MODULE 2

HAZARD, RISK AND VULNERABILITY ASSESSMENT

SYLLABUS:

- Hazard types and hazard mapping.
- Vulnerability types and their assessment- physical, social, economic and environmental vulnerability.
- Disaster risk assessment –approaches, procedures.

HAZARD MAPPING

Hazard mapping involves a graphical representation of the location, magnitude and temporal characteristics of hazards on 2 or 3 dimensional surfaces. The objective of this it to represent the spatial and temporal characteristics of the hazard as well as its magnitude using graphical symbols.

Hazard can be categorised based on their origin, that is, whether they are natural, human-induced or technological.

Natural hazards

Natural hazards are phenomena experienced in the physical environment which are harmful to humans and caused by forces for which there is no control.
Examples of natural hazards are floods, earthquakes, volcanic eruptions and hurricanes.

Human-induced hazards

Human-induced hazards are changes of natural processes within the earth's system caused by human activities which accelerate or aggravate damaging events. Oil spills, atmospheric pollution, and major armed conflicts are some of such hazards.

Technological hazards

Technological hazards are dangers caused by technological or industrial accidents, infrastructure failures or certain human activities. Nuclear activities and radioactivity, dam failures, transport, industrial or technological accidents (explosions, fires, spills).

Hazards can be single (such as volcanoes and earthquakes), sequential (such as flood) or combined (such as earthquake accompanied by tsunami) and, as a result, causing a flood or torrential rains leading to landslides in their origin. Each hazard is categorized by:

- Location
- Intensity
- Occurrence
- Probability
- Duration
- Distance
- Speed of onset

- Spatial dispersion
- Temporal spacing

DATA REQUIREMENTS OF HAZARD MAPPING

Spatial characteristics such as location, distribution and dimension; temporal (duration and speed of onset) and magnitude are the major data requirements for hazard mapping. Such information can be obtained through the following sources:

Base maps

Base maps represent topographic layers of data such as elevation, roads, water bodies, cultural features and utilities. Creation of a base map is a time-consuming activity. It is therefore desirable to use as a base, an existing map or orthophoto where possible. An adequate base map must be plan metric, that is, a representation of information on a plane in true geographic relationship and with measurable horizontal distances. It must also have sufficient geographic reference information to orient the user to the location of the hazard.

Remotely sensed images

Satellite images are increasingly becoming preferred sources of readily available information of locations or events on the earth's surface compared to conventional ground survey methods of mapping that are labour intensive and time consuming. Depending on the sensor type or capabilities (spatial resolution, spectral resolution, radiometric resolution and temporal resolution), different images may be obtained from different service providers to feed into the information extraction process.

RADARSAT, TerraSAR-X, ALOS and LIDAR, for instance, are some of the sensors that produce Digital Elevation Model (DEM) depicting topography. GeoEye, QuickBird and ALOS-PRISM are preferred sensors for visual mapping as they are of high spatial resolutions.

Field data

Through the advances of technology, ground surveying methods using electronic survey systems like Total Station, the global positioning systems (GPS) and Laser Scanners, have all greatly increased opportunities for data capture in the field.

CARTOGRAPHIC REPRESENTATION OF HAZARD

Maps are the most operative way to convey actual and relative location. Maps can be simply defined as flat geographic portrayals of information through the use of symbols. Such approaches help hazard maps not to just convey the existence of natural hazards, but also to note their location, severity, and likelihood of occurrence in an accurate, clear, and convenient way. The application of cartography in hazard mapping will eventually lead to the creation of following.

Base map

Base map which contains sufficient geographic reference information to orient the user to the location of the hazard.

Scale and coverage

Scale and coverage which draw the relationship between linear measurement on the map and the actual dimension on the ground. Small-scale maps show less detail for a large area and are applicable for regional development planning. Large-scale maps, on the other hand, reveal more detail for a small area and are more suitable for local or community level development planning. The scale used for a hazard map is dependent upon not only the hazard information to be shown, but also upon the scale of the base map. Therefore, the choice of scale for a hazard map may consider the following issues: o Number of hazards to be displayed at a go; o The hazard elements necessary to be displayed; o Range of relative severity of hazards to be shown; o The area of interest to cover; o The use of the map with other planning documents and; and o Function of the map, for example, whether it is to be an index or detail map.

Types of symbols

On a hazard map, symbols are used to represent reality. Symbols are selected for their legibility and clarity and/or map production characteristics. Location, for instance, can be depicted using one of these basic geometric symbols – point, line or an area. Points are more preferred for displaying volcanoes, while areas have been used for showing flooding.

APPROACHES TO HAZARD MAPPING

Many approaches to hazard mapping have been developed. In all such approaches used, the key factors of consideration in the spatial analysis (valuation of likelihood losses of hazards) are appreciating that:

- All components of a hazard assessment vary in space and time
- As the consequences of hazards are usually large, it is prudent to include vulnerability and risk reduction strategies in the process.

Geographic Information System (GIS) mapping and ***Participatory mapping*** are the approaches discussed.

Hazard Mapping Using Gis

GIS is increasingly being utilised for hazard mapping and analysis, as well as for the application of disaster risk management measures. The nature and capability of GIS provides an excellent basis for processing and presenting hazard information in the form of maps. GIS is very useful in arranging a high volume of data necessary to produce a hazard map. The three-dimensional representation available in modern GIS offers opportunity to model hazard. GIS also provides various methodologies in creating and analysing hazards. The flowchart represents the general procedure for the mapping of hazards in GIS.

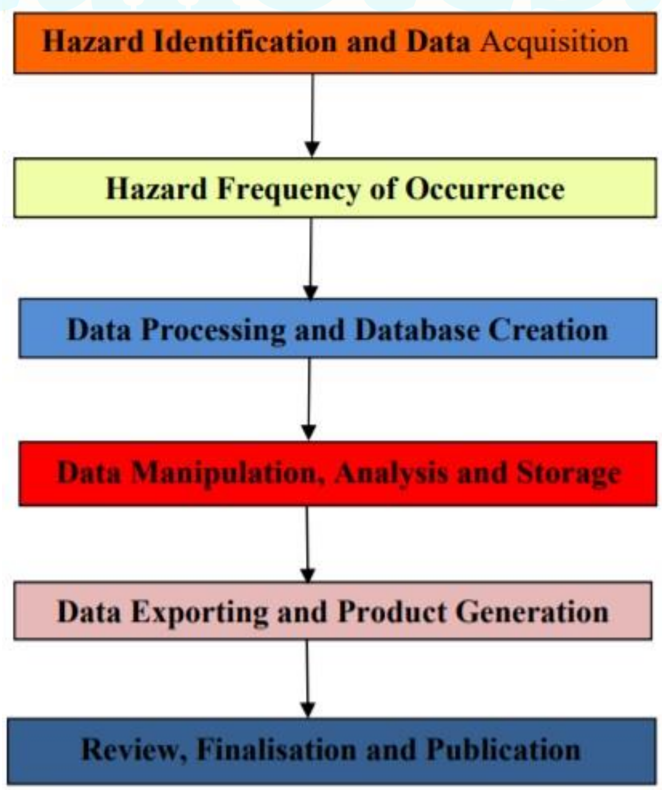

Fig1: GIS mapping of hazard

Participatory mapping

Participatory mapping is a technique that allows for the integration of local level participation and knowledge in the map production and decision taken process. It is an interactive process that draws on local people's knowledge and allows them to create visual and non-visual data to explore social problems, opportunities and questions.

In participatory mapping, the main objectives are to:

- Collect evidence assets of the study area and issues during the mapping process
- Interpret the study area mapping experience and related experience to answer questions that have been developed about the study area
- Develop a presentation that synthesises the participatory mapping experience and presents the conclusion and possible questions for further investigation.

Conducting Participatory Mapping

Whenever participatory mapping is to be conducted, the foremost issue of consideration is the 'goal of the work' which outlines the nature and essence of activities to be done. Once the goal has been decided, the next stage is the organisation of activities of participatory mapping in two blocks – preparation and implementation. The preparation involves 'scouting' and 'designing survey instrument, materials and directions. The implementation may be organised into sessions (usually four) - preparation of participants or people involved in the participatory mapping activity; undertake participatory mapping field trip; make presentations and carry out debriefing exercises.

Utilisation of Participatory Mapping

Participatory mapping is a powerful tool that increases stakeholder involvement and provides a means for participants to express their ideas in an easily understandable visual format. Participatory mapping is commonly used in the following ways:

- To create maps that represent resources, hazards, community values, usage (e.g., for recreation or other visitor use), perceptions, or alternative scenarios
- To gather traditional knowledge and practices and to collect information (hazards, environmental, socioeconomic, visitor use, etc.) for assessments or monitoring
- To identify data gaps.
- To inform other data collection methods (e.g., formal surveys, interviews, etc.)
- To evaluate existing programmes, plans and activities
- To facilitate the decision-making process

- To assist with data gathering for research
- To empower stakeholders
- To conduct trend analysis
- To educate stakeholders about issues and interrelationships of resources outside their immediate areas of concern A participatory mapping method includes community mapping with paper maps and conversion of community paper maps into GIS maps.

APPLICATIONS OF HAZARD MAPS

Hazard maps have various applications that may be broadly captured as in spatial planning, risk reduction measures, instruments used in emergency planning and raising Disaster risk Management:

- Spatial planning:

  Hazard maps provide a basis for communal and district spatial planning processes (e.g., definition of hazard zones in development plans and formulation of building regulations)
- Risk reduction measures:

  Hazard maps assist in the localisation and dimensioning of hazard protection measures (e.g., flood protection structures, avalanche barriers, etc.)
- Instruments used in emergency planning:

  Hazard maps indicate where the biggest risks arise and the events most likely to occur. This information can be used as a source of orientation in emergency planning.
- Raising awareness among the population:

  Hazard maps help to demonstrate potential risks to the population and to increase awareness of eventual protective measures.

VULNERABILITY ASSESSMENT

The concept of vulnerability was defined as the degree to which a system is exposed and susceptible to the adverse effects of a given hazard. It is also defined as vulnerability as “Exposure to risk and an inability to avoid or absorb potential harm”. Both vulnerability and its antithesis, resilience, are determined by ***physical, environmental, social, economic, political, cultural and institutional factors***”

Vulnerability = (Exposure) + (Resistance) + Resilience

Exposure: at risk property and population

Resistance: Measures taken to prevent, avoid or reduce loss; and Resilience: Ability to recover prior state or achieve desired post-disaster state.

Types of Vulnerability

Physical vulnerability

This refers to the potential losses to physical infrastructure such as roads, bridges, railways, radio and telecommunication mast and other features in the built environment. Physical vulnerability also includes impacts on the human population in terms of injuries or deaths. Vulnerability is analysed per group of constructions (i.e., structural types) having similar damage performance. It is an intrinsic quality of a structure and it does not depend on location.

Social vulnerability

Social vulnerability refers to losses as experienced by people and their social, economic, and political systems. In this context, vulnerability refers to the extent to which elements of society such as children, the aged, pregnant and lactating women, single parents, physically and mentally challenged, the poor and destitute, social class, caste, ethnicity, gender, family systems, political systems, economic systems and cultural values degrade after being exposed to a hazardous condition. Levels of exposure to hazards, access to financial, social, natural, physical and human capital as well as policies, institutions and processes will influence the degree to which individuals, groups of persons or systems will degrade.

Economic vulnerability

This refers to the potential impacts of hazards on economic assets and processes (i.e., business interruption, loss of productive capacity, secondary effects such as increased poverty and job loss) and includes vulnerability of different economic sectors. Economic vulnerability is usually combined with social vulnerability during assessments.

Ecological/environmental vulnerability

This refers to the degree of loss that an ecosystem will sustain to its structure, function and composition as a result of exposure to a hazardous condition. This includes degradation, biodiversity loss and loss of productivity.

VULNERABILITY ASSESSMENT

This refers to the quantification of the degree of loss or susceptibility to an element at risk. The assessment is essential when conducting a risk assessment. Vulnerability assessments have not always been a part of risk assessment, but in recent times, they have become indispensable due to the recognition that disasters occur as a result of interactions between hazards and vulnerable elements. Variations exist in the method of quantification of vulnerability based on the following:

a. Type of vulnerability being measured, that is, it is physical, social, economic or ecological.
b. The scale at which vulnerability is being measured, whether at the individual, household or community level.
c. The type of hazard. Different hazard types call for different methods of quantification as not all methods of vulnerability quantification are used for the different hazard types.

Data needed for vulnerability assessment and their usefulness

- Historical data on the magnitude of a hazard and the level of damage it caused to specific elements such as buildings built from sand or wood.
- Socio-economic data such as level of education, access to pipe borne water, access to secure shelter, social networks, sanitation, income level, access to credit, access to land, access to technology etc. The emphasis here is on the level of access that an individual, household or community has to various assets.
- Level of exposure to hazardous conditions
- Data on policies, institutions and processes which influence capacity of individuals, households and communities.

APPROACHES TO PHYSICAL VULNERABILITY ASSESSMENT

There are a wide variety of ways to measure physical vulnerability. Two (2) main methods can be distinguished. These are the ***empirical and analytical methods*** as shown below table.

- The ***analytical methods*** rely on the use of geotechnical engineering software and are often limited to individual structures.
- The ***empirical methods*** can be applied to groups of related structures.

Group	Method	Description
	Analysis of observed damage	Based on the collection and analysis of statistics of damage that occurred in recent and historic events. Relating vulnerability to different hazard intensities.
Empirical methods	**Expert opinion**	Based on asking groups of experts on vulnerability to give their opinions, e.g. the percentage damage they expect for the different structural types having different intensities of hazard. This is meant to come to a good assessment of the vulnerability. Method is time consuming and subjective. Re-assessments of vulnerability after building upgrading or repair are difficult to accommodate.
	Score Assignment	Method using a questionnaire with different parameters to assess the potential damages in relation to different hazard levels. The score assignment method is easier to update, e.g. if we think about earthquake vulnerability before and after application of retrofitting.
Analytical models	**Simple Analytical models**	Studying the behaviour of buildings and structures based on engineering design criteria, analysing e.g. seismic load and to derive the likelihood of failure, using computer based methods from geotechnical engineering. Using, e.g. shake tables and wind tunnels, as well as computer simulation techniques.
	Detailed Analytical methods	Using complex methods. It is time consuming, needs a lot of detailed data and will be used for assessment of individual structures.

Table 1: Methods of measuring physical vulnerability

METHODS OF MEASURING SOCIO-ECONOMIC VULNERABILITY

Socio-economic vulnerability is indicator-based and can be assessed by analysing the level of exposure and coping mechanisms of individuals, households and communities.

Analysis of exposure and coping is done taking into consideration policies and processes and adaptation strategies of affected individuals, households and communities as shown in Figure 2.

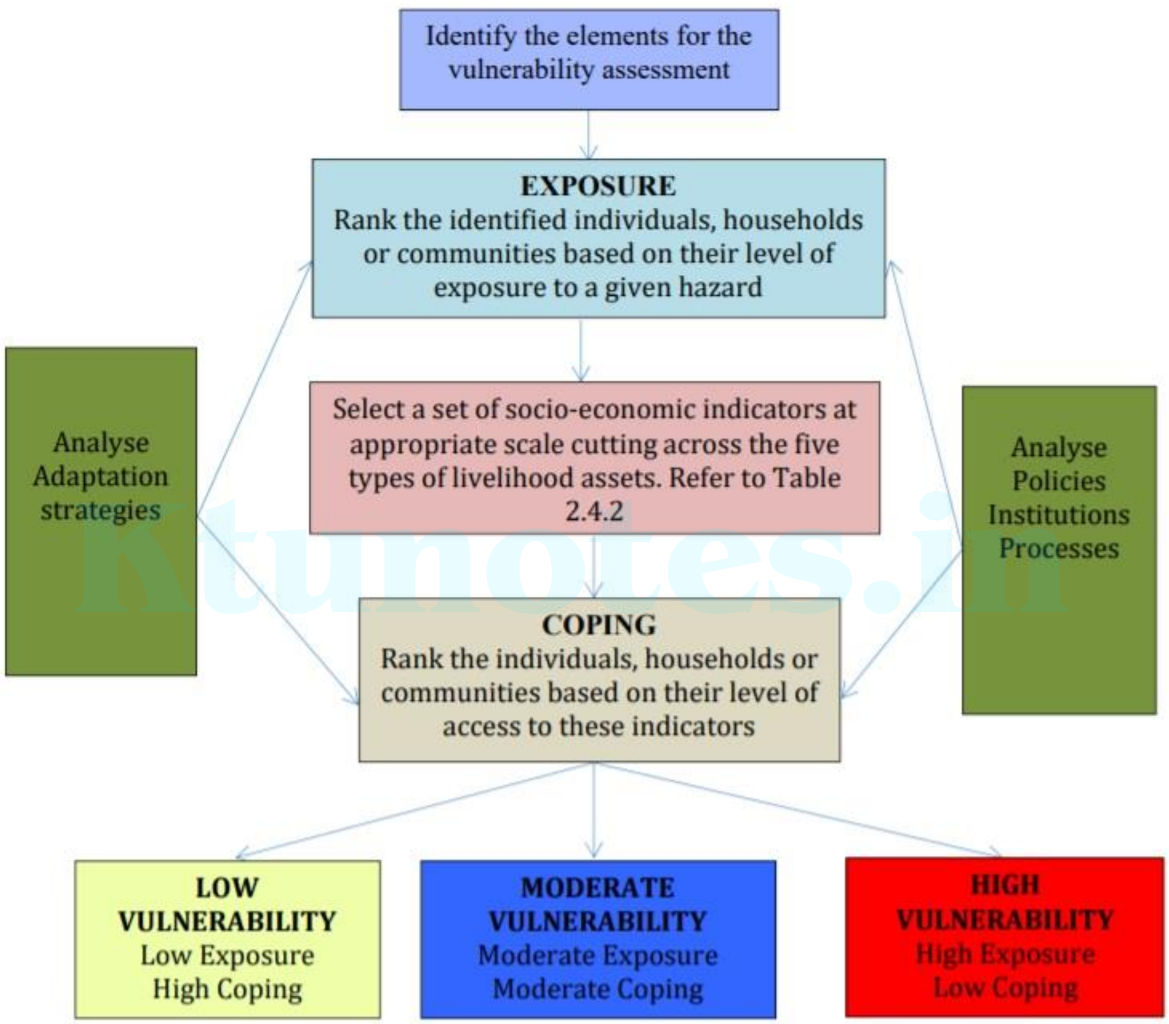

Fig 2: Method for assessing socio-economic vulnerability

Human Capital	Natural Capital	Social Capital	Physical Capital	Financial Capital
Health	Land and produce	Networks and connections	Infrastructure • Transport - roads, vehicles, etc. • Secure shelter & buildings water supply & sanitation	Savings
			• Energy communications	
Nutrition	Water & aquatic resources	Patronage	Tools and technology • Tools and equipment for production • Seed, fertiliser, pesticides • Traditional technology	Credit/debt - formal, informal, NGOs
Education	Forest products	Neighbourhoods		Remittances
Knowledge and skills	Wildlife	Kinship		Pensions
Capacity to work	Wild foods & fibres	Relations of trust and mutual support		Wages
Capacity to adapt	Biodiversity	Formal and informal groups		Dividends
	Environmental services	Common rules and sanctions		Return on Investments

Table 2: Socio-economic indicators

METHODS OF REPRESENTING VULNERABILITY

- ***Vulnerability indices:*** Based on indicators of vulnerability; mostly no direct relation with the different hazard intensities. These are mostly used for expressing social, economic and environmental vulnerability. V
- ***Vulnerability table***: The relation between hazard intensity and degree of damage can also be given in a table.

- ***Vulnerability curves:*** These are constructed on the basis of the relation between hazard intensities and damage data.
    - Relative curves: They show the percentage of property value as the damaged share of the total value to hazard intensity.
    - Absolute curves: Show the absolute amount of damage depending on the hazard intensity; i.e., the value of the asset is already integrated in the damage function;
    - Fragility curves: Provide the probability for a particular group of elements at risk to be in or exceeding a certain damage state under a given hazard intensity.

DISASTER RISK ASSESSMENT

Disaster risk was defined as the likelihood/probability of serious damage, deaths and injuries occurring as a result of a potentially damaging hazard interacting with vulnerable elements such as people and properties. Thus, disaster risk arises out of an interaction between a hazardous condition and vulnerable elements.

Fig 3: Disaster Risk

Disaster Risk Assessment

Risk assessments form an important aspect of risk reduction strategies. Risk assessment was defined and regarded as a methodology to determine the likelihood and magnitude of damage or other consequences by analysing potential hazards and evaluating existing conditions of vulnerability that jointly could likely harm exposed people, properties, services, livelihoods and the environment they depend on.

Components of Risk Assessment

There are two (2) main components:

- Risk analysis: The use of available information to estimate the risk caused by hazards to individuals or populations, property or the environment. Risk analyses generally contain the following steps:

Hazard identification, hazard assessment, elements at risk/exposure, vulnerability assessment and risk estimation.

- Risk evaluation: This is the stage at which values and judgement enter the decision process by including the importance of the risk and associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risk.

Risk assessment involves the assessment of hazards and vulnerabilities. Thus, risk assessments are inextricably linked to and strongly influenced by the nature and likelihood of a hazard as well as the extent of loss that may occur due to the hazard.

CONTEMPORARY APPROACHES TO RISK ASSESSMENTS

- ***Multi-hazard***: The same area may be threatened by different types of hazards. Each of these hazard types has different areas that might be impacted by hazard scenarios. Each of the hazard scenarios also might have different magnitudes. For instance, water depth and velocity in the case of flooding, acceleration and ground displacement in the case of earthquakes. These hazard magnitudes would also have different impacts on the various elements at risk, and therefore require different vulnerability curves.
- ***Multi-sectoral***: Hazards will impact different types of elements at risk.
- ***Multi-level***: Risk assessment can be carried out at different levels. Depending on the objectives of the risk study, it is possible to differentiate between national, regional, district and local policies, plans and activities to see how they have contributed to increased or reduced risk, their strengths and weaknesses in dealing with risks, and what resources are available at the different levels to reduce risks.
- ***Multi-stakeholder***: Risk assessment should involve the relevant stakeholders, which can be individuals, businesses, organisations and authorities.
- ***Multi-phase***: Risk assessment should consider actions for response, recovery, mitigation and preparedness.
- ***Qualitative methods***: This involves qualitative descriptions or characterisation of risk in terms of high, moderate and low. These are used when the hazard information does not allow us to express the probability of occurrence, or it is not possible to estimate the magnitude. This approach has widespread application in the profiling of vulnerability using participatory methodologies. Risk matrices can be constructed to show qualitative risk. A risk matrix shows on its y-axis probability of an event occurring, while on the x-axis potential loss. The probability is described categorically as low, medium and high, while the potential loss is also described similarly as in Figure 4.

Fig 4: An example of a risk matrix used for assessing risk qualitatively

A. Hazards	B. Hazard Likelihood **0 low – 5 is high**	C. Impact Severity **(Vulnerabilities/ Resources)** **0 is low – 5 is high**	D. Risk Score **B x C** E. Priority	E. Priority

Fig 5: Risk assessment matrix

Earthquake	Lightening	Debris Flow	Civil unrest	
Flood	Heat Wave	Hazardous materials release	Terrorism	
Fire	Drought	Transportation accident	Market fires	
Storms	Pandemic (e.g., HIV/AIDS, flu)			
Fire		Water shortage		
Food poisoning	Landslide	Power shortage		

Fig 6: Potential hazards

- ***Semi-quantitative methods***: These techniques express risk in terms of risk indices. These are numerical values, often ranging between 0 and 1. They do not have a direct meaning of expected losses; they are merely relative indications of risk. In this case, risk is expressed in a relative sense. The main difference between qualitative and semi-quantitative approaches is the assignment of weights under certain criteria which provide numbers as outcome instead of qualitative classes. The semi quantitative estimation for risk assessment is found useful in the following situations:
  - As an initial screening process to identify hazards and risks
  - When the level of risk (pre-assumed) does not justify the time and effort
  - Where the possibility of obtaining numerical data is limited Semi-quantitative approaches consider a number of factors that have an influence on the risk.

A range of scores and settings for each factor may be used to assess the extent to which that factor is favourable or unfavourable to the occurrence of instability (hazard) and the occurrence of loss or damage (consequence). The matrix of hazards and consequences is used to obtain a ranked risk value. This is made by combining a set of hazard categories with a set of consequence categories. The final risk values can also be categorised and ranked with qualitative implications. The risk estimation can be done separately for loss of life and economic loss.

The semi-quantitative approach could be adapted to cover larger areas (spatial or GIS based). This approach may be applicable at any scale or level of analysis, but more reasonably used in medium scales.

Nowadays, such a semi-quantitative approach can efficiently use spatial multi-criteria techniques implemented in GIS that facilitate standardisation, weighting and data integration in a single set of tools. Semi-quantitative risk can also be conceptualised as:

Risk = Hazard * Vulnerability / Capacity

Although the equation is only conceptual, it allows incorporating the multi-dimensional aspects of vulnerability, and capacity. In this approach, indicators are used to characterise vulnerability and capacity, for instance, by relating it to population characteristics. These indicators are often integrated with hazard indicators using Spatial Multi-Criteria Evaluation

Quantitative methods

This aims at estimating the spatial and temporal probability of risk and its magnitude. In this method, the combined effects, in terms of losses for all possible scenarios that might occur, are calculated. There are several approaches; they express the risk in quantitative terms either as probabilities, or expected losses. In this approach, risk is perceived as follows:

Risk = Hazard * Vulnerability / Capacity

The equation given above is not only a conceptual one, but can also be actually calculated with spatial data in a GIS to quantify risk from hazards. The way in which the amount of elements-at-risk are characterised (e.g., as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g., annual probability).

General	Type	Principle	
Qualitative	Qualitative	Based on relative risk classes categorised by expert judgment. Risk classes: High, Moderate and Low	
	Semi-Quantitative	Based on relative ranking and weights assignments by a given criteria. Risk index: Ranked values (0-1, 0-10 or 0-100). (dimensionless)	
Quantitative	Probability	Probabilistic values (0-1) for having a predefined loss over a particular time period	
	Economic risk	Quantification of the expected losses in monetary values over a specific period of time	
		Probable Maximum Loss (PML)	Probable Maximum Loss (PML) The largest loss believed to be possible in a defined return period, such as 1 in 100 years, or 1 in 250 years
		Average Annual Loss (AAL)	Expected loss per year when averaged over a very long period (e.g., 1,000 years). Computationally, AAL is the summation of products of event losses and event occurrence probabilities for all stochastic events in a loss model.
		Loss Exceedance Curve (LEC)	Risk curve plotting the consequences (losses) against the probability for many different events with different return periods.
	Population risk	Quantification of the risk to population	
		Individual risk	The risk of fatality or injury to any identifiable (named) individual who live within the zone impacted by a hazard; or follows a particular pattern of life that might subject him or her to the consequences of a hazard.
		Societal risk	The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

Table 3: Different ways of expressing risk

Population Risk

Population risk can be expressed as individual risk or societal risk. Individual risk is the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by a hazard, or follows a particular pattern of life that might subject him or her to the consequences of a hazard. Individual risk can be calculated as the total risk divided by the population at risk. For example, if a region with a population of one million people experiences on average 5 deaths from flooding per year, the individual risk of being killed by a flood in that region is 5/1,000,000, usually expressed in orders of magnitude as 5×10-6. Societal risk is the risk of multiple fatalities or injuries in the society as a whole, and where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses. Below shows an example for population risk.

- **What are the risks from driving an automobile?**
- **There are 15,000,000 accidents per year, 1 in 300 of which result in death, there are 250,000,000 people**

$$Societal\ Risk = 15{,}000{,}000 \frac{accidents}{year} \times \frac{1}{300} \frac{accidents}{year} = 50{,}000 \frac{deaths}{year}$$

$$Individual\ Risk = \frac{50{,}000\ deaths / year}{250{,}000{,}000\ people} = 2 \times 10^{-4} \frac{deaths}{person \cdot year}$$

$$Lifetime\ Risk = 2 \times 10^{-4} \frac{deaths}{person \cdot year} \times 70\ years = 0.014 (1\ in\ 70)$$