Indian Ocean Tsunami Warning System- Achievements and Challenges to be considered in the post 2015 era

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1. Objectives of the paper

The objective of this paper is to share the experience in establishing the Indian Ocean Tsunami Warning and Mitigation System, a successful collaborative effort by Indian Ocean member states under UNESCO/Intergovernmental Oceanographic Commission (Paris). The paper is presented to highlight key learning achievements and good practices. It also focuses on policies which had to adopted, on capacity development which had to be undertaken both with respect to technology and institutional development and also on the measures which had to be taken to promote institutional coordination, exchange of data and information and vital links of dialogue both on a routine basis and when a hazard is active across a region.

2. Introduction to the Indian Ocean Tsunami Warning System

In the aftermath of the Indian Ocean Tsunami, the Indian Ocean States decided to establish a tsunami warning system under UNESCO/IOC, Paris which governs global tsunami warning systems under the United Nations. The first meeting of the Indian Ocean member states was held in Paris in March, 2005. This was followed by a Ministerial meeting in Mauritius in April 2005 which set the agenda for the establishment of the IOTWS via an Intergovernmental Coordination Group (ICG). The IOTWS also established its Secretariat in Perth assisted by the Government of Australia. The Head of the Secretariat coordinates all activities of the ICG which has been meeting almost annually to coordinate all activities and the 10^{th} sessions are scheduled to be held in Oman in early 2015.

At the first meeting in Paris it was decided that the Indian Ocean Tsunami Warning System (IOTWS) will be a coordinated network of national systems and capacities where each member state has the responsibility of identifying the hazard, assessing the risk and issuing the warning to its population within their respective territories, for which they will be assisted by Regional Tsunami Service Providers (RTSP) to be established in some of the Indian Ocean countries. India, Indonesia and Australia pioneered the establishment of RTSPs to serve the member states. All three RTSPs monitor the full Indian Ocean basin in collaboration with the other Indian Ocean states using state of the art technology.

The IOTWS has been developed as an End-to-End Tsunami Warning System. The upstream includes detection, verification, threat evaluation, tsunami forecast, warning dissemination and the downstream includes, delivery of public safety message, initiation of national counter-measures, preparation and implementation of standardised response.

The establishment of the IOTWS was facilitated by working groups, covering the three principal pillars, namely,

- Risk Assessment and Reduction (*collect data and undertake risk assessment)*
- Detection, Warning and Dissemination (*develop hazard detection, monitoring and early warning services and communicate threat information and early warnings*
- Awareness and Response (*build national and community response capabilities)*

Given the above background, it was evident that national capacities in a number of areas had to be enhanced so that the respective warning centers and the supporting institutions will be well equipped to receive, analyze information the hazard, assess the risk and issue the warning to the communities who have been adequately trained on how best to respond to the specific type of warning issued.

The Working Groups mentioned above commenced work in the following critical areas to achieve the overall objectives.

- Seismic measurements, data collection and exchange
- Sea level data collection and exchange, including deep ocean tsunami detection instruments
- Risk assessment and management
- Tsunami hazard identification and characterization including modeling and prediction
- Establishment of a system of interoperable centers
- Enhancing national capacities in awareness, preparedness and response

UNESCO/IOC also organized the First Meeting of the GLOBAL-ICG-Tsunami Warning Systems in Paris, in March 2009 to promote collaboration and share knowledge among the global systems.

3. Tsunami Detection, Warning and Dissemination

A Tsunami Warning System must alert all persons on every vulnerable coast of imminent danger, covered by the system. The response of such a system must be rapid (as soon as possible), accurate (minimize false warning), reliable (continuous operation), effective (to save lives). UN-ISDR Framework for effective Early Warning Systems encompass **four** critical linked elements, namely,

- Risk Knowledge
- Detection, Monitoring and Warning Service
- Dissemination and Communication
- Response Capability

These elements encompass the knowledge of hazards, vulnerability, preparedness and response. For an efficient early warning system it is mandatory to have strong links among the four critical components at all operational levels.

The hazard detection of a Tsunami Early Warning Systems can be broadly classified into Minimal, Standard and Advanced. In the Minimal System warning is based on earthquake detection only. Standard System includes tsunami detection followed by earthquake detection, using ocean based equipment. In the Advanced System earthquake detection and tsunami

detection are followed by tsunami forecasting. The latter has been successfully adopted by the Pacific Tsunami Warning System. The advanced system requires the computation and storage of a large number of scenarios of tsunami sources and the corresponding inundation of exposed areas. This information could be accessed and analysed easily when an earthquake having the potential of generating a tsunami takes place leading to reliable warnings. IOTWS operates as an Advanced System adding reliability to the system and is frequently monitored and upgraded under the leadership of the RTSPs.

A reliable tsunami warning system requires information arising from three instrumentation networks, namely, an improved seismographic network, a real time sea level observation network covering the Indian Ocean basin and the deployment of deep sea pressure sensors capable of detecting the tsunami as it travels over the deep ocean. The IOTWS through national and international collaboration have strengthened the seismic and tidal observation networks. Indian, Indonesia and Australia, the three RTSPs have deployed deep sea pressure sensors (tsunami buoys) for early tsunami detection. The three RTSPs had to establish a common template for the entire Indian Ocean coastline in order to develop a uniform warning mechanism through tsunami wave modeling and forecasting. Since the three RTSPs utilized different operating systems and equipment, they had to conduct numerous trial runs on varying hypothetical cases to ensure that they would produce similar forecasting during a hazardous event.

The IOTWS through several initiatives have assisted the National Warning Centers to upgrade their facilities and provide training on tsunami warning and in particular on interpreting the warning issued by the RTSPs at national level. They have also focused on the limitations of the system in the form of simplifications in providing the tsunami wave height at 1m depth during hazardous event. The importance of conducting inundation studies at national level and the need to refine the forecasting to accommodate variations of bathymetry and shoreline geometry has been identified.

Since the Indian Ocean Tsunami of December 2004 there have been several hazardous situations, and the IOTWS Secretariat has conducted surveys on the performance of both national and RTSP systems in facing such situations. The IOTWS Secretariat in collaboration with the RTSPs have also conducted many training programmes for the benefit of officers in charge of Warning Centers to enhance their knowledge and operating procedures. In addition the IOTWS Secretariat conducts regular tests (IO Wave) exercises to check the system as a whole and its preparedness to respond to a given hazardous situation. These perform as stress tests on the system.

From 2005 to 2013, an Interim Advisory Service for the Indian Ocean was provided by the Pacific Tsunami Warning Centre and the Japanese Meteorological Agency. From 12 October 2011 Australia, Indonesia and India have taken the role of RTSPs, and provide tsunami bulletins and information to all Indian Ocean countries. At the 9th Session of the ICG/IOTWS held in Jakarta in Nov 2012, the performance of RTSPs was reviewed and it was observed that all three RTSPs met the standards required by ICG/IOTWS. They were requested to assume full operational service from March 31, 2013. Meanwhile the JMA & PTWC were requested to cease Interim Advisory Service for the Indian Ocean from March 31, 2013.

4. Risk Assessment and Reduction

The Working Group on Risk Assessment and Reduction was established at the 1st ICG/IOTWS held in Perth in August 2005 giving high priority for this important subject. During the following period the Working Group conducted a survey to identify the needs of its membership. The important issues identified by the membership were,

1. Initiate Investigative Studies on Tsunami Hazard Sources and Data Collection
2. Prepare Integrated Regional Tsunami Hazard Map /Risk Model to enhance understanding of the Tsunami Hazard
3. Develop Uniform Guidelines for Tsunami Risk Assessment based on the wide experience available among the member countries
4. Provide Guidance on Tsunami Hazard Mitigation
5. Strengthen the Capabilities of Indian Ocean States in the field of Tsunami Risk Assessment and Mitigation via well structured Training Programmes.

The Working Group adopted a four pronged approach to achieve its tasks

1) Assisted the member states together with Secretariat to conduct investigative studies on hazard sources and data collection. The early work done in the Makran Source area is a good example of this type of initiative.
2) The Indian Ocean Tsunami Hazard Map was prepared by Geo Science Australia based on probabilistic tsunami hazard modeling and in full consultation with the Working Group, regional and external experts.
3) Tsunami Risk Assessment Guideline was prepared and published as a UNESCO Manual and Guideline No.52. This Guideline was prepared over a two year period having convened several workshops in order to consult the regional and external experts. Priority was given to the understanding of the existing risk assessment framework in Indian Ocean Countries and to ensure that the guidelines captured the existing knowledge base of Indian Ocean States.
4) Several Seminars and Workshops were held during the preparation of the Tsunami Hazard Map and the Risk Assessment Guideline. After the successful preparation of these two documents a Design Workshop and a Training Programme comprising a Seminar and Training Workshop were conducted for member states in Bangkok 2009 to plan and provide training to member states on the use of the Tsunami Hazard Map and the Risk Assessment Guideline. Thereafter several training workshops have been conducted successfully both at national and regional level.

The Indian Ocean Tsunami Hazard Map and the Tsunami Risk Assessment Guideline (Manual and Guideline No 52) were the first of its kind to be developed by any of the Tsunami Warning Systems. The members of the Working Group contributed generously to their development. Throughout their development several Workshops have been conducted with the objectives of sharing experience, enhancing knowledge base and training. The Working Group encourages the adoption of this guideline or develop national guidelines/addendums based on the said guideline. The Training Workshops conducted for the benefit of the member states have been most productive in enhancing the knowledge base of professionals engaged in risk assessment and reduction.

The Working Group has also contributed to several publications by UNESCO and other international organizations. Currently the Working Group is revising the UNESCO Manual and Guideline No 52 in order to cover adequately areas which were not fully covered and to accommodate new challenges. The Working Group will thereafter conduct a 'Training the Trainer Workshop' for the benefit of the membership also develop a strategic document outlining a mechanism to sustain the said training programmes.

An example of good practice can be cited from Oman where its Government is currently undertaking risk assessment studies along its entire coastline. The project has two principal phases namely the overall risk assessment along the full coast of Oman and detailed risk assessment of selected coastal principal cities. This will enable the authorities to undertake risk management measures effectively and on a priority basis.

With the establishment of the IOTWS it is possible to focus on risk assessment within a tsunami forecasting and early warning framework. While operating within a Tsunami Forecasting Framework and through the use of a standardized tsunami forecast system including, tsunami source characterization, tsunami measurements, and tsunami forecast models, it is possible to develop a capability to serve

- Real-time operational needs (event based as implemented by the RTSPs)
- Hazard/Risk Assessment needs (for strategic risk assessment)
- Research and Development opportunities

Outcomes of detailed inundation modeling which have to carried out for risk assessment can be integrated with the tsunami forecasting on the coastline provided by RTSPs (based on simplified assumptions), to provide improved forecasting for the benefit of the coastal communities. A case study on this subject is in progress for the City of Galle Sri Lanka.

5. Awareness and Response

A dedicated Working Group was established at the 2nd ICG/IOTWS to work on the critical areas relating to Education, Awareness, Preparedness, Response and Evacuation to ensure that coastal communities are in position to face the challenges of hazardous situations with high degree of confidence. Evacuation planning, simulations and drills, clear understanding of public warnings and coordinated response are important elements in the chain of events.

Disaster preparedness involve a vast range of tasks which have to be duly carried out to ensure that government agencies, voluntary and private organizations and the community as a whole respond efficiently and in an appropriate and timely manner. This should lead to a well coordinated response as a major disaster event will require an integrated response by different sectors including community, non- governmental and governmental institutions and the latter operating and at different administrative levels. It is necessary to promote and achieve inter-institutional coordination through the implementation of a variety of measures.

In order to avoid the development of chaotic situations and improvisations during the response phase, it is important to follow Standard Operation Procedures (SOPs) for disaster prevention and management. This is of vital importance in relation to warnings relating to the rapid onset of extreme events. SOPs list and describe in sufficient detail the sequence of activities to be

implemented either following a warning or a hazard event. The IOTWS while giving priority to this important area has conducted numerous training programmes for the benefit of member states.

The Working Group has given due consideration to human security, identified the importance of community based disaster response/ management and worked towards establishing resilient societies. The capacity to absorb and withstand impacts of hazards, to emerge from disaster events and to adapt efficiently to changing conditions is a hallmark of resilient communities.

6. Learning Achievements and Good Practices

The successful implementation of the Indian Ocean Tsunami Warning System in a highly structured and organised manner is an important achievement for Indian Ocean states. The said success was mainly due to the spirit of cooperation and effective collaboration displayed by the member states and RTSPs working towards a common goal ably guided and driven by the IOTWS Secretariat. This approach enabled system integration on which the success of the IOTWS was dependent, to be achieved at every level.

Regional Tsunami Service Providers (RTSPs) work in full collaboration with the National Tsunami Warning Centers (NTWCs) and National Focal Points. The collaboration among member states are based on international and multilateral cooperation, on open and free data exchange, protection and security to all member states, transparent and accountable administrative and operating procedures with governance provided by IOC though the IOTWS Secretariat.

The member states respected the individual and collective responsibilities for the effective functioning of IOTWS. In this respect the member states

- Engaged in joint operation of international and regional networks for detection and monitoring connected with RTSPs/NTWCs
- Accepted the responsibility for issuing warnings in their territory and for protecting its own population.
- Ensured that warning agencies and focal points at national level established strong links with emergency preparedness authorities (national, provincial and local) to ensure human security.
- Promoted risk assessment studies of cities and regions in order to undertake disaster risk reduction measures for human, food, environmental and infrastructure security.
- Worked towards establishing resilient communities who are prepared to face the challenges of the rapid onset of extreme hazardous events.

7. Challenges to be considered in the post 2015 era

Since the Indian Ocean Tsunami of December 2004, the Indian Ocean basin has been on alert on several occasions for tsunami warnings even leading to evacuation by several countries. IOTWS will be further strengthened as an Advanced Tsunami Warning System to provide rapid, accurate and reliable forecasting for human security. The need to operate with Multi Hazard Early Warning Framework has also been duly recognized. Attention is focused on early warning and evacuation relating to rapid onset of extreme events which can impact coastal communities

within a very short time and still remains a major challenge. Equally attention should be focused on chronic hazards having a slow onset.

It is important that nations undertake risk assessment studies of vulnerable cities and regions exposed to high hazards. The outcome of risk assessment studies must be utilized for strategic disaster risk reduction via hazard and vulnerability mitigation and improving preparedness. This will contribute to human security and the protection of the built and natural environment.

As identified previously, tsunami wave forecasting on the coastline provide by RTSPs is based on simplifying assumptions. The member states have to undertake detailed inundation modeling and integrate with the tsunami wave height forecasting provided by RTSPs to develop improved forecasting during a hazardous event. The outcome of inundation modeling for risk assessment studies can be effectively used for this purpose.

The need to provide training in risk assessment to officers from member states is a high priority so that they would be able to be at the forefront in undertaking such studies. Knowledge of hazards, vulnerability and preparedness is of vital importance in this exercise. Recent disasters and its impact on communities and infrastructure have focused on the importance of conducting 'vulnerability checks' whereby factors leading to reduction and increase of vulnerability are examined on a routine basis and where necessary appropriate measures undertaken for mitigation.

An integral component of a successful end-to-end system is the presence of Standard Operation Procedures which has to be accepted and respected by the stakeholders. It was recognised that SOPs have to be adopted by various agencies for risk management (prior to or detecting a hazard event) and disaster management (during a hazard event). Stakeholders comprising both information suppliers and information receivers should be made educated on all key elements of the end-to-end system and the relevant SOPs and communications which have to be complied.

Coastal community resilience is identified as the capacity to absorb and withstand impacts of hazards, to emerge from disaster events and to adapt efficiently to changing conditions. Economic and social development pressure in coastal areas, increasing population density and distribution, human induced vulnerabilities, together with increasing frequency and duration of storms, long term sea level rise and other hazards both chronic and episodic have created conditions for disasters of high severity occurring more frequently. The period of time between disasters and recovery is becoming smaller and coastal communities have restricted capacity and reduced time to recover and emerge. Some communities are continuously facing disasters, event after event, depriving them of time to plan and achieve long term recovery. In effect they lead a life of continuous response to varying disasters. Such communities have to be identified as high risk areas and studies have to be undertaken on special area risk assessment and management.

It is important that every effort is taken to building hazard resilient communities which can only be developed via a three pronged approach of reducing the impact of hazards, reducing vulnerability and improving preparedness. The community should be encouraged to harness the full potential of their indigenous knowledge in developing measures on improving preparedness.

Enhanced coastal community resilience enables populations at risk to adapt a wide range of coastal hazards with a greater degree of confidence.

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