adjustments, and may have erroneous beliefs about the effectiveness of the adjustments of which they are aware. In a similar vein, recent studies reveal that the perception of hazard is often associated with demographic characteristics (Hakes and Viscusi, 2004) and personality traits (Chauvin, Hermand, and Mullet, 2007). These findings convey a message that the timing of hazard and individual differences may influence the way people respond to the hazard, either mentally or behaviourally. This project suggests that future studies shall take these factors into account in the procedure of data collection and interpretation.

Ideally, the findings extracted from the questionnaire survey should be collated and evaluated by the triangulation method, as quantitative and quantitative data are complementary in nature (Jick, 1979; Silverman, 2001). However, due to the disapproval of qualitative-data collection procedure (i.e., interviewing residents) from the local community leaders, qualitative data were thus inaccessible here. This project highly recognises the importance and imperativeness of triangulation method in the field studies and suggests it to future researchers of hazard studies.

To conclude, this project established a possible link between social identity theory and social dilemma theory in analyzing group cohesion. The findings implied that group cohesion may be a dynamic trigonometric function, in which cohesion is jointly affected by a series of community and personal factors, including: group membership (Perkins et al., 1990), sense of group (e.g., Levine and Moreland, 2006), flood severity, and group behaviour (identified in this project). Future studies may consider further analyzing the inter-associations among these factors, and other potential contributors to group cohesion, so that a full picture of cohesion variance can be clearly unveiled.

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Chapter 12

PALEO-LANDSLIDES AS A COMPONENT OF MULTI-HAZARDS (CASE STUDY OF THE BELICA RIVER BASIN, CENTRAL SERBIA)

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ABSTRACT

Landslide mapping in the Belica River basin in central Serbia revealed three landslides with surfaces larger than 0.5 km^2: Belica landslide (10.49 km^2), Bukovče landslide (0.4 km^2) and Ribnik landslide (0.59 km^2). The analysis of lithological, structural and morphological characteristics of the landslide locations showed that their formation cannot be explained by traditionally known genetic factors. This has led to the identification of earthquakes as potential stressors that could affect the formation of the studied mega-landslides. Seismic characteristics of the Belica River basin were analysed using the data from both pre-instrumental and instrumental (1909-2011) periods. The relation between earthquakes and the studied landslides was analysed through the slightly modified referent criteria. Out of six criteria, four support the seismic origin. The region where the landslides occur is a proven seismic region. Spatial distribution of landslides coincides with the strike of active faults or seismic zones. The dimensions of the case examples meet the required criterion for seismically induced mega-landslides. Geological and geomorphological settings are not sufficient to explain the positions of landslides. Further geotechnical research could show whether the slope stability indicates that the slope failures were seismically induced. The criterion of liquefaction occurrences for establishment of the role of seismic activity was not met due to insufficient evidence. Spatial distribution of lithological structures was used to determine the relative age of the landslides. Over 6 m thick alluvial sediments in the central part of the Belica River basin cover the foot of the Belica landslide. Such lithological relation of Quaternary sediments and Belica landslide points to its Pleistocene or Early Holocene age.

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Keywords: Paleo-landslide, mega-landslides, earthquakes, Belica River basin

1. INTRODUCTION

Certain parts of the world are subject to the impact of a variety of natural hazards. Apart from the spatial coincidence, there is a possiblity of synchronized activity, occurring as a consequence of causal relations between the hazards, which is referred to as a *multihazard*. It is necessary to differentiate the notions of a multihazard and a multihazard risk. In the first case, there is a causal (genetic) relation between two or more hazards. In the second case, two or more hazards might also be related just in a temporal or spatial way (occur simultaneously or consequently within a territorial unit, but without a mutual causal relation) (Kappes et al, 2010). The second case asks for an integrative study of the risk assessment (determination of vulnerability and resilience of the society) in the conditions of multiple hazards, with or without a causal relation between the hazards.

The landslides may be related and synchronized with earthquakes, volcanic eruptions, tsunamis (submarine landslides; Marui and Nadim, 2009) or floods. In cases of earthquakes and volcanic eruptions, the landslides are exclusively the secondary process, while in combinations with tsunamis and floods, landsliding is mostly the primary process. Synchronized processes of earthquakes and landslides were studied by Keefer (1984,1994), Crozier et al. (1995), Rodriguez et al. (1999), Pinto et al. (2008), Yin et al. (2009), Hancox and Perrin (2009). The main conclusion of these authors is that $M > 4$ earthquakes may initiate the landsliding process.

The earthquakes with $M \geq 7$ may initiate the formation of mega-landslides with volumes that exceed $10^8 m^3$. Landslides formed as consequences of volcanic eruptions were studied by Melosh (1987), Zaruba and Mencl (1969), Costa and Schuster (1991). The volumes of moved sliding bodies formed by combination of these processes may also exceed $10^9 m^3$.

As a primary process, the landslides may cause the formation of tsunamis. In such cases, the main scarp and a part of the sliding plane are above the sea level, while the landslide body is below sea level. Thus, the landslides of this kind are called the submarine landslides. They are characteristic for the litoral areas of volcanic islands (Whelan and Kelletat, 2003). These synchronized processes were studied by Holcomb and Searle (1991), Hürlimann et al. (2000), Ward (2001a, 2001b), Whelan and Kelletat (2003), Harbitz et al. (2006), Coppo et al. (2009).

Such combinations of multihazards have the largest spatial span, which may exceed 1000 km (Coppo et al, 2009). Being a primary process, the landslides may also initiate the floods. Combination of these processes often occurs in the river valleys of V-shaped cross sections. The sliding mass dams a river valley, causing an upstream lake formation and a subsequent floodwave outburst (Zeremski, 1964; Shang et al, 2003; Duman, 2009). In the cases when landsliding is the primary process, the activation of secondary hazards enlarges the affected territory.

This chapter shows the analysis of three pre-historic landslides in the Belica River basin in central Serbia (situation map in Figure 4). By the area and volume, the studied landslides, named Belica, Bukovče, and Ribnik, fall in the category of mega-landslides (e.g. Pinto et al, 2008). Being integrated into the natural-cultural landscape, the landslides were detected only in 2008 (Milošević, 2010), through preserved structural and morphological elements. The

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activity of landslides of such dimensions has not been detected on the territory of Serbia in the historic period. Considering the fact that the average precipitation in the area is only 800 mm, the hypothesis of the study is that seismism was one of the possible factors of mega-landslides formation.

Apart from the general data on the studied landslides, the chapter gives the analysis of indicators that point to seismism as a potential initial factor. The applied method refers only to the landslides formed in the pre-instrumental period.

2. Physio-Geographical Characteristics

The Belica River basin is situated in the central part of the northern temperate belt (Eastern hemisphere), in central Serbia (Figure 4). It is a left tributary of the Velika Morava River. The area of the Belica River basin is 231 km^2, the highest point being at 708 m a.s.l. (Mt.Crni Vrh) and the lowest at 109 m a.s.l. General orientation and inclination follow the NW-SE direction, with smaller deviations in the lower course. Morphologically, the Belica River basin includes three units: plains, hilly area and mountain area. The plains include the alluvial plain and the river terraces of the Belica, with inclinations up to 3º. The hills are the contact zone between the plain and mountainous parts, with the inclinations up to 10º. Hypsometrically, this zone spreads to 300 m a.s.l. Above this zone, the mountainous area is situated, with the inclinations up to 40º. For the purposes of this study, the lithological units within the basin were grouped into primary and secondary sediments. In the group of primary sediments, there are clastic sediments of considerable thickness, deposited during the lacustrian phase in the Neogene and later. This group comprises sands, alevrites, sandy clays, clayey sands, clays, etc. (Dolić et al, 1981). Spatial distribution of primary sediments includes the plain (Quaternary sediments) and hills (Neogene sediments). The group of secondary sediments comprises the regolith of compact rocks. In the Belica River basin these lithologies are distributed in the northern section and represented mostly by metamorphic rocks: gneiss, mica-schist, dolomitic marbles and amphibole schists (Figure 4). The regolith of these rocks is of varying thickness, and of sandy and clayey composition. It is thicker in the zones of greater tectonic damage. The significant structural faults are the Belica fault, Bunar-Majur fault and Jagodina fault (Milošević, 2010).

The climate is continental, with the average annual temperature of 11.2ºC. January is the only month with the average temperature below zero (-0.4ºC). Precipitation depends on altitude, and the annual values range from 600 mm to 950 mm. The months with highest precipitation are June and November, while the lowest precipitation is in October and February.

2.1. Physio-Geographical Position of Landslides

Positions of the three studied landslides (Belica, Bukovče and Ribnik) are similar in many aspects. They lie in the altitude range between 114 m and 257 m a.s.l, in the zone of hills. The lowest point on the topographic surface of the studied landslides is in the zone of contact between the hills and the plain. The Belica landslide has a northern aspect, while

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Bukovče and Ribnik are oriented towards the east. The landslides are developed in the Neogene sediments (the group of primary sediments, as defined above), whose bedding is undisturbed. However, the sediment layers within the landslide body have been subsequently disturbed by the ongoing process, which determined the development of secondary landslides of smaller dimensions (in the case of Belica landslide). The Belica landslide is situated in the area where the river valley has a conspicuous asymmetry. As a consequence of local tectonic processes and the uplift of the block in the northern part of the basin, the right valley side became much steeper and without tributaries, as a result of increased lateral undercutting. These circumstances were the predispositions to the Belica landslide formation.

Three studied landslides are situated in the precipitation zone of 650-700 mm.

3. Landslides Characteristics

Belica landslide is situated on the right side of the Belica River valley, and is 11.5 km wide. Structural and morphological indicators of sliding have been detected (landslide scarp, pseudo-terraces), while the recent processes are observed only as secondary features (secondary landslides).

The landslide area starts from the ridge which is the divide between the Belica and Lugomir Rivers, and ends in the Belica River alluvial plain. The length varies from 313 m to 1870 m. The width of the landslide stretches from the mouth of the stream Vrbski Potok into the Belica River (on the west) to the south-western foothill of the Ćelijan hill on the east (Trnava village). In this area, the Belica does not receive any right tributary, so the drainage is endorheic.

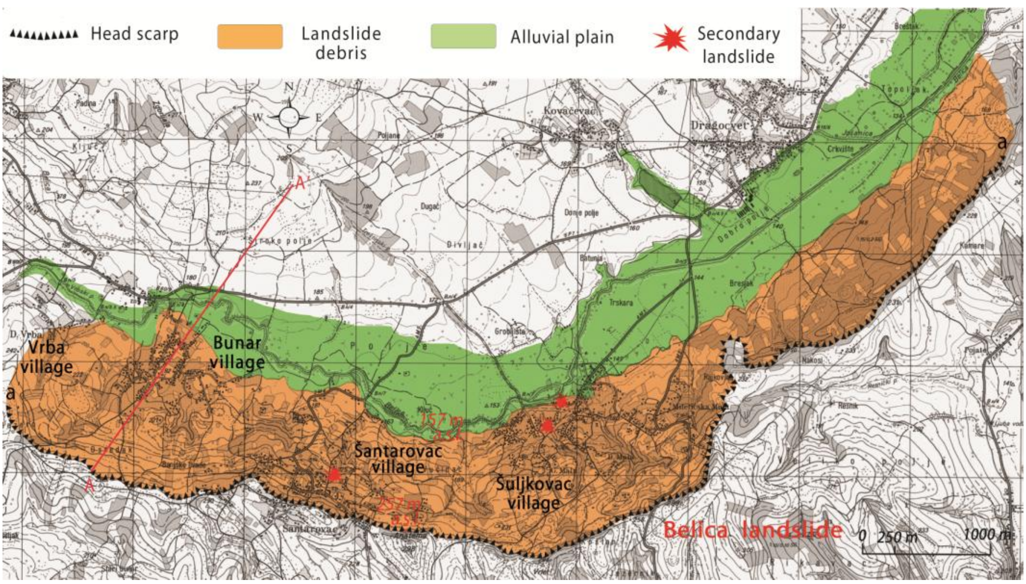

Figure 1. Position of the Belica landslide. Sections a-a' and A-A' refer to Figure 6 and Figure 8, respectively.

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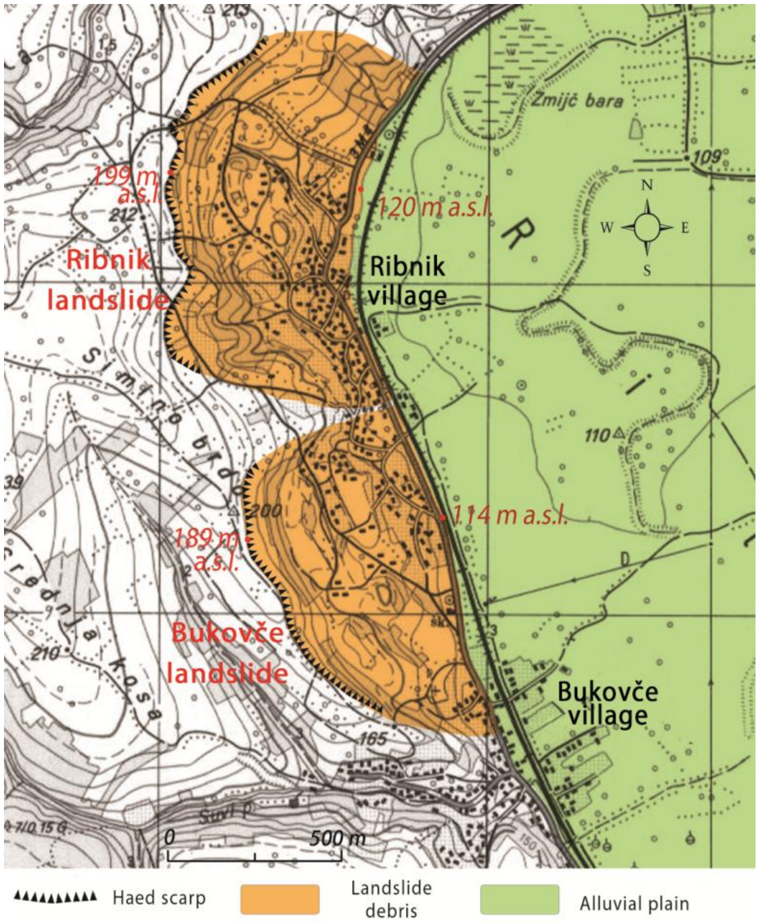

Figure 2. Positions of Bukovče and Ribnik landslides.

In the western part of the landslide there are certain indicators (toponyme Veliko Jezero, meaning “large lake”; and hygrophyte vegetation) which point to previous existence of a lake in that area (Mijatović, 1941). The lake was most probably formed immediately after the sliding, and positioned between the landslide scarp and the sliding mass. The total area of the Belica landslide is 10.49 km^2, which is 4.5% of the total Belica River drainage area. Approximate volume of the landslide is 260 x 10^6 m^3 (0.26 km^3). Average denivellation between the landslide scarp and the lowest topographical point (on the contact with the alluvial sediments of the Belica) is 93.1 m. The landslide foot is situated below the alluvial sediments of Quaternary age. Four villages are located along this sliding belt: Bunar, Šantarovac, Šuljkovac and a part of the Vrba village. Parts of these settlements are lying on the morphological elements of the landslide, mostly on pseudo-terraces and the main landslide scarp (Šantarovac).

Bukovče landslide is situated on the left valley side of the Belica, between the stream Suvi Potok on the south and the hill Simino Brdo on the north-west. Structural and morphological indicators of sliding are present. Apart from the landslide scarp and the pseudo-terrace, there is also a pseudo-valley, which is out of the hydrological function. Estimated volume of the sliding mass is 10 x 10^6 m^3. The Bukovče landslide covers almost

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the entire valley side, at the length of 486 m, with the width of 1212 m and the total area 0.4 km^2. The maximum denivellation between the landslide scarp and the lowest topographical point of the landslide is 75 m. A part of the Bukovče village, together with the local school, is situated on the pseudo-terraces of this landslide.

To the north from the Bukovče landslide, also on the right valley side of the Belica River, there is the Ribnik landslide. It covers 0.59 km^2, and the estimated volume is 15 x 10^6 m^3. The length reaches 608 m (approx. 90% of the entire slope), while the width is up to 1057 m. Denivellation between the landslide scarp and the lowest topographic point is 79 m.

All morphological elements are prominent: the main scarp, debris accumulation, and pseudo-terraces. Neither recent processes nor natural hydrographical objects have been observed on the landslide body. About 80% of the Ribnik village is situated on this landslide. Buildings are present on all parts of the landslide, except on the main scarp (Figure 2).

4. RESEARCH OF EARTHQUAKES AS A LANDSLIDE GENETIC FACTOR – A METHODOLOGICAL FRAMEWORK

Seismism is one of the endogenous genetic factors of landslides. Large number of researchers determined that there is no visual difference between the landslides induced by earthquakes and those induced by precipitation (Wen et al. 2004). Therefore, the estimation of the role of this factor in the Belica River basin was difficult, requiring the comparison of historical seismic activity and spatial relations between the main faults and the landslides. The importance of seismic activity for the development of landslides is determined by Okunishi et al, 1999:

- proximity to the zone of the crustal rupture that induced the earthquake
- the coincidence of the slope aspect with the direction of the maximum seismic vibration.

Up to a point, the slope stability depends on the direction of seismic moment in relation to the direction of slope inclination. Seismic moments whose direction coincides with the slope inclination are much more “effective” than the moments of opposite direction. It has been determined that the minimal earthquake magnitude which initiates the landslides is M 4 (Keefer, 1994). The earthquakes of magnitude >5 usually produce a small number of landslides, as opposed to those of M>7.5, which can trigger thousands or tens of thousands of landslides. Keefer and Wilson (1989) used the data on 37 earthquakes in order to determine the relation (1) between the magnitude and the average area of landslide occurrence in an earthquake:

$$\log 10\, Ae = M - 3{,}46 \quad (5 < M < 9{,}2) \tag{1}$$

where Ae is the total area affected by landslides (in km^2), and M is an earthquake magnitude. Out of the total number of landslides, as much as 95% is situated on less than half an area Ae (Keefer, 1994), which means that their number is rapidly decreasing with the distance from the epicenter. The same author stresses the high linear correlation between the earthquake

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magnitude and the total landslide volume (Figure 3), which is defined by the following relation (Keefer, 1994):

$$\mathit{log\ 10\ V = 1{,}45M - 2{,}50}\ (5{,}3 \leq \mathrm{M} \leq 8{,}6;\ \mathrm{r2} = 0{,}876;\ \mathrm{n} = 15) \quad (2)$$

where V is the total landslide volume (m^3) and M is an earthquake magnitude.

With a magnitude M>5, the significance of an earthquake as a triggering factor is undisputable, as well as the volume of the sliding material, which has a linear increase with the increase of the magnitude.

Confirmation to this correlation can be found in the Balkans as well. Trkulja (1998), while studying the seismic characteristics of the area of Banja Luka in Bosnia and Herzegovina, mentions 47 landslides that originated as a consequence of seismic activity (M 5.6) in 1969. Sometimes it happens that the total number of landslides is significantly smaller than expected, considering the earthquake magnitude (Okunishi et al, 1999), which indicates that an earthquake is a necessary, yet not a sufficient condition. The most usual factors leading to such deviations are rainfall deficit and the vegetation soil-cohesion effect.

In order to determine whether an earthquake has been the main triggering factor for landslides in the Belica River basin, we will analyze the referent criteria defined by Jibson (1996; cited by Ost et al, 2003). This method may be of particular importance in the cases of seismic activity in pre-instrumental period, when it is not possible to determine the exact magnitudes of an earthquake. In Serbia, instrumental measurements of earthquakes have started only in the year 1910.

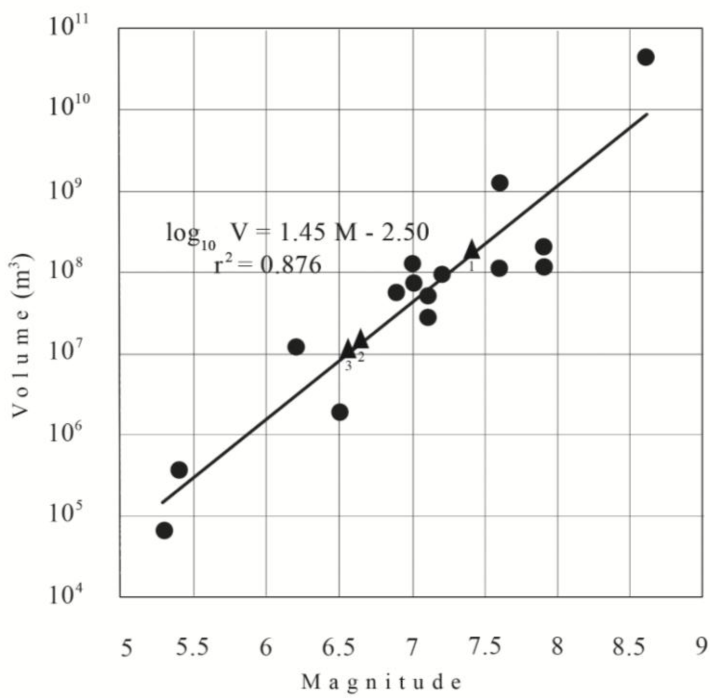

Figure 3. Relation between earthquake magnitude and total landslide volume (Keefer, 1994). 1 – Belica landslide, 2 – Ribnik landslide, 3 – Bukovče landslide.

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About two decades earlier, a group of geo-scientists started to collect data and observations about earthquakes (the number of casualties, material damage, topographic deformations (liquefaction).

The referent criteria by Jibson (1996), which indicate the seismic origin of landslides are the following:

- Ongoing seismicity in the region which has triggered landslides
- Coincidence of landslide distribution with an active fault or seismic zone
- Geotechnical slope stability analysis showing that earthquake shaking would have been required to induce slope failure
- Large size of landslides
- Presence of liquefaction features associated with the landslides
- Landslide distribution that cannot be explained solely on the basis of geological or geomorphic conditions.

5. Results

5.1. Ongoing Seismicity in the Region which Has Triggered Landslides

Tectonic landslides are characteristic for the Belica River basin. The main sources of energy which induce them are tectonic strains caused by subduction of the African plate under the Eurasian plate. Within the distance of 410 km from the subduction line, seismically active faults may generate the earthquakes with a maximum magnitude of 5.73 in a 100-years return period (Petrović, 1998).

According to the data obtained by the Seismological Survey of Serbia, continuous seismic activity of various magnitudes and intensities has been detected for the Belica River basin. The first written record on seismic activity of this area dates back to the 15th century. The sources that mention the 1893 earthquake, with epicenter in Radošin, mention also certain morphological consequences and subsequent processes. In the vicinity of the town of Jagodina, a 50-cm wide fissure was formed, which yielded the fountains of water, mud and sand (Figure 7, Cvijić, 1924; Lazarević, 2000), which can be determined as liquefaction. This is an important document, regarding the fact that it indicates that the earthquake could at least once trigger the landslides in the studied area. This first recorded earthquake was a magnitude 5.1 (Table 1). In 1921, the Belica River basin was struck by the strongest earthquake in the 20th century, with the magnitude 5.8.

Seismic activity was continued also in the 21st century, with M 4.2 with the epicenter close to the town of Jagodina (June 22nd, 2002). This earthquake has not, however, induced any hillslope processes, partially because of the extreme drought in the second half of June 2002 (Milošević, 2010).

The analysis of potential volume of the Belica landslide (0.26 km^3) and mathematically defined magnitude necessary to initiate this landslide (see relation (2)), it could be expected that in the past, this river basin had to be struck by the earthquake with M > 7. In the Belica River basin, this magnitude has a return period of 1000 years. This fact poses the question of the age of the process.

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Lithological and structural relations may point to a relative age. The primary indicators are the alluvial sediments in the middle course of the Belica River, which accumulated over the toe of the Belica landslide and are over 6 m thick (Milošević, 2008). On the basis of this lithological relation between Quaternary sediments and Belica landslide, we can infer that the landslide is of Upper Pleistocene or early Holocene age.

Table 1. Strongest earthquakes with the epicenter in the Belica River basin and its surroundings, from 1893 to 2008

Year	Date	Magnitude	Epicenter		Settlement
			φ	λ	
1893	04-09	5.1	43° 49' 47.44" N	21° 09' 19.49" E	Rabenovac
1893	04-10	5.1	44° 07' 11.55" N	21° 11' 07.58" E	Radošin
1893	07-27	5.1	43° 46' 11.41" N	21° 16' 31.57" E	Izbenica
1894	03-16	5.1	43° 52' 47.47" N	21° 13' 31.53" E	Dragoševac
1895	06-16	5.1	44° 01' 11.52" N	21° 16' 31.60" E	Ribare
1901	08-29	5.1	43° 59' 59.52" N	21° 17' 07.58" E	Ribare
1910	12-03	5.1	43° 58' 11.50" N	21° 15' 19.60" E	Jagodina
1910	12-03	5.1	43° 58' 47.50" N	21° 16' 31.60" E	Jagodina
1921	07-01	5.8	43° 50' 59.45" N	21° 11' 07.51" E	Loćika

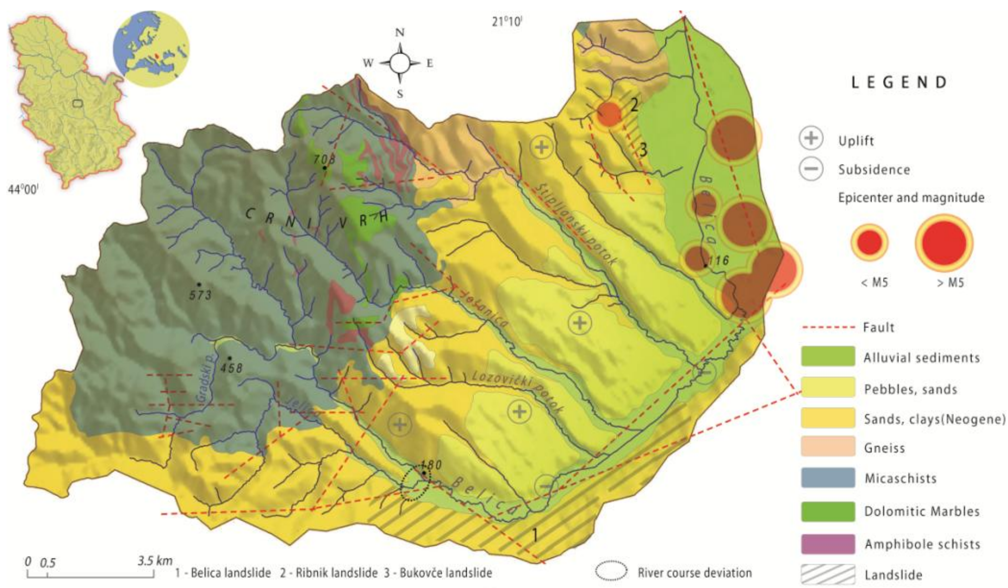

Figure 4. Lithological and structural map of the Belica River basin, with the epicenters of stronger earthquakes.

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5.2. Coincidence of Landslide Distribution with an Active Fault or Seismic Zone

If we analyze the relation of epicenter positions of strongest earthquakes in the last 110 years and most conspicuous faults in the Belica River basin with the close surroundings, a certain spatial analogy may be noticed.

Seismically the most active zones are related to Belica and Jagodina faults, as well as along the fault which follows the western rim of Mt. Juhor (Figure 5), whose magnitudes are even exceeding the value of 5. By analyzing the map, we can notice a meaningful spatial relation between these dislocations and mega-landslides in the Belica River basin.

The strike of landslide direction matches the strike of most significant faults. The Belica landslide stretches parallelly with Bunar-Majur fault, and Belica fault in the north, while in the south and south-east it is outlined by the fault in the western rim of Mt.Juhor. These dislocations converge in the zone of unclear watershed between the Lugomir River and the Belica River, to the south of the town of Jagodina.

The landslides Bukovče and Ribnik are located parallelly along the Jagodina fault, but there is also a micro-fault which corresponds to the landslide scarp of these mega-landslides (Figure 4). One of the landslides recorded in the instrumental period had an epicenter along this micro-fault (Figure 5). This relation leads to another quality: that the aspect of the slopes where these landslides occur coincides with the direction of the maximum seismic vibration (in the sense of Okunishi et al, 1999).

Along the tectonic lines, or at the places where they intersect, the main release of primary strains and decompression occur, and major zones with continuous development of landslides are formed. Therefore, this criterion favors the seismism as the causal factor.

Figure 5. The head scarp of the Ribnik landslide.

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5.3. Geotechnical Slope Stability Analysis Showing That Earthquake Shaking Would Have Been Required to Induce Slope Failure

Within the present research, there were no technical conditions for geotechnical analysis of geological formations. More detailed research in future, which would be directed towards land use planning of this area, could provide a financial framework for such an analysis.

5.4. Large Size of Landslides

This referent criterion stands for the analysis of *landslide development coefficient* (C), which is a relation between the length of a landslide and the length of a slope on which it is developed:

$$C = Ll / Ls \quad (3)$$

where Ll is the length of a landslide, and Ls is the length of a slope. The landslide development coefficient may have a maximum value of 1, which would mean that a landslide is developed along the whole slope from top to bottom. Ost et al. (2003) and Sorriso-Valvo (1992) stress that the landslides in seismic zones have a greater development coefficient ($C \geq 0.5$) compared to the landslides situated out of these zones. The studied mega-landslides in the Belica River basin, it is significant that their development coefficients are larger than 0.8 ($C \geq 0.8$). The Belica landslide has a maximum value $C = 0.98$, while the values for the landslides Bukovče and Ribnik are $C = 0.9$ and $C = 0.8$, respectively.

Considering its total width of 11,500 m, the whole Belica landslide was analyzed for the development coefficient (Figure 4). The determined maximum coefficient is $C_{max} = 0.98$, and the minimum $C_{min} = 0.61$ (average $C = 0.92$). Such continuously high development coefficient points to a genetical and dynamical synchronization of the whole landslide body, and to the fact that the sliding plane is determined by the same geological structure. In other words, even though the Belica landslide is composed of various disconnected morphological elements, it is basically a single, homogeneous genetical-dynamical body. As for the Bukovče and Ribnik landslides, considering the significantly smaller width and scarp, it can be claimed with certainty that these landslides are homogeneous bodies.

5.5. Presence of Liquefaction Features Associated with the Landslides

This criterion asks for the detection of fractions of isolated sand lenses, either in the landslide body or its surroundings. The age of the landslides which are hypothetically considered to be triggered by earthquakes is at least several centuries. Therefore, even if there was a liquid fraction, it must have been washed away by denudation process in the meantime. Liquefaction was present in the studied area (at several places in the surroundings of the town of Jagodina) during the 1893 earthquake, but there is no written record about the activated landslides. Some authors consider, however, that the occurrence of liquefaction is not

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necessary during the seismically triggered landsliding (Ost et al, 2003). Regarding this referent criterion, it is not possible to determine the role of seismic activity with certainty.

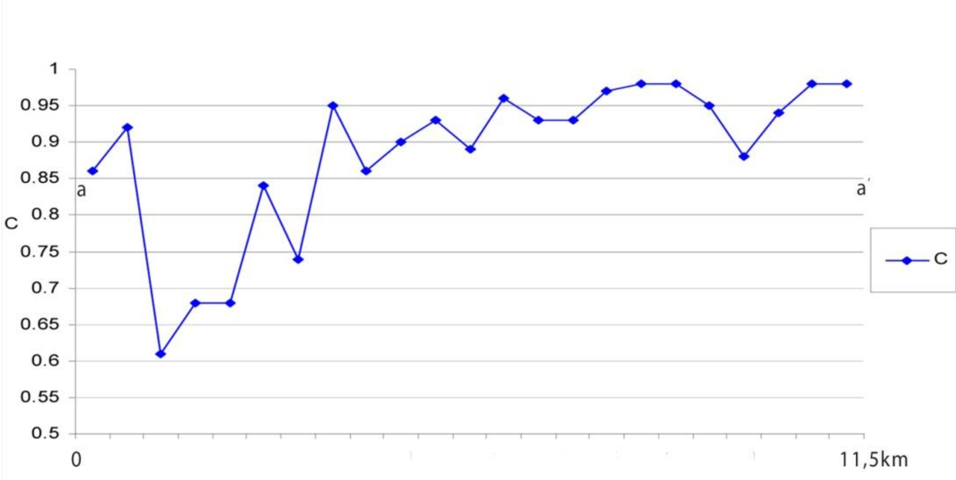

Figure 6. Landslide development coefficient (the example of the Belica landslide, C=0.92), in E-W direction. Generated from a digital elevation model. Section a-a’ refers to Figure 1.

Figure 7. Liquefaction in the lower course of the Belica River, after the 1893 earthquake (Photo: Đ. Stanojević, 1893; after Cvijić, 1924).

5.6. Landslide Distribution that Cannot be Explained Solely on the Basis of Geological or Geomorphic Conditions

This criterion has been analyzed through the lithological-structural and morphological anomalies detected in the field. As previously established within the criterion 5.4, the studied landslides have a high development coefficient ($C \geq 0.8$). This characteristic was established

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also for some examples of landslides which were formed as a consequence of heavy precipitation (Milošević, 2010), which possibly threatens the validity of the criterion 5.4. However, the analysis of the lithological and structural relations reveals the essential difference. At the landslides which have a high development coefficient and were triggered by heavy precipitation, the topographic slope inclination corresponds to the slope of lithological structures which act as a hydrological aquicludes (sliding planes). Such landslides belong to the group of concordant landslides (c.f. Cui et al, 2009). On the other hand, all of the three studied landslides are developed in the zone of non-disturbed (horizontal) beds of Neogene sediments (sands, alevrites, sandy clays; Dolić et al, 1981).

Such lithological-structural relations indicate that these landslides belong to the group of oblique landslides (failure occurs at an angle to the bedding; c.f. Cui et al, 2009). Thus, the landslides with such a high development coefficient and such a large size require the existence of a larger structure. In this case, these structures are the faults, as the zones of seismic energy release. Morphological anomaly which corresponds to this referent criterion is a river course deviation (Milošević, 2008).

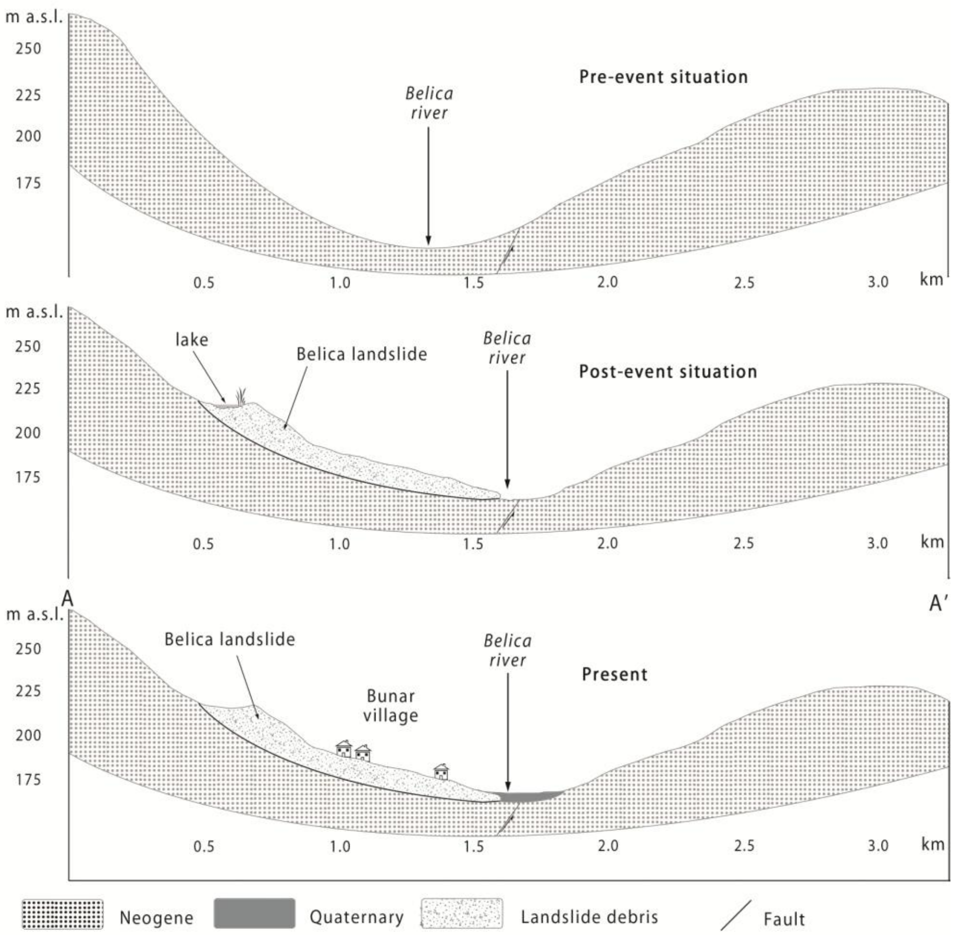

Figure 8. Evolutional phases of the Belica landslide development. Section A-A' refers to Figure 1.

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Figure 1 shows the deviations of the stream Vrbski Potok and the Belica River. Along the N-S oriented line where the Vrbski Potok turns towards the north under the 90º angle (and starts the deviation), there is the western rim of the Belica landslide.

The length of the landslide body is the largest in this section: 1870 m. Thus, we can assume that the pushing force upon the river course was the largest in this zone, if we take into account that the length of the landslide body decreases away from this area. The sliding mass did not dam the river, but only deviated its course.

The main reason for this lies in the fact that the Belica valley has a U-shaped profile in this sector (Figure 8). It is also significant that the direction of deviation is opposite to neotectonic movements in the basin, and to the general orientation of hydrographic network. All the facts from the previous analysis lead to the conclusion that only the processes with the elements of paroxysm could result in this morphological anomaly.

Hillslope process of lower intensity would not lead to any morphological consequence, regarding the fact that vertical and lateral erosional component of the Belica River would easily remove the slowly-advancing hillslope material.

CONCLUSION

All the presented material points to the conclusion that there were two key factors which influenced mega-landslide development. The first could be defined through the morphometric characteristics of the drainage basin, which resulted from the morphostructural relations. The Belica landslide is situated in the zone of conspicuous drainage asymmetry, or more precisely, in the concave part of the river course as a whole - on the subsiding block along the uplifting Crni Vrh block (Figure 4). This fact caused the lateral undercutting of the right valley side of the Belica River, which resulted in the slope characteristics favorable for landslide development.

As the right (steeper) valley side of the Belica River is edged by faults on the north and the south, this is the zone where the release of primary strains and decompression with resulting earthquake could take place, making the second potential factor for landslide development. It is only indirectly that we can determine whether an earthquake triggered the Belica, Bukovče and Ribnik landslides, due to the fact that it must have occurred during the pre-historic period. Using the criteria for determination of causal relations between earthquakes and landslides, suggested by Jibson (1996), we detected that out of six given criteria, four support the seismic origin of the studied landslides: the first (seismism in the region), the second (coincidence of landslide positions and positions of active faults or seismic zones), the fourth (landslide dimensions) and the sixth (landslide positions that require more than solely geological or geomorphological interpretation). Although the third and the fifth criterion have not been detected in the field, their absence is by no means a negation of the initial hypothesis.

As for the third criterion, the future geotechnical analyses could increase the arguments about the potential seismic origin. The fifth criterion (liquefaction) could not have been detected due to the long time span: the subsequent erosional processes were able to wash away its traces. In other words, the present lack of lithological elements of liquefaction does not indicate that it was not present at all.

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Chapter 13

SELF-EFFICACY AND LEARNING PROCESSES ASSOCIATED WITH THE ELDERLY DURING DISASTERS AND CRISES

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ABSTRACT

Learning during a natural disaster may be particularly important for older adults, as often the elderly are among the most susceptible to loss of life, health, or property. Although age and learning in the context of natural disasters has received little scholarly attention, much is known about the relationship between age and learning in other contexts, especially with regard to self-efficacy. In general, research has found that older individuals lack confidence in their own ability to master a new skill (Knowles, 1973). Organizational studies have indicated that older individuals may be less likely than others to adopt behaviors to which they have low self-efficacy, (Fossum et al, 1986), while other studies indicate reluctance to training and redevelopment activities (Cleveland & Shore, 1992; Rosen, Williams, & Foltman, 1965).

The efficacy problems of older audiences seem to revolve around reappraisals and misappraisals of their capabilities. Since self-efficacy is in part determined by comparisons to others (Bandura, 1977), older individuals will likely perceive even less self-efficacy if they do not have similar behavioral models against which to compare their own; older individuals may have fewer opportunities to observe models of the same age successfully navigate a crisis. This chapter examines various means of promoting accurate appraisals of efficacy within older populations, including both behavioral practice and mediated interventions. It focuses on the development of public service announcements and warning systems featuring appropriate behavioral models, the underlying psychological mechanisms that may lead to their success, and specific obstacles faced by older audiences when processing evacuation messages.

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Previous studies have showed that as a vulnerable population, the elderly face higher threats of injury and loss in a disaster. This can be seen through an examination of Hurricane Katrina victims in Louisiana; 49% of the 971 confirmed deaths were of individuals 75 years or older. By way of comparison, data from the 2000 census indicates that 11.7% of the overall population of New Orleans fell into this age bracket (Kamo, Henderson, & Roberto, 2011). Guaranteeing the health and safety of older individuals during an evacuation is a critical consideration for disaster managers and first responders.

Although the specific risk factors endemic to the elderly during natural disasters have been studied extensively, little is known about motivating factors for this demographic that may be critical in getting them to reduce their susceptibility to a natural disaster and experience efficacy. This chapter will propose various means of promoting accurate appraisals of self- efficacy within older populations. These include the use of televised warning messages featuring individuals perceived to be similar. The chapter will also examine the relationship between emotional and cognitive appeals, and the utility of both cognitive and affective appeals in reaching older audiences. Finally, specific needs and barriers to evacuation associated with older audiences will be addressed.

Cognitive Processes among Older Individuals

As a demographic group, the term elderly generally refers to people aged 65 years and older, who have experienced multiple dimensions of physical, psychological and social changes, and are approaching the end of the human life cycle. Previous cognitive studies on aging mainly focused on the memory declination of the elderly, which suggested that many types of memory would decline with aging, yet semantic memory and general knowledge would remain steady or increase into the late adulthood (Warner, 2005). Although age and learning in the context of natural disasters has received little scholarly attention, much is known about the relationship between age and learning in other contexts. There is some evidence, for example, that older adults perform more poorly than the younger populations at tasks that require immediate recall of recently acquired information; older adults, however, may perform as well as or better than their younger counterparts on tasks involving more global levels of understanding (Radvansky, 1999).

According to social cognitive theory (Bandura, 1989), people learn within a social context that facilitates knowledge acquisition through observation, reinforcement, and modeling process (Ormrod, 1999). Older adults have been gaining knowledge from their past experiences to form a comprehensive worldview; they may be prone to process single-loop learning based on existing schema (Argyris & Schon, 1996). In general, research has found a negative relationship between age and confidence in the ability to master new skills (Knowles, 1973).

Given a long history of research in cognitive psychology explicating a link between self-efficacy and knowledge acquisition, the observed differences in learning tendencies among older audiences may be a product of their own estimates of an inability to learn. In organizational studies it has been suggested that older individuals may be reluctant to learn new skills and abilities unless they believe that mastery of the skill is possible (Fossum et al, 1986). Research on workplace behavior further suggests that as employees get older, they are

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less likely to participate in training and development activities than are younger employees (Cleveland & Shore, 1992; Rosen, Williams, & Foltman, 1965). An argument can therefore be made that the efficacy problems of the elderly revolve around reappraisals and misappraisals of their capabilities. Physical capabilities may also decrease with age, thus triggering efficacy reappraisals for activities in which the mediating biological functions have been significantly affected (Bandura, 1989). There is, however, a great deal of variability across behavioral domains, education, and socioeconomic status in terms of these efficacy concerns; it is not possible to identify uniform declines in self-efficacy as a product of age (Baltes & Baltes, 1986).

This variability in self-efficacy is in part determined by against whom the elderly compare themselves. Older individuals who make social comparisons regarding their capabilities against people their age are less likely to view themselves as declining in capabilities than those who rely on comparisons with younger people. When individuals observe a similar model performing a task successfully, this experience helps to bolster their own self-efficacy (Bandura, 1977). However, when the model fails, it can negatively affect self-efficacy. This has the potential to lead to great harm, given the link between self-efficacy and health behaviors; for example, self-efficacy has been identified in the literature as the strongest predictor of health behaviors for community-dwelling women aged 65 to 92 years (Conn, 1998). Older individuals may also have fewer opportunities to observe models of the same age successfully navigate a crisis, specifically the act of evacuation.

With the reserve capacity below the threshold needed to cope successfully with the challenges that they face, problems for the elderly may arise either from severe depletion (lack of reserve resources) or from particularly serious challenges (Grundy, 2006). Although vulnerability is neither age-related nor age-specific, older adults have greater risks of exposure to specific challenges and a reduced capacity to respond in time. Learning therefore during a natural disaster may be particularly important for older adults as often the elderly are among the most at risk in terms of access to resources and specific physical limitations.

However, before learning can take place, the targeted audience must believe that a risk exists (in this case a natural disaster); they must believe that the risk can cause harm and that they are susceptible to that risk. The underlying cognitive processes and responses to risk information can be articulated through a model of risk communication known as the Hazard/Outrage Model (Sandman 2003, Lachlan & Spence, 2007, 2010).

RISK=HAZARD+OUTRAGE

As a cognitive and affective model, Risk=Hazard+Outrage (RHO) suggests that effective communication during an extreme event should ideally attempt to create levels of knowledge acquisition and affective response that are appropriate for the situation. Therefore, in a natural disaster, evacuation messages should containing components such as information that the threat is real, its level of severity, potential harm to individuals, and the actions individuals can take to avoid this harm. This assertion is stated though the formula Risk = Hazard + Outrage. If an affected public does not understand the nature of a risk, then that public needs to be educated. If that public understands the hazard, then an appropriate degree of negative affect must be induced; enough to motivate action, but not lead to antisocial behavior.

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Sandman further explicates hazard as the technical assessment of a risk, while outrage is the cultural assessment (Sandman 2003). The correlation between hazard and outrage in a given circumstance may actually be quite low. For instance, there are some risks that are fairly benign but lead to overreaction by the general public (e.g. SARS), and some that pose very real threats but go largely ignored (e.g. highway safety). Lachlan and Spence (2010) conceptualize outrage to include reactions to risk information; they also extend Sandman's model to offer that negative affect may be separately related to the risk itself or to those responsible for the risk (when applicable). When properly induced, outrage may motivate individuals to take up specific, non-routine actions that are beneficial under the circumstances. This may include both remedial actions (such as evacuation), and behaviors related to emotional factors such as need for control, trust, and responsiveness (self-efficacy).

Thus, elderly populations must believe that the natural disaster is real and they are susceptible. Rosenstock (1974) noted that the perceived threat or danger can be viewed in two dimensions: severity and susceptibility, both of which are components of the dimension of hazard. Severity refers to the perceived amount of an individual's subjective harm expected from the threat, while susceptibility refers to the likelihood of an individual's feelings concerning the seriousness of contracting a threat. If older individuals believe the threat is real then they may be likely to respond. If the hazard is not perceived as real, the message will likely be rejected. However it is possible that the hazard is accepted but no action occurs; this is because outrage has not been adequately induced. Outrage in the model refers to the cultural seriousness of a threat, and although it is multi-faceted, one component of outrage is action. Thus if audiences believe a hazard is real, they are more likely to take self-protective actions (efficacy).

Two distinct types of efficacy are represented in the literature and are used when evaluating what to do in the event of a hazard, they are response efficacy (i.e., to what extent the recommended response is effective and feasible in averting the threat) and self-efficacy (i.e., how confident they feel about their ability to perform the recommendations to avert the threat) (Witte, 1998; Witte et al., 2001). One problem for elderly populations is that they may perceive the hazard from a natural disaster as being real, and that the recommended response is adequate to protect them from the hazard, yet they may not see themselves as being able to complete the recommended actions. In other words, without adequate affective motivation (outrage) it is likely that older audiences will experience response efficacy, but that a lack of self-efficacy may attenuate behavioral responses. Without the adequate induction of outrage, specifically self-efficacy, a message may be received and accepted, but not acted upon.

Several suggestions could be offered as to why the efficacy problems exist in the elderly in regards to evacuations. One significant factor may be the conditions for vicarious learning present during extreme events, and the impact of this context on knowledge acquisition.

EVACUATION LEARNING

Evacuation refers to the collective movement of people away from the threats or actual hazard of a disaster; it is an immediate and rapid response which tries to ensure the safety and the least loss of all expected residents of a structure, city, or region. People may need more than institutionally framed warnings to emotionally cope with a crisis; they may either seek

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information from informal information networks, or simply take their own response action (Vihalemm, Kiisel, & Harro-Loit, 2011, Spence et al, 2007a). Following Katrina, consistent patterns emerged in the data, profiling the typical older respondent who had difficulty evacuating (Spence, et al. 2007b). Older adults who experienced difficulty evacuating tended to come from lower income brackets, and many suffered from physical or mental disabilities. These disabilities likely limited mobility and impacted the degree to which these individuals could process emergency information. Given data such as these, is likely that the main challenges for evacuation of older adults include a slow response before evacuation, safety and health care concerns during evacuation, and psychological resilience and long-range effects after evacuation, pre-existing experiences, and self-efficacy affect evacuation information processing (Cherry, Allen, & Galea, 2010). Given the arguments laid out above, it is also not difficult to see how these factors could also contribute to a lack of perceived self-efficacy.

Older adults have been found to have differences from younger adults in perceiving hazard characteristics and reacting to affective responses to risk, relevant channel beliefs and information seeking behaviors, as well as behavioral prediction via subjective norms and information gathering capacity which is akin to perceived behavior control (Ajzen, 1988, 1991, 2002; Griffin, Dunwoody, & Neuwirth, 1999). The perceived gap between knowledge held and knowledge needed for the elderly serves as a pivotal point in the decision to deal with evacuation (Kahlor, 2010). As the affective response to a crisis typically presents as negative emotions such as fear, dread, or worry (Griffin et al., 1999; Witte, 1992, 1994), those negative emotions would worsen the pre-existing cognitive conditions for older adults. According to Witte (1992), when perceived threat outweighs the perceived efficacy, people are more likely to engage in defensive, avoidant, or reactant responses to process fear control. For older audiences, this could mean choosing to stay in place despite warning that evacuation is necessary to minimize harm.

One suggestion for improving self-efficacy in the evacuation learning process is to provide accessibility and capability to acquire sufficient disaster information for the elderly population. As noted by Bandura (1989), people learn within a social context that facilitates knowledge acquisition through observation, reinforcement, and modeling process (Ormrod, 1999). However, a simple youtube.com sample of evacuation public service announcements supports the contention that these PSA’s are geared toward motivating younger audiences. Existing support messages largely ignore older populations, and rely on younger spokespersons that appear physically fit and highly knowledgeable. Elderly audiences therefore do not have the opportunity to see similar others perform evacuations. It follows then that older populations may believe that the response, evacuation, is sufficient to guard against the hazard, but not believe that they have the ability to take the response. As in the example above, the paradox of high response efficacy couple with low self-efficacy may occur under these conditions.

It may be the case that the relationship between a lack of similar behavioral models and low self-efficacy could be overcome rather easily. With regard to evacuation efforts, emergency management agencies may be able to address this phenomenon with a relatively small number of messages. According to exemplification theory (Zillmann, 2002), the selective samples representing a population of all possible occurrences, which, based on the shared focal characteristics, will affect the formation and modification of beliefs about phenomena (Zillmann, 2006). Zillmann (2006) argues exemplification theory addresses “the

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formation and modification of beliefs about phenomena and issues” based on exemplars (p. 221). People tend to use heuristics as cognitive shortcuts to help process information, and one of these is exemplified properties from media portrayals of issues. Exemplification theory predicts that exemplars that are concrete, iconic, and emotionally arousing, influence issue perceptions more than abstract, symbolic, and emotionally inconsequential exemplars (Zillmann, 2002). Thus, exemplars are especially likely to have an impact if they are attentionally favored, emotionally interesting and heuristically available (Zillmann & Brosius, 2000) as these are the exemplars most likely to be stored and retrieved from memory. These exemplars are stored in the memory and more easily retrieved than base rate information. According to exemplification theory, information is evaluated in a subjective and biased manner, rather than in a detailed systematic way (Busselle & Shrum, 2003).

Utilizing proper exemplars in Public Service Announcements would help older adults form positive judgments about evacuation from a first-person perspective rather than a third-person perspective. Older individuals may be able to acquire the belief that they can deal with the evacuation, successfully evacuate, and gain benefits from the evacuation. Setting exemplars in television warning announcements and public service announcements via proper sensation arousal, consistent with older adults’ subjective and descriptive norms, would to some degree fill the gap of positive learning models in their social connections (Ajzen, 1999). These portrayals could also be used to induce appropriate levels of outrage, as discussed above. One does not need to create the impression that lots of older people evacuate; rather, a small number of carefully crafted and well-placed messages, featuring older spokespersons and inducing appropriate levels of arousal, may set off exemplification processes leading to self-efficacy associated with evacuation.

Exemplification theory can also be applied to the hazard and outrage model. In regard to hazard, exemplification can be seen as a tool to enhance the threat appraisal. Exemplars may help increase the persuasiveness of simple fear arousing or evacuation messages. For example, Aust and Zillmann (1996) suggest that victims’ emotional testimonials outweighed inexpressive testimonials in viewers’ perceived threats of risk in developing food poisoning from a fast-food restaurant; Gibson and Zillmann (1993) posit that quotes in a news story impact judgments about the frequencies of occurrence for events. Therefore, exemplars can be used to create messages that will highlight and in some cases allow people to overestimate the fear, susceptibility, and severity of a threat.

Exemplification can also be used to induce outrage. The act of seeing a similar model perform an evacuation behavior, in a concrete and tangible manner, can produce an emotional reaction that the viewer will store for later retrieval when the situation calls for it. Subsequently, if or when the response is retrieved it will have a positive impact on the efficacy response of the viewer. Therefore, the way in which evacuation warnings are produced needs to be completely reexamined, focusing on the use of behavioral models which will serve as exemplars to older populations (and for that matter, other underrepresented subpopulations). Using similar models as exemplars also may positively influence perceived efficacy for the elderly population, as it can bolster their confidence against the negative expectancy of evacuation. Conn (1988) suggests that outcome expectancy is a significant predictor of stress management rather than that of prevention behaviors. Thus, using exemplars to manipulate outcome expectancies may alleviate the stress associated with doubts associated with one’s ability to evacuate, and contribute further to self-efficacy.

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Other Barriers

In addition to appraisal, learning, and action there are other issues which can be addressed to bolster evacuation in older populations. Interpersonal networks (particularly outside of the immediate family) are critical for the elderly and can aid greatly in the decision to evacuate (Lyons et al, 1995). While past research suggests that numerous non-mainstream audiences may be reliant on interpersonal networks during crises and disasters (Spence et al 2007b), interpersonal networks can also be a source of distraction, delay, and misinformation. Thus, it becomes important for emergency managers to consider these interpersonal networks, the types of information they provide regarding evacuations, and ways in which these networks can be used to facilitate evacuation efforts on the part of older audiences.

One way to maximize the effectiveness of interpersonal networks is to formalize them to an extent. Initial attempts at these types of arrangements have produced mixed results. While some state emergency management agencies have attempted to make special arrangements for older populations, such as pick-up points for transportation, these attempts have not proved to be effective. Emergency management agencies may wish to consider campaigns encouraging people to set up interpersonal networks and agreements on courses of action. Research in health communication suggests that interpersonal messages may be far more effective than mediated campaigns in motivating people to action (Backer, Rogers, & Sapory, 1992; Rogers & Storey, 1987). Encouraging people to "adopt" elderly individuals in the case of an emergency may help prevent harm. If interpersonal relationships are developed over time, older individuals may be more comfortable with the recommendation to evacuate (Spence et al, 2008).

It has also been suggested that one reason that older adults hesitate to evacuate is their affiliation and connection with the current community and family members; another reason was their anxiety to take care of their possessions and personal health conditions after evacuation. Studies in the aftermath of Hurricane Katrina also echoed that displaced older adults' psychological well-being was positively related to their age and physical health; older displaced women coped with displacement better than men; avoidant coping was negatively related to the older adults' well-being; income, education, and race were largely unrelated to psychological well-being (Kamo, Henderson, & Roberto, 2011). The act of evacuating with known others, with whom interpersonal relationships have been formed, may help encourage the decision to evacuate.

New Media Adoption

The encouragement of the adoption and use of new media may also have novel effects on evacuation. Older adults depend more upon traditional mass media and interpersonal communication than on new media. Among this particular group, television and interpersonal networks are the most commonly used sources for acquiring information about important news events (Greenberg, 1964; Spence et al, 2007b). Television may be the preferred medium if a crisis erupts in the evening, while a crisis triggered during normal working hours may lead people to rely on interpersonal channels and radio. However, complex and accurate knowledge can benefit older adults and the social realm in which the older adults interact

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(Kahlor & Rosenthal, 2009). Multi-dimensional interaction would increase the efficacy of both individuals and institutional crisis communication plans and consequently the public's response to crisis messages (Vihalemm et al., 2011). However, adoption rates of immersive media and social media are low among this age group. Positive self-enhancement interaction in new media replaces the traditional top-down message dissemination, which may stimulate the motivation of the double-loop learning process for older adults. Studies on computer mediated communication have revealed that older adults who received computer training have enhanced self-esteem and mental ability, improved intergenerational social interaction and community involvement (Eilers, 1989); their levels of self-confidence have increased while levels of loneliness have decreased (Danowski & Sacks, 1980). They also felt more involved in the increasing technological society because of their familiarity with computers (Morris, 1994). It stands to reason then that among the small percentage of older audiences using immersive media, it can be used to bolster self-perception and engender self-efficacy concerning evacuation.

PETS

The presence of a pet such as a dog or cat can create an impediment to successful evacuation, particularly for elderly populations. Households with pets are slightly more than half as likely to evacuate as those without them (Whitehead et al, 2000), and individuals often will return home during a disaster in order to retrieve or care for a pet. Elderly populations frequently refuse to evacuate if it entails leaving their pets behind (McCann, 2011). In 2006, President George H. W. Bush signed the Pets Evacuation and Transportation Standards Act (PETS Act) into law (Lenard & Scammon, 2007). This makes the receipt of federal disaster assistance funds contingent on plans providing for the needs of people with service animals and/or household pets. Although this is a law, many are unaware of this and therefore may not evacuate due to a relationship with a pet. Emergency management agencies would be wise to take this into consideration when designing emergency messages and campaigns related to evacuation efforts; ensuring that the elderly are aware that their pets will be protected and cared for.

CONCLUSION

When designing and implementing messages concerning evacuation efforts, emergency managers are faced with a number of highly specific challenges endemic to elderly populations. Since these messages are typically disseminated through mass media channels, there are a number of factors related to the psychological processing of crisis information that emergency managers should heed. It is likely the case that older audiences experience high response efficacy, but low self efficacy. Evacuation messages should be designed with this in mind, finding ways of adequately motivating older audiences while reassuring them that they are capable of successfully evacuating. One way of doing this is through the use of exemplars, using spokespersons that older individuals will perceive as similar. Psychologists and communication scientists should work with emergency management personnel on

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research and development investigating the specific message features that will facilitate these results.

Further, emergency managers should continue to develop programs encouraging interpersonal communication about evacuations, and community arrangements for evacuation efforts. Given the power of interpersonal relationships in making health decisions, individuals and community organizations should be encouraged to develop programs not only providing information concerning evacuation efforts but tangible behavioral plans that to help older people overcome physical and perceptual limitations. There may also be some value in considering the use of new media technologies to facilitate knowledge acquisition and bolster self-efficacy.

These are, of course, only a small number of suggestions that are based on the extant research in social marketing, risk management, and crisis communication. Scholars and practitioners alike should continue to strive to develop best practices in evacuation efforts for these and other specific populations. While challenging, the move toward subgroup-specific campaigns may eventually lead to greater reductions in harm to health and property. The current chapter stands as a first step in considering the needs of the elderly during events requiring evacuation.

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Chapter 14

The Unintended Consequences of Government Involvement: Connecticut and Tropical Storm Irene

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Abstract

Tropical Storm Irene tore through northern Atlantic states on August 28, 2011, leaving severe property damage in its wake. As part of its efforts to manage the post-disaster response, Connecticut officials asked insurers to waive hurricane deductibles on home insurance policies. Some insurers waived deductibles before pressure was brought to bear; others did so only after state insurance officials, the governor, and a United States Senator publicly called on them to waive the hurricane deductibles. This Chapter analyzes the ramifications of using political pressure in this manner. Although waiving the deductibles was touted as a pro-consumer action, insurers will respond to the increased contractual uncertainty by increasing prices for policies, thereby harming insureds over the long term. This response also raises fairness issues: those who paid more for better coverage in the face of hurricanes spent money for nothing, while those who neglected sufficient hurricane coverage were bailed out.

Introduction

Tropical Storm Irene tore through northern Atlantic states on August 28, 2011, leaving severe property damage in its wake. As homeowners sought reimbursement from their insurance companies, many Connecticut residents found themselves in a unique position. Connecticut allows insurers to sell policies with separate, higher deductibles that, unlike its neighboring states' policies, are triggered when a hurricane warning is issued, rather than when a storm ultimately strikes as a hurricane.

These separate hurricane deductibles generally equal one to five percent of the insured value. As a consequence of a hurricane warning issued two days before the eventual landfall,

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Connecticut homeowners found themselves confronted by deductibles that could equal five percent or more of their homes' values rather than their policies' standard deductible of $500 or $1,000. (Ha 2011).

Irene eventually struck Connecticut as a lesser tropical storm. As part of its efforts to manage the post-disaster response, Connecticut asked insurers to waive hurricane deductibles. Some insurers did so immediately; others waived the higher hurricane deductibles only after state insurance officials, the governor, and a United States Senator from Connecticut publicly encouraged them. In all, insurers representing 80% of Connecticut homeowners agreed not to apply their hurricane deductibles to losses from Irene. (Ha 2011). Superficially, encouraging insurers to waive deductibles would make insureds better off, since they bear a smaller loss from Irene. However, the very real negative consequences should not be ignored. State officials' interfering in this manner increases uncertainty for insurers, who then increase insurance prices over the long term; these increased prices are borne by insureds. This response also raises fairness issues: those who paid more for better coverage in the face of hurricanes spent money for nothing, while those who neglected sufficient hurricane coverage were bailed out.

Consequences of Government Involvement

Any model of insurance premium pricing includes, as one determinant of price, the insurer's expected future payouts. (Seog 2010). When expected payouts decrease, the premiums will decrease. Conversely, should expected payouts rise, so too will premiums.

An immediate consequence of insurers' being effectively forced to waive hurricane deductibles is that premiums for homeowners insurance will be increased today and throughout the future. Because insurers are reliant on state insurance regulators to approve their insurance policies and premiums, insurers cannot easily ignore pressure brought to bear by prominent state officials. Therefore, it is not surprising that most homeowners insurers writing policies in Connecticut responded to political pressure by waiving their hurricane deductibles and instead charging homeowners lower generally applicable deductibles. Insurers might expect, however, that hurricane deductibles may be politically uncollectible in future natural disasters similar to Irene, which raises the amount insurers expect to pay for future losses and, therefore, homeowners insurance premiums. Insureds may receive a one-time windfall today, but this windfall comes at the expense of not only insurers, but also all future Connecticut insureds who must make higher premium payments.

Further, a state government that steps in during hurricanes could be expected to "protect" insureds at other times, whether in the face of other natural disasters, in a health epidemic, in life insurance markets with heavy loss of life due to an excluded cause, or in other ways. Forcing insurers to waive hurricane deductibles acts as a signal that Connecticut officials will, with a greater likelihood than before, behave similarly in these other circumstances which, in turn, raises insurers' expected payments across insurance lines. We could therefore expect premiums in life, automobile, or health insurance to similarly increase or, to the extent premiums cannot be raised, for insurers to exit the market; although, given the costs documented by Worrall (2002), exit may be delayed. These higher premiums must be paid even if insurers end up allowed to collect deductibles in future disasters. In addition, what is

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effectively expropriation – the state taking from insurers and giving to insureds – has been argued in other contexts to carry broad negative economic repercussions that could manifest themselves in Connecticut's economy as a whole. (La Porta et al. (2008); Mahoney (2001); Perlman (1982); Thomas and Worrall (1994)).

Government involvement raises not just financial concerns but also fairness considerations. Insureds who had spent many years and many dollars paying for better coverage with lower hurricane deductibles found themselves, after the hurricane deductibles were waived, in the same position as neighbors who declined to purchase lower deductibles for hurricane damage. Ironically, the state officials who helped unfortunate homeowners out of the "unfair" situation of hurricane deductibles applying to a tropical storm created new problems of unfairness in the process. No mention was made of refunding premiums to insureds who purchased more comprehensive but ultimately no more valuable hurricane coverage. Equal treatment of all insureds would suggest that, if state officials were to interject on behalf of insureds without comprehensive hurricane coverage, they should do the same on behalf of insureds with comprehensive coverage. Otherwise it is a seemingly arbitrary decision to help one group of citizens and ignore the others.

It may be argued that it is unfair or that there is no sound basis for hurricane deductibles to become activated upon a hurricane warning if the storm later makes landfall as a lesser tropical storm. However, there can be compelling reasons for having hurricane deductibles, which take effect upon a hurricane warning rather than upon the storm ultimately striking as a hurricane, that would argue in favor of honoring this contract term. As just one example, Connecticut homeowners knew two days before Irene's landfall that they would be liable for a percentage of all damage, rather than a comparatively small fixed deductible; consequently, Connecticut homeowners without comprehensive hurricane coverage had two days during which they could adopt loss-preventative measures, knowing they would share in any averted losses, that they might not otherwise undertake if they were unsure about the deductible scheme until the storm ultimately struck. Such loss prevention improves the welfare of all parties and should be promoted. Ignoring this term of the contract may keep this desirable loss prevention from occurring.

CONCLUSION

Connecticut's response to Tropical Storm Irene is an example of a potentially poor disaster management choice. While in the short term homeowners will enjoy a highly visible one-time windfall, the windfall must of course be paid for, with the costs shouldered both by homeowners, through increased premiums today and in the future, as well as by the insurer, its employees, and its owners.

By helping only some homeowners while ignoring those who paid for better coverage that was ultimately given to all, the state involvement also creates issues of unfairness even as it attempts to address another situation that might mistakenly be classified as unfair. Connecticut residents will be harmed in the long-term by the state's disruption of private markets. Exploring the ramifications of these disruptions should serve as a reminder to other governments to consider fully the consequences of public involvement in private management of natural disasters before acting.

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