UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

Expert Meeting:

Establishment of a regional working group and working process between NWIO Countries on risk knowledge

Gap analysis and strategy for regional cooperation to develop a unified regional tsunami hazard map developed by a NWIO working group on Risk Knowledge

Muscat, Oman

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Meeting Report and Conclusions

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About this document

The document was prepared by Rick Bailey under a consultancy arrangement with the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organisation (UNESCO). It contains a summary of the discussions of the Expert Meeting, which includes an assessment of current capabilities of Member States of the North West Indian Ocean (NWIO), a review of current understanding of scientific knowledge and identification of gaps and priorities requiring further research and study. The agreements and work plans for the way ahead are also documented here.

The document is intended as an **internal working document** to serve as a reference for the actors involved in the upcoming discussions on the enhancement of tsunami risk knowledge in the NWIO.

CONTENT

Abbreviations

(N)DMO	(National) Disaster Management Office / Organization
CAP	Common Alert Protocol
CFP / CFZ	Costal Forecast Points / Costal Forecast Zones
ComMIT	Community Model Interface for Tsunami
DSS	Decision Support System
EOC	Emergency Operations Centre
EQ	Earthquake
ESCAP	Economic and Social Commission for Asia and the Pacific
ETA	Estimated Time of Arrival
EWA	Estimated Wave Amplitude
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICG	Intergovernmental Coordination Group
ICG/IOTWMS	Intergovernmental Coordination Group for Indian Ocean Tsunami Warning and Mitigation System
ICG/PTWS	Intergovernmental Coordination Group for Pacific Tsunami Warning System
IOC	Intergovernmental Oceanographic Commission
IOTIC	Indian Ocean Tsunami Information Centre
IOTR	Indian Ocean Tsunami Ready
IOTWMS	Indian Ocean Tsunami Warning and Mitigation System
IOWave	Indian Ocean Tsunami Exercise
LDMO	Local Disaster Management Organization
M / MW	Earthquake Magnitude / moment magnitude
MSZ	Makran Subduction Zone
NTWC	National Tsunami Warning Centre
NWG	National Working Group
NWIO	North Western Indian Ocean
NWIO-WG	North Western Indian Ocean - Working Group
PDMO	Provincial / State Disaster Management Organisation
RWG	Regional Working Group
SOP	Standard Operating Procedure
TEMPP	Tsunami Evacuation Maps, Plans and Procedures
TEWS	Tsunami Early Warning Systems
TNC	Tsunami National Contact
TSP	Tsunami Service Providers
TT	Task Team
TT-MSZ	Task Team on Scientific Tsunami Hazard assessment of the Makran Subduction Zone

TT-Near Field	Task Team on Tsunami Preparedness for a Near-Field Tsunami Hazard
TTF	Trust Fund for Tsunami, Disaster and Climate Preparedness
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WG	Working Group

INDIA

IB/PIB	Intelligence Bureau / Press Information Bureau
ICMAM	Integrated Coastal and Marine Area Management
IMD	India Meteorological Department
INCOIS	Indian National Centre for Ocean Information Services
ISRO	Indian Space Research Organisation
ITEWC	Indian Tsunami Early Warning Centre
MHA	Ministry of Home Affairs
MoES	Ministry of Earth Sciences
N (S/D)EOC	National (State / District) Emergency Operations Centre
NCMC	National Crisis Management Committee
NDMA	National Disaster Management Authority
NDRF	National Disaster Response Force
NGRI	National Geophysical Research Institute
NIOT	National Institute of Ocean Technology
NPP	Nuclear Power Plant
NRSC	National Remote Sensing Centre
SDMA	State Disaster Management Authorities
SOI	Survey of India - National Survey and Mapping Organisation

IRAN

GSI	Geological Survey of Iran
IGUT	Institute of Geophysics of the University of Tehran
IIEES	International Institute of Earthquake Engineering and Semiology
INCOH	Iranian National Centre for Ocean Hazards
INIOAS	Iranian National Institute for Oceanography and Atmospheric Science
IRIMO	Iranian Meteorological Organization
NCC	National Cartographic Center
NCC	National Cartographic Center
NGO	National Geographical Organization
PMO	Port and Maritime Organization

OMAN	
DGMET	Directorate General of Meteorology
DGOPS/ROP	Royal Police of Oman
EMC	Earthquake Monitoring Centre
MOE	Ministry of Education
NCCD	National Committee for Civil Defence
NMHEWS	National Multi-Hazard Early Warning Centre
PACA	Public Authority for Civil Aviation
PACDA	Public Authority for Civil Defence and Ambulance
PART	Public Authority for Radio and TV
SQU	Sultan Qaboos University

PAKISTAN	
DDMA	District Disaster Management Authority
NDMA	National Disaster Management Authority
PDMA	Provincial Disaster Management Authority
PEMRA	Pakistan Electronic Media Regulatory Authority
PMD	Pakistan Meteorological Department
PMSA	Pakistan Maritime Security Agency

1. Executive Summary

Hazard and risk assessments are a critical element in end-to-end tsunami early warning systems and play a vital role to educate and inform communities and relevant authorities on the threat and potential impacts of tsunamis on coastal communities. If the authorities and communities are unaware or do not understand the hazard and the risk, they will most likely not be prepared to respond appropriately.

Hazard assessments require a detailed scientific understanding of the threat and how it is generated. **Unfortunately, much remains unknown about the complicated seismic structure and behaviour of the Makran Subduction Zone (MSZ).** Accordingly, the likely magnitude and impact of future tsunami events in the Makran region generated by undersea earthquakes is also unknown, which makes planning to prepare for and mitigate the effects of such events difficult.

A **Regional Working Group (RWG)** was established at the Expert Meeting, which reviewed the scientific gaps and priorities in key areas that were identified by the Expert Consultation on Scientific Tsunami Hazard Assessment of the MSZ, 8 March 2019, Kish Island, Iran. There was much continuing discussion on the differences in seismic structure of the western and eastern segments of the MSZ, whether the western segments of the MSZ are locked and the role of splay faults in determining the rupture characteristics and maximum potential magnitude of associated earthquakes. It was also considered that the earthquakes of historical events had also most likely created secondary effects (such as submarine landslides) that worsened the size and impacts of the generated tsunamis (e.g. 1945). There is also the potential for meteo-tsunamis in the region.

Based on the continuing discussions on the seismicity and other potential secondary sources, it was considered difficult to determine the maximum credible earthquake magnitude for the MSZ. It was therefore suggested the best approach is to jointly undertake a unified Probabilistic Tsunami Hazard Assessment (PTHA) for the region by regional and international experts to assist decision makers and alike. The international experts agreed to develop a framework to help guide the development of the PTHA for the MSZ, based on their studies for other regions.

Fundamental to the development of the PTHA is also the joint development of a seismo-tectonic model, which may help better consider the characteristics of the seismicity of the MSZ. Such a model would also be fundamental and help studies on the design of optimal seismic, Global Navigation Satellite System (GNSS) and sea level monitoring networks in the region for hazard assessment and warning. The complexity of the MSZ also reinforced the need for far greater sharing of seismic and sea level data in real time between the countries and with the Tsunami Service Providers (TSPs: Australia, India, Indonesia), which are working under the auspices of the United Nations Educational, Scientific and Cultural Organisation (UNESCO) Intergovernmental Oceanographic Commission (IOC) Indian Ocean Tsunami Warning & Mitigation System (IOTWMS) . The TSPs provide tsunami threat information services for all Member States of the Indian Ocean.

Further work was encouraged on seismic and paleo-tsunami field studies aimed at a better understanding of the seismicity and tsunamigenic history of the region to enhance an understanding of the tsunami generating mechanisms and recurrence in the Makran region. It was also shown that tsunamis with amplitudes above lowest warning levels may propagate into the Arabian/Persian Gulf and the Red Sea, requiring an extension of the present coverage and Area of Service (AoS) of the IOTWMS.

The meeting agreed the highest priority to address gaps in current knowledge and understanding is the joint development of a unified based PTHA for the North-West Indian Ocean (NWIO) Region, which can then be used to undertake the appropriate risk assessments. This will support preparedness

planning, education and awareness of relevant authorities and communities on the tsunami threat. This will in turn help enable appropriate and effective community responses to the tsunami threat.

It was proposed the earmarked project funds be used to facilitate four joint activities on priority issues that will support the development of the PTHA, **supported by three Expert Teams including experts from each Member State and invited international experts**. **This will enable capacity building benefits from regional cooperation and the leveraging of international expertise**. The four activities to be undertaken by the Expert Teams include : a) **Develop a seismo-tectonic model** to best represent the current understanding of the complexities of the MSZ; b) **Identify the most appropriate tsunami propagation models** for use by the PTHA and future inundation modelling; c) **Provide guidance on the inclusion in the PTHA of tsunamis generated by atypical effects** (submarine landslides, mud volcanoes, etc.) and **extending the area of coverage to include the tsunamis in the Red Sea and Arabian/Persian Gulf in the PTHA framework**, or though other measures; and d) **Develop a Unified PTHA for the NWIO.**

A follow up meeting was proposed for December 2019 (Hyderabad, India) of nominated national experts and invited experts to agree on the framework and the full course of work to develop a unified PTHA . Follow up meetings of the Expert Teams have also been proposed for May/June (Iran) and/or August (India). The ensuing **results of the development of a unified PTHA will be presented at a scientific conference** at the inter-sessional meetings of the working groups and task teams of the Intergovernmental Coordination Group (ICG) for the IOTWMS, which are proposed for some time between November 2020 and January 2021 in Oman.

The ICG/IOTWMS Task Team on Scientific Tsunami Hazard assessment of the Makran Subduction Zone (TT-MSZ), which was established during the 12th session of the ICG/IOTWMS, will oversee implementation of the actions agreed at the Expert Meeting in close association with the other ICG/IOTWMS Working Groups and Task Teams, in particular the Sub-regional Working Group for the North West Indian Ocean (WG-NWIO).

2. Introduction

2.1 Background

Countries in the north-western region of the Indian Ocean (NWIO) are facing the threat of tsunamis from not only the far-field, but importantly from near-field tsunamis generated by the Makran Subduction Zone (MSZ) (See Figures 1). Although the MSZ is still not well understood, it can be concluded from past events such as in 1945 that tsunami waves generated by a Makran source could reach the shores of India, Iran, Pakistan, Oman and other adjoining countries within a few tens of minutes with height of several metres. This poses enormous challenges to existing tsunami warning systems and a deadly and socio-economic threat to low-lying coastal communities (see Figure 2). Recent tsunami events in Palu and Sunda Strait in Indonesia have highlighted the near-field threat from tsunamis also generated by atypical sources, such as submarine landslides and volcanic collapses. The NWIO region is also subject to submarine landslides (e.g.1945, 2013), mud volcanoes (e.g. 2013), and meteo-tsunamis (e.g. 2017).

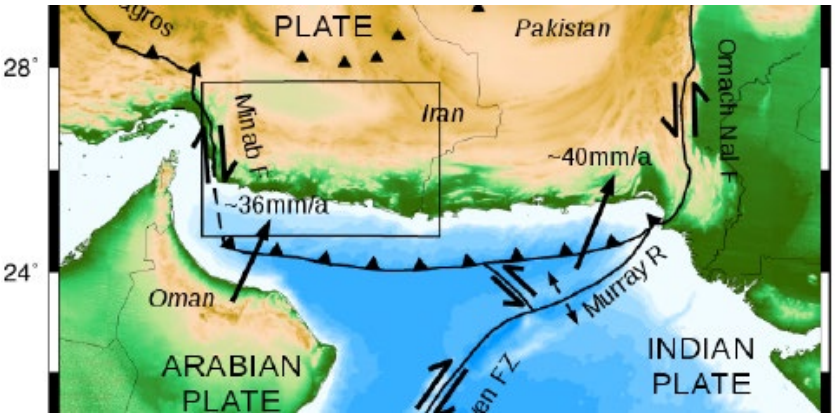


Figure 1: **Makran Subduction Zone plate tectonics in the North West Indian Ocean**

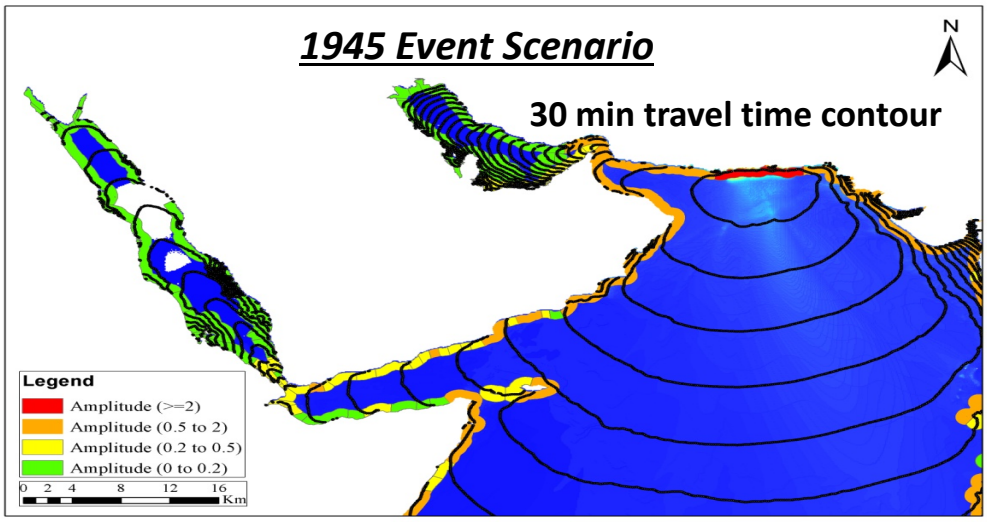


Figure 2: **Modelled propagation of a Makran-sourced tsunami using the 1945 event. The wave amplitudes are for propagation in deep water.**

Realising the urgent need to strengthen the end-to-end tsunami early warning and mitigation system in the Makran region to help address these challenges, a sub-regional Working Group for the North West Indian Ocean (WG-NWIO) was established at the 10th Session of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning & Mitigation System (ICG/IOTWMS)(March 2015, Muscat) with India, Iran, Oman, Pakistan and Yemen as founding members (See Annex A1). The ICG/IOTWMS is a major subsidiary body of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

A report on "Tsunami Early Warning Systems in countries of the North West Indian Ocean Region" (see http://www.ioc-tsunami.org/unescap-synthesis-report-Apr17), which was prepared by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) in association with the WG-NWIO, further reiterated the immediate need to enhance the collective understanding of the Makran tsunami hazard. This will enable NWIO Member States to assess their tsunami risk, strengthen national warning systems, enhance warning chains, develop evacuation plans, build emergency response capacity and raise community awareness, preparedness and resilience with specific emphasis on a near-field tsunami threat.

To identify the current scientific understanding, gaps and priorities in tsunami risk knowledge in the NWIO, an Expert Consultation on Scientific Tsunami Hazard Assessment of the MSZ was organised on the 8th March 2019, Kish Island, Iran. This was immediately followed by the 11th Session of the ICG/IOTWMS, which established the Task Team Scientific Hazard Assessment of the Makran Subduction Zone (TT-MSZ) to address the identified gaps and priorities (See Annex A2).

To help address the challenges and the work of the TT-MSZ, the IOC-UNESCO is implementing a multi-national project aimed at "Strengthening tsunami early warning in the North West Indian Ocean region through regional cooperation". Funded by the UNESCAP Trust Fund for Tsunami, Disaster and Climate Preparedness, the project has two main objectives:

I) Better understanding of the risk knowledge based on scientific research
II) Improvement of tsunami warning services at the National Tsunami Warning Centre (NTWC) level and the organisation of national warning chains and rapid response with due emphasis on self-protection for near source events.

Details of the first objective of the project on enhancing tsunami risk knowledge for the NWIO can be found in Annex A3.

2.2 Expert Meeting Key Objective and Agenda

The project was launched during two back to back meetings hosted in Muscat by the Oman Directorate General of Meteorology. The IOC-UNESCO IOTWMS Secretariat and Indian Ocean Tsunami Information Centre (IOTIC) jointly coordinated the event. The first meeting (01-02 September 2019) was a High-Level Conference on tsunamis in the Makran region to reflect on national strategies for tsunami early warning and community preparedness, especially in the context of near-field tsunamis and the need for enhancing national tsunami warning chains. The second meeting (03-06 September 2019) was an Expert Meeting with the key objective to formulate a strategy for regional cooperation to develop a regional tsunami hazard assessment for the Makran region to underpin risk assessments, early warnings and community preparedness activities. Participants at these meetings included representatives from tsunami warning centres and disaster management agencies, seismologists and tsunami modellers from India, Iran, Oman, Pakistan, United Arab Emirates and experts from Australia, Germany, Italy, Norway, Portugal, USA and UN agencies.

The agenda for the Expert Meeting can be found in Annex A4. The meeting involved nominated experts in hazard and risk assessment from each country, with contributions and the support of invited international experts and representatives from UN organisations (see Annex A5).

The meeting aimed to achieve the following goals:

1. Share information on national initiatives on tsunami hazard and risk assessment and their application in the North West Indian Ocean region.
2. Exchange of latest scientific results and studies on the tsunami hazard in the Makran Source Zone, including non-seismic tsunamis.
3. Identify a list of potential studies to underpin a better understanding of tsunami hazard and risk in the region.
4. Develop a strategy for international, regional and national cooperation in the development of national standards, concepts and polices for risk assessment.
5. Develop a strategy for collaboration on the development of a unified tsunami hazard map for the region.
6. Begin preparations for a Scientific Conference in Oman sometime between 2nd half of 2020 and early 2021 to present and evaluate the outcomes from the project.

2.3 Methodological approach of the meeting

A Regional Working Group (RWG) was established composed of the attendees at the Expert Meeting to address the key objective of the meeting and its desired outcomes. The meeting followed a six-step sequence:

1. Welcome and opening:
   - Status of IOTWMS and the TTF project
   - Information on the NWIO-WG and TT-MSZ
2. Setting the scene:
   - Objectives of the meeting and session organisation
   - Presentation on best practices in tsunami hazard assessment and their applications
   - Experiences from the Palu and Sunda Strait tsunami events in 2018 in Indonesia
   - Outcomes from the High-Level Conference and the importance of hazard and risk assessment from the “last mile” perspective.
3. Presentations by each country on national initiatives in hazard and risk assessment
4. Review of the latest scientific understanding of the MSZ, gaps in knowledge and priorities for research.
5. Discussion on practical applications of hazard and risk assessments
6. The way forward:
   - Discussions on a strategy to develop a unified regional tsunami hazard map through regional cooperation and assistance of international partner agencies.
   - Agreements on follow-up activities and responsibilities

In order to set the scene, several presentations were included to provide relevant background information and the context of the project and the meeting. The Member State presentations provided an assessment of the current capabilities in the region in tsunami hazard and risk assessment, including the capabilities of some Member States to support the capacity development of others. The RWG then reviewed the outcomes from the Expert Consultation (2019) and discussed the present gaps in knowledge and priorities for further research to enhance the current understanding of the tsunami hazard posed by the MSZ. Some key pathways were identifed and reviewed by the Member States to ensure they also met with national objectives. A strategy was then developed, which prioritised the

research and studies needed to develop a unified tsunami hazard assessment for the region through regional cooperation supported by international partner agencies. This unified tsunami hazard assessment once completed will then be able to be used by the Member States in the region to undertake national risk assessments to underpin national education, planning and implementation of appropriate community responses to the tsunami threat to the region. To enable this, the TT-MSZ of the ICG/IOTWMS was tasked with the actions required to support the development of the unified tsunami hazard assessment. Expert Teams were identified to support this work.

The presentations from the meeting can be found at: http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=2522

3. Setting the Scene

Dr Srinivasa Kumar provided an update on the status of the IOTWMS and the scope and status of the UNESCAP project. Since the ICG/IOTWMS meeting in 2015 there has been a focus on the last mile and enhancing capacity in the NWIO. Dr Mohammad Mokhtari as chair of the WG-NWIO and Dr Juma Al-Maskari as chair of the TT-MSZ updated the meeting on the terms of reference and work of these two groups.

Rick Bailey provided an overview on the objectives of the meeting and the session organisation. He highlighted the main outcomes expected from the project with regards to the risk knowledge objective:

1. Availability of latest scientific insights on the tsunami hazard as an input for risk assessment activities in the countries;
2. Concept and inputs for a unified regional tsunami hazard map.

Dr Stefan Lorito provided a general presentation on the importance, methods, data needs and outputs from Probabilistic Tsunami Hazard Assessments (PTHAs) (See Figure 3).

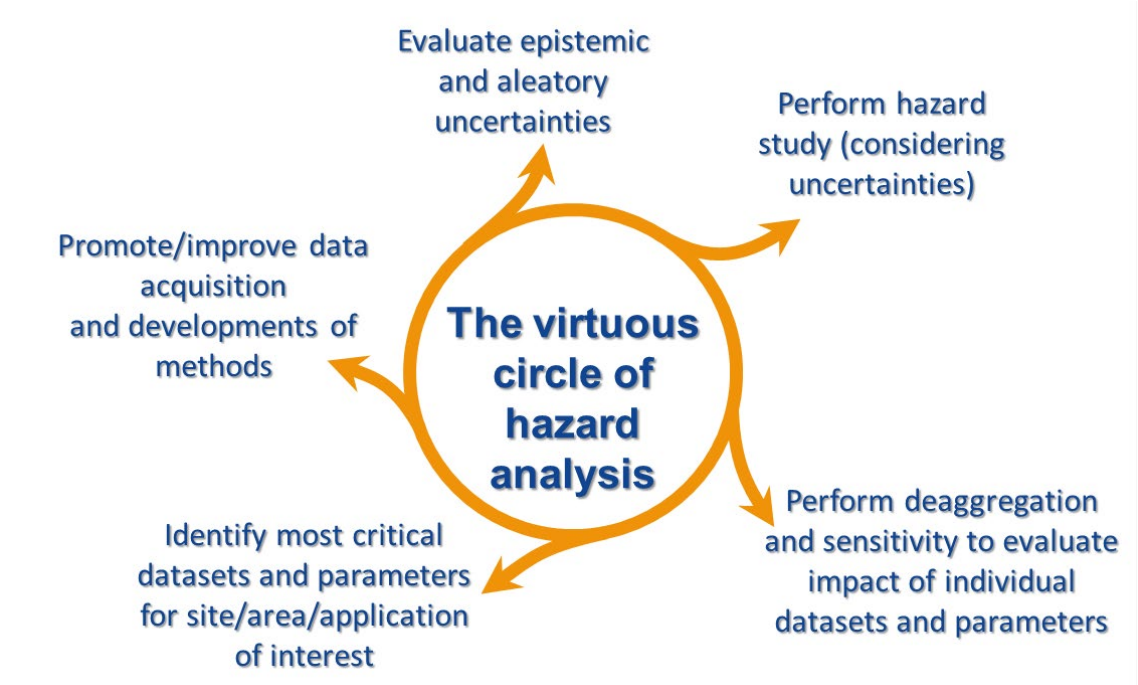


Figure 3: **The methods and importance of Probabilistic Tsunami Hazard Assessments (PTHAs)**

Dr Stefano Lorito detailed the Global Tsunami Model (GTM) international initiative. The GTM overall vision and goals are to collaboratively achieve a thorough understanding of tsunami hazard and risk, together with the processes that drive them:

- Facilitate compatibility and improve probabilistic tsunami hazard and risk analysis methods through the development of standards, guidelines, methods, tools, and identification of key research questions;
- Development of regional and global reference probabilistic tsunami hazard and risk maps, as well as standardized processes for developing local hazard and risk analyses;
- Establish reference pools of experts for completing and reviewing tsunami hazard and risk assessments from stakeholders;
- Provision of a consistent input and contribution to multi-hazard risk assessment through high-level harmonization with organizations covering other natural hazards;
- Interaction with stakeholders to ensure relevance and proper dissemination of results and uncertainty communication to non-scientists;
- Develop the above products while being mindful of their benefits for society.

Dr Stefano Lorito discussed some of the work the GTM was involved with for the Global Assessment Report for Disaster Risk Reduction 2015 (GAR15) and the production of global tsunami risk maps (full tsunami risk analysis, but not disaggregation of the hazards). He also discussed GTM hazard assessments undertaken for the North East Atlantic and Mediterranean Seas (NEAMS) Tsunami Warning & Mitigation System by the TSUnami hazard MAPS for the NEAM region project (TSUMAPS NEAM). He emphasised the importance of fully documenting the methodologies used for any hazard/risk assessments

Ardito Kodijat discussed experiences and the results of field studies for the Palu-Donggala Tsunami event of 28 September 2019 in Indonesia. The tsunami was generated by submarine landslides caused by a local earthquake. The current tsunami warning system does not have the technical capacity to detect and warn for such events. The first tsunami wave arrived in three minutes. The NWIO region is also potentially threatened by tsunamis generated by submarine landslides. The lessons to be learned:

- Hazard knowledge and risk understanding need to be understood by all people living in tsunami risk area;
- Local knowledge needs to be capitalized to educate local community on tsunami hazard, risk understanding, early warning, as well as action for response to save lives;
- Education, awareness, and preparedness need to be prioritized and given as a high urgency (all over the country, especially areas with high tsunami threat);
- Self-Evacuation Protocol is key to survive local tsunami, especially with very short lead times.

Harald Spahn presented on the importance of hazard and risk assessments from the last mile perspective. He recalled the findings of the ESCAP and WG-NWIO analysis of “Tsunami Early Warning Systems in countries of the North West Indian Ocean Region” and the Expert Consultation in 2019. The gaps in scientific knowledge about the MSZ, especially the lack of consensus on maximum credible sesimic sources for tsunami propagation models that underpin production of inundation and evacuation maps, coupled with the need to include atypical tsunamis generated by non-subduction sources such as submarine landslides, make it very difficult for decision makers to adequately make political choices on appropriate hazard scenarios on the basis of which preparedness measures such as evacuations and awareness-raising can be planned. He also stressed the importance of awareness and self-evacuation for near-field events. The risk must therefore be understood and well communicated to facilitate community awareness to enable preparedness.

4. National Initiatives on Tsunami Hazard and Risk Assessment of the MSZ: their application for planning, emergency response, evacuation mapping etc.

This session was mainly focused on taking stock of the current status of each Member State's national initiatives on tsunami hazard and risk assessment. Based on a questionnaire prepared by the ICG/IOTWMS Task Team of Capacity Assessment and Tsunami Preparedness, a common template was sent by Rick Bailey to India, Iran, Pakistan and Oman representatives prior to the meeting to summarise and update the latest national status.

India, Iran, Pakistan and Oman at the meeting then presented their updated status on tsunami hazard and risk assessment, providing a briefing on their method of approach. This was also an opportunity to demonstrate some of the hazard and risk assessment products and outcomes. The information provided by each Member State included:

- Type of hazard assessments undertaken
- Coastal areas covered
- Data used
- Examples of hazard assessment products
- Type of risk assessments undertaken
- Communities assessed
- Member State needs for capacity development
- Member State's ability to help develop the capability of other countries

A summary and comparison of the current status of Member State initiatives are given in Tables A and B. All the countries have undertaken at least a deterministic approach for identifying the tsunami hazard to their respective vulnerable coastal areas. Pakistan has begun applying a probabilistic approach. The outcomes for Pakistan include hazard and inundation maps that were generated for a couple of the most vulnerable cities. However, Pakistan is yet to undertake a risk assessment. India has undertaken hazard and risk assessments for the entire coastline at the national, regional and city level, except the Andaman and Nicobar islands. Inundation maps have been prepared, but only limited evacuation maps for a few communities. Oman has undertaken hazard and risk assessments at the national and city levels. Hazard and inundation maps for a number of cities have been prepared, but no evacuation maps. Iran has undertaken hazard assessments and produced evacuation maps for just a few vulnerable locations. All these countries are sharing these outcomes with their respective disaster management offices to make the information available to vulnerable communities.

The major challenge for all countries was found as usual to be the generation of high-resolution data. This is a common problem faced by all these countries and a priority in the development of tsunami emergency plans in national disaster management programmes It was also observed that the entire coast (i.e. down to village level) of each country is yet to be completely covered by both hazard and risk assessments. Many of the most vulnerable areas still need to be provided with higher resolution hazard and evacuation maps. This is an ongoing process. For future activities India, Iran, Oman and Pakistan showed interest in either initiating or further developing a probabilistic tsunami hazard assessment approach and to cover all vulnerable areas.

All countries expressed a priority in having increased capacity to develop evacuation maps (see Tables C and D). Most gave a priority to extending hazard and risk assessments down to the village level. India and Iran have the capacity to train the other countries in hazard, evacuation and inundation mapping. India has the capacity to train in risk assessments. Pakistan has the capacity to train in probabilistic tsunami hazard assessments.

TABLE A:

National Initiatives in Tsunami Hazard & Risk Assessment

Country	India	Iran	Oman	Pakistan
HAZARD ASSESSMENT				
Undertaken	Y	Y	Y	Y
Capability	5		4	5
Multi- hazard	Y	Y	Y	N
Areas*	N,R	R,V	N,C	C
RISK ASSESSMENT				
Undertaken	Y	N	Y	N
Multi-hazard	Y	N	Y	N
Areas*	N,R,C	N	N,C	N

Y = YES N = NO

5 = strong capability -> 0 = no capability

*National (N), Regional (R), City (C), Village (V)

TABLE B:

Data Used and Hazard Assessment Products

Country	India	Iran	Oman	Pakistan
DATA USED FOR HAZARD ASSESSMENTS**				
Bathymetry	Y / N	Y / Y	Y / N	Y / Y
Seismo-Tectonic model	Y / N	Y / Y	Y / N	Y / Y
Topography	Y / N	Y / Y	Y / N	N / N
Land cover	Y / Y	N / N	N / N	Y / N
Infrastructure	Y / N	N / N	Y / N	N / N
HAZARD ASSESSMENT PRODUCTS				
Deterministic	Y	Y	Y	Y
Probabilistic	N	N	N	Y
Field studies	Y	Y	Y	N
Hazard map	Y	Y	Y	Y
Inundation map	Y	Y	Y	Y
Evacuation map	Limited	Y	N	N
Guidelines	N	Y	Y	N

Y = YES N = NO **Used (Y or N) / Publicly Available (Y or N)

5 = strong capability -> 0 = no capability

*National (N), Regional (R), City (C), Village (V)

TABLE C:

Priorities for improving national capacity in hazard and risk assessment

Country	India	Iran	Oman	Pakistan
HAZARD ASSESSMENT				
Deterministic	4	3	3	1
Probabilistic	5	3	4	3
Field studies	4	3	4	3
Hazard map	5	5	3	4
Inundation map	5	5	3	4
Evacuation map	5	5	5	4
RISK ASSESSMENT				
National	5	3	2	4
Regional	5	3	2	3
City	5	3	4	5
Village	5	3	3	5
Neighbourhood	5	3	3	5

5 = high priority -> 0 = low priority

TABLE D:

Capacity to give training in hazard and risk assessment

Country	India	Iran	Oman	Pakistan
HAZARD ASSESSMENT				
Deterministic	4	5	3	1
Probabilistic	3	3	3	4
Field studies	4	3	2	1
Hazard map	5	5	2	4
Inundation map	5	5	3	4
Evacuation map	5	5	2	1
RISK ASSESSMENT				
National	5	1	3	1
Regional	4	1	2	1
City	4	1	2	1
Village	4	1	2	1
Neighbourhood	4	1	2	1

5 = high capacity -> 0 = low capacity

5. Review of Current Scientific Knowledge, Gaps and Priorities

The Expert Consultation on scientific tsunami hazard assessment of the Makran Subduction Zone, which was held in early 2019 on Kish Island, Islamic Republic of Iran, was attended by 59 experts from 12 countries (Australia, Germany, India, Indonesia, Iran, Oman, Pakistan, Portugal, Russian Federation, Switzerland, Thailand, USA), 1 UN agency, research institutions, universities, private organisations and 3 IOC-UNESCO secretariat staff. It was organised by the IOC of UNESCO and hosted by the Iranian National Institute for Oceanography and Atmospheric Science (INIOAS) with support from the UNESCO Jakarta and Tehran offices.

The RWG reviewed the current scientific knowledge, gaps and priorities identified for each of the areas examined by the Expert Consultation (2019), then discussed the latest findings, research and study priorities that the UNESCAP project may support to enhance the scientific understanding of the MSZ and NWIO.

5.1 Seismicity of the Makran Subduction Zone and Credible Maximum Earthquake Magnitude

The Expert Consultation (2019) noted Member States require guidance on a credible maximum earthquake magnitude for tsunami hazard maps and inundation models. However, this is difficult to determine given the seismic complexity of the region. Mechanisms of deformation along the eastern Makran are better understood than in the western Makran.

Current Status:

- Low seismicity in Western Makran with increasing activity towards Eastern Makran.
- Geological evidence is consistent with the seismic record and indicates deformation increasing eastward.
- Paleo-tsunami research points to the occurrence of a past large earthquake (M9+) in the MSZ region.

Gaps:

- Lack of consensus on maximum earthquake magnitudes and seismic source parameters in the MSZ.
- The geological structure of western MSZ has not been sufficiently studied.
- Mechanisms of deformation along the plate interface are not well-constrained (e.g. slow strain release, lateral stress transfer, locked plate interface).
- More seismic profiling is required off-shore along north-south transects and on-shore in Oman.

Future Priorities:

- Off-shore active seismic profiling is essential for constraining mechanisms of deformation along the MSZ and constraining fault rupture models.
- Inversion of present-day deformation measured by GNSS to quantify strain accumulation and earthquake potential of the MSZ.
- Consider the occurrence of more probable, smaller magnitude events (>M8.0) rather than less probable, large-magnitude event (>M9.0) for hazard an bd risk assessment in the MSZ.
- Form a group of experts to define a strategy for estimating the credible maximum earthquake magnitude.

Presentations were provided by Dr Issa El-Hussain and Dr Mohammad Mokhtari on the current work to determine the lithospheric structure internal architecture. Paleotsunami work in the MSZ on the western India part was also presented by Dr Sumer Chopra, along with an update on the seismic hazard in Oman by Dr Issa El-Hussain. The status of various research and field studies were detailed. The completion of the seismic transect in the Oman Sea and the Sultanate of Oman needs to be supported to get a better handle on maximum magnitude estimates. Paleotsunami studies, especially on the sedimentary record, need to be conducted and supported to give a better insight on the estimated maximum magnitude for the MSZ. An update of the seismic hazard of Oman was presented and the

question of underestimating the maximum earthquake in western Makran was raised and discussed by the RWG. Integrated geophysical, geological and paleotsunami research are crucial elements to better estimate the western Makran maximum magnitude. There was much discussion on what role splay faults along the MSZ may or may not have in governing the magnitude and characteristics of earthquakes and the resulting tsunamis.

The RWG considered:

- It remains difficult to quantify the maximum credible earthquake for the MSZ due to the seismic complexity of the regions.
- Submarine landslides also caused by the earthquakes generating tsunamis in past events (i.e. secondarybeffects) may explain the larger impacts of such events, compared to size of tsunami expected from earthquake magnitude alone (e.g. 1945).
- More GPS data would help determine locking on the MSZ.
- Gravimetric data would help further scientific understanding of the MSZ, but costly (access to data from oil companies would be beneficial and help reduce costs).
- Need to form a group of experts to formulate opinions and recommendations to DMOs on how to deal with planning based on the current understanding of the MSZ, including development of a policy statement for stakeholders/decision makers.
- A single database for all to use would facilitate better accessibility to data needed for hazard and risk assessments.

RWG recommendation: Need to build a common seismo-tectonic model for the region to solve many of the problems, not just the maximum credible earthquake. This will help underpin development of a PTHA for the NWIO.

5.2 Optimal Observing Networks for Effective Tsunami Warning in the Makran Subduction Zone

The Expert Consultation (2019) noted while several stations are available within national networks, limited seismic and sea level data are shared globally or with the IOTWMS Tsunami Service Providers (TSPs). There is a need to determine the optimal observing networks required for effective tsunami warning in the MSZ and to encourage Member States to work towards establishing those networks.

Current Status:

- National monitoring networks including broadband, sea-level and GNSS stations are installed in India, Iran, Oman and Pakistan.
- Limited data is shared globally and with the IOTWMS Tsunami Service Providers (TSPs).
- Some data is shared between IOTWMS Member States through bi-lateral agreements.

Gaps:

- Current networks of seismic stations and sea-level stations in the Makran region, and their data sharing with the TSPs, are inadequate for effective tsunami warning.
- Dense coastal GNSS networks are required for real-time data inversion to determine displacement parameters for tsunami warning.
- There is a need to determine the optimal [number and location] network of seismic, GNSS and sea-level stations in the MSZ region for effective tsunami warning.

Future Priorities:

- Form a group of experts to define the optimal [number and location] network of seismic, GNSS and sea-level stations in the MSZ region, including co-located monitoring equipment.
- Enhance networks and exchange seismic, sea-level and GNSS data among MSZ Member States and with IOTWMS TSPs.
- Utilise GNSS and strong motion accelerometer data inversion for rapid estimates of displacement and earthquake source parameters in real-time.

- Invite high-level policy makers to future science meetings to convince them of the importance of real-time seismic, sea-level and GNSS data sharing for saving the lives of their citizens.

The RWG discussions focused on the limited availability of seismic, sea level and GNSS data:

- This is still the case and was further discussed.
- The discussion showed that data could also be available in more than one agency in the same country, such as research universities, but not shared widely among agencies.
- There is an emphasis and agreement that all the above mentioned types of data are important and contribute to early warning from tsunamis.
- HF Radar data can also be added to the list of data to be exchanged for Tsunami Early Warning. HF-radars are in use in Oman and India, but the data are not shared.
- There is an agreement among the RWG that greater real-time exchange of data is required. This should start immediately.
- Some seismic data is now shared (2 stations from each side) between Oman and Iran on a bilateral agreement. More is neded. Other bilateral agreements are on the way.

Dr Sumer Chopra from Institute of Seismological Research (ISR) shed light on the available data in ISR, especially seismic and GPS data for Gujrat -India which is close to the MSZ. This data could enhance early warning for MSZ if exchanged with other NTWCs.

The RWG considered:

- There is a need to draft a multi-lateral agreement for data sharing.
- A common seismic model was suggested to help determine the optimal observing networks in the MSZ.
- The meeting also discussed the need for real-time data exchange to be stressed to high-level decision makers in the MSZ. The best way to do this is to include it in the discussions of the ICG/IOTWMS and highlight the issues and consequences.

RWG recommendations: a) Greater and timely exchange of seismic, sea level and GNSS data is required; b) Case-studies showing added value and the importance of real-time data sharing for early warning is a powerful tool to convince high-level decision makers on the need to resource more data.

5.3 Hazard Assessment in the Makran Subduction Zone

The Expert Consultation (2019) noted a unified tsunami hazard map is critical for constraining the extent of potential inundation in the region. Such a map would enable more confident tsunami response planning including development of detailed tsunami evacuation maps, plans and procedures.

Current Status:

- There have been several recent advances in Makran tsunami hazard assessments giving a clearer picture of the region. However, there remain many areas of uncertainty including the Iranian coast and Arabian/Persian Gulf.
- Tsunamis generated by landslides have occurred multiple times in the Makran historical record (e.g. 1945; 2013).
- The Global Tsunami Model provides a platform for science-based understanding of tsunami hazard and risk.

Gaps:

- Consensus on the occurrence of large historical earthquakes in the western Makran.
- Reliable measurements from the 1945 tsunami such as run-up, flow depth, inundation distance and timing of reported telegraphic cable breaks.

- Understanding of the probability of a mega-event at the southern limit of Zagros along the Iranian shore of the gulf.
- Geological and sedimentary records along the Makran coast are sparse, especially in Iran.

Future Priorities:

- Produce a probabilistic tsunami hazard assessment for the Makran region.
- Undertake tsunami risk assessments in coasts bordering the Makran region incorporating available data on vulnerability and exposure.
- Constrain the run-up and inundation using the 1945 event and produce a database.
- Reach a consensus on the seismic character of the Western Makran subduction zone.
- Encourage field studies in the Makran (and Arabian/Persian Gulf) region, including geophysical (e.g. seismic and geodesy) and geological (e.g. paleo-tsunami) studies.

RWG discussions began with a presentation by Haider Hasan on high resolution inundation modeling for selected locations in Pakistan (Karachi, Gwadar) based on the 1945 tsunami. Mention was made of an upcoming UNDP project where earthquake and tsunami risk for western Karachi will be developed by NED university. Currently discussions happening on whether to use a probabilistic or deterministic model. It would be good to leverage both the UNESCAP and UNDP projects to make sure findings from the UNESCAP project can be used to develop hazard and risk maps for Karachi.

The three remaining presentations were dedicated to the probabilistic tsunami hazard assessment, including methodological overview of previous PTHA studies in the Makran region (Andrey Babeyko), a report on the new Australian PTHA for the Indian Ocean (Gareth Davies), and a report on the current status and short-term perspective of the Global Tsunami Model (GTM) initiative (Stefano Lorito).

The RWG considered that since probabilistic assessment involves several steps and is currently not methodologically unified, discussion should be concentrated on a feasible way of doing a PTHA in the Makran region. In particular, two already existing probabilistic frameworks could be considered for adaptation in the Makran region: a TSUMAPS-NEAM framework and the Australian-PTHA framework. Re-use of the existing local results/datasets could be an advantage (e.g., PSHA results to support regional tsunamigenic source model as well as dataset of propagation scenarios calculated during previous projects). However, these results/datasets cannot be adopted “as it is” and need to be updated (PSHA for larger magnitudes in Western Makran; propagation dataset to include off-megathrust sources).

RWG recommendation: the WG-NWIO and TT-MSZ should strive for a probabilistic hazard analysis, because it incorporates and extends the deterministic analysis. Participants agreed that the first step within the UNESCAP project should be elaboration of the two alternative roadmaps to implement one of the two above-mentioned PTHA-frameworks within the realm of the Makran region. Detailed roadmaps will help to review existing data, to identify gaps and, very important, to identify possible contributions of NWIO TWS partners and guide their practical cooperation in doing a PTHA.

5.4 Potential impact of Seismic and Secondary Non-Seismic Effects on Tsunami Generation in Makran Subduction Zone including the Red Sea and Arabian/Persian Gulf

The Expert Consultation (2019) found atypical mechanisms have repeatedly demonstrated their capability to cause tsunamis. However, such mechanisms are not currently integrated into the tsunami hazard assessments and warning systems, which were designed to detect subduction zone earthquake generated tsunamis. Advancements in the tsunami monitoring network design are critical for progressing this important issue.

Current Status:

- Tsunami Early Warning is currently mainly based on real-time earthquake and sea level monitoring, coupled with model scenarios and warning dissemination systems.
- A number of studies of atypical tsunami sources including submarine landslides, on-shore earthquakes, and meteo-tsunamis have been conducted in the Makran (and Arabian/Persian Gulf) region.

Gaps:

- Limitation of the current tsunami early warning systems (only for tectonic earthquakes) that are not adapted to atypical tsunami sources.
- Complexity of bathymetry and topography and other data/information (e.g. bedrock topography) in most of the coastal areas.
- Reviews of past atypical tsunami events from the historical and pre-historical records.

Future Priorities:

- Research and studies to improve the understanding of tsunami hazard in Makran region, including the possibilities of atypical tsunami sources, such as submarine landslides, onshore tsunami sources and meteo-tsunamis.
- Studies to determine if tsunamis can impact Red Sea and Arabian/Persian Gulf coastlines.
- Strengthen monitoring networks to help better understand and forecast atypical tsunami events and incorporate necessary procedures into operational tsunami early warning systems.

The RWG discussed the potential for atypical tsunamis in the Makran region from submarine landslides, onshore earthquakes, volcano collapses and meteorological events in the backdrop of the recent Indonesian tsunamis in Palu and the Sunda Strait. While subduction earthquakes are by far the main source of tsunamis (approximately 85%), such atypical mechanisms have also repeatedly demonstrated their capability to cause tsunamis. Currently tsunami monitoring and warning system capabilities are more focused on subduction earthquake generated tsunamis. Advancements in tsunami monitoring network design are critical for incorporating warning capabilities for atypical mechanisms.

The RWG discussed the relevant problems through a general introduction and four targeted presentations. In general terms, the atypical generating mechanisms examined here were highlighted during historical or recent events in the MSZ and worldwide. They include:

- Strike-Slip earthquakes, especially in the context of strongly indented or protruding coastlines, as in the case of the earthquake and deadly tsunami of 14 November 1994 in Mindoro, Philippines;
- Underwater landslides triggered by large earthquakes, as documented in countless instances worldwide, but more specifically in the Makran during the 1945 megaearthquake, Palu in Indonesia on 28 September 2018, and the 2013 Baluchistan event, the latter featuring an epicenter located on land;
- Volcanic phenomena in the context of the recent disaster at Krakatau, Indonesia, on 22 December 2018 where the collapse of the volcano and resultant landslide generated a deadly tsunami in Sunda Strait. But also including potential sources as the Red Sea islands of Jebel at Tair and Zubair, Yemen, which erupted most recently in 2007, 2011 and 2013. Mud volcanoes, whose eruption is often triggered by nearby earthquakes, constitute an additional hazard, especially in the Makran area, where such activity was reported, notably following the 1945 and 2013 events;
- Meteo-tsunamis, especially in the context of the recent event at Bandar Dayyer, Iran on 19 March 2017.

The first presentation was given by Dr. Carl Harbitz, speaking by videoconferencing from Norway. He stressed in particular the diversity in landslide sources, which is rooted in the structural makeup of the sliding material, directly affecting the dynamic evolution of the tsunami source. This represents a serious additional problem in terms of real-time forecasting of tsunami hazard under operational conditions.

The second presentation, by Dr. Mehdi Masoodi, of Hormozgan University, reviewed known episodes of eruption of mud volcanoes worldwide, and in particular in the regional context of the MSZ. Mechanisms for the triggering of their activity by co-seismic or post-seismic stress transfer during seismic events were presented and discussed.

The third presentation, by Dr. Emile Okal, addressed the question of the mechanism of penetration into the Arabian/Persian Gulf by tsunamis originating in the Indian Ocean, using the model of a narrow slit carved into a wall separating a deep basin from a shallower one, leading to the excitation of eigenmodes of oscillation of the shallow basin. When applied to the Gulf, results were generally compatible with Huygens diffraction at the slit, but it was found that significant amplification took place at a few specific locations, most significantly around Siraf and Dayyer, Iran.

The fourth presentation, by Pantajali Kumar, presented a comprehensive set of simulations of potential tsunamis originating both from the MSZ and in various sections of the Red Sea. The work showed that tsunami waves above the minumum warning threshold amplitude can propagate into the Red Sea and Arabian/Persian Gulf. Even relatively small tsunamis above the warning threshold may cause serious issues for safe navigation through busy shipping channels, such as Straits of Hormuz, causing potential loss of life and major disruptions to economies around the world.

The RWG considered the challenges presented by these atypical sources to stakeholders in the fields of mitigation and operational warning. It was noted that some of the relevant hazards, such as volcanic eruptions and meteotsunamis, occur as part of general processes evolving over time frames of days to months. This should provide a level of heightened alert, to be passed on to the populations at risk and sustained during the full episode, the latter being in itself a considerable practical challenge. Also, underwater landslides triggered during volcanic crises have been successfully modeled ahead of time in the case of Montserrat by P. Heinrich and colleagues, and with a most remarkable level of quantitative accuracy at Krakatau by R. Paris and colleagues. These could give some hope in terms of future mitigation in other specific locales, albeit with little direct applicability to the MSZ. Tsunamis generated by volcanic explosions inside the oceanic column have also been the subject of laboratory experiments of a promising nature, most recently by H. Fritz; their application to the problem of mud volcanoes could be valuable in the context of MSZ tsunami hazards.

RWG recommendations: a) Areas targeted for specific effort should include the more detailed documentation and modeling of past episodes of atypical tsunamis, as well as an effort towards the systematic mapping of structures deemed hazardous in this respect, including unstable sedimentary masses offering potential for underwater land sliding. The mechanics of mud volcano eruptions should also be further investigated; b) Tsunamis generated by atypical mechanisms (e.g. landslides, mud violcanoes, etc) should be included in hazard and risk assessments by inclusion in the PTHA framework or through other measures; c) ICG/IOTWMS should consider extending the Area of Service (AoS) of the IOTWMS to include the Red Sea and the Arabian/Persian Gulf.

6. The Last Mile: the value and importance of hazard assessments

Hazard and risk assessments are critical to educate communities and relevant authorities on the threat and potential impacts on coastal communities. If the authorities and communities are unaware or do

not understand the hazard and the risk, they will most likely not be prepared to respond appropriately. Hazard knowledge and risk assessments are used as the basis for contingency and disaster response plans and developing community preparedness (see Figure 4). These assessments are extremely important in helping to develop evacuation maps, which are key to successful warning chains and appropriate community responses. Currently, however, DMOs and decision makers working on the last mile don't know how to adequately determine the Makran tsunami threat due to differences in expert findings and lack of scientific consensus. Notwithstanding all the possible progress in tsunami research, there will always be uncertainties and the unknown. It is therefore essential to establish a dialogue and ongoing strong communication between science and politics addressing these issues to ensure appropriate decisions on local preparedness and response strategies.

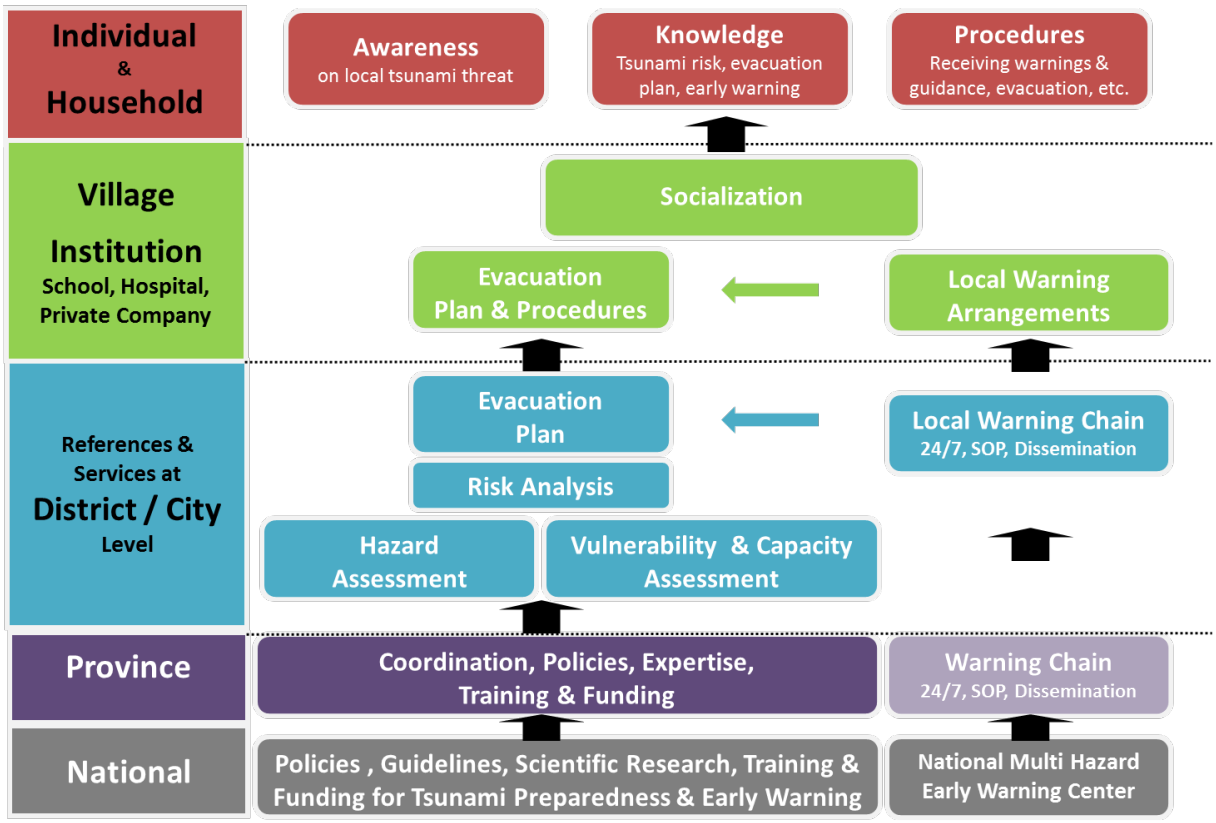


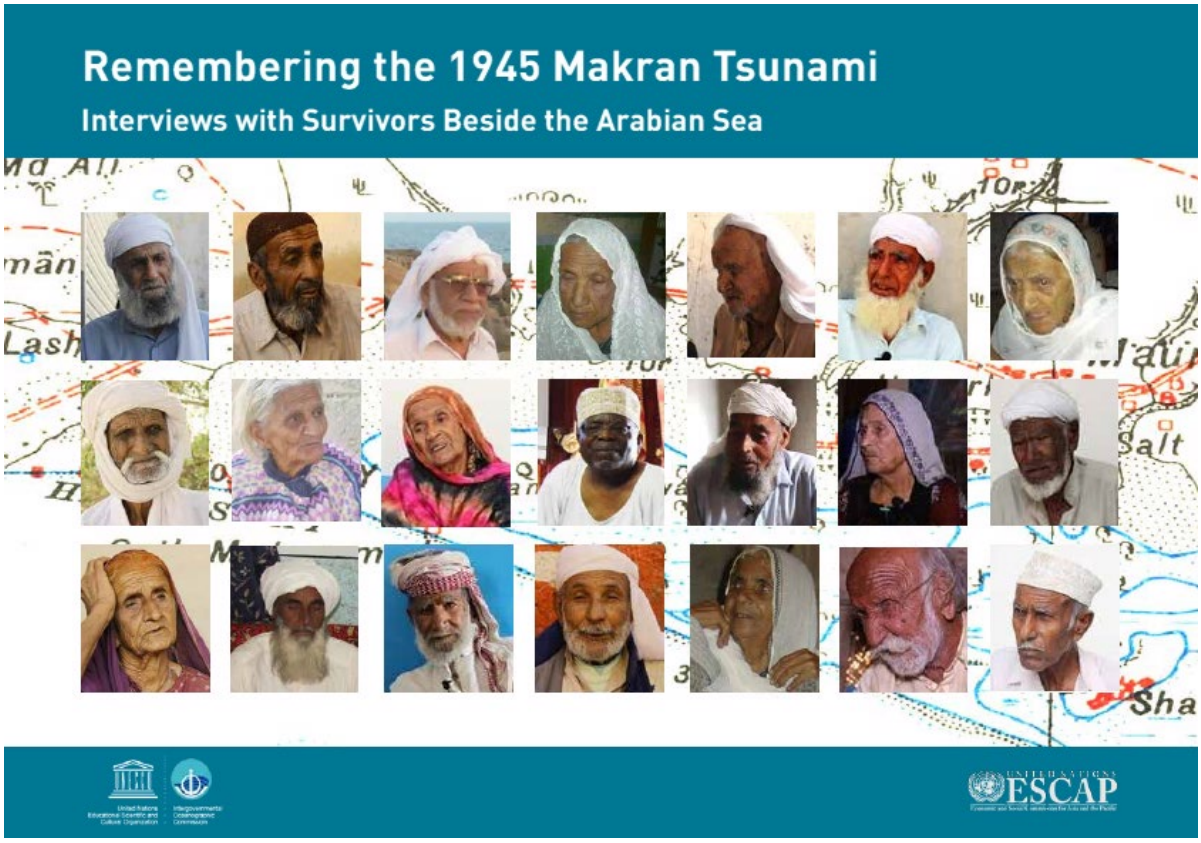
Figure 4: **Tsunami preparedness – a consecutive step and multi-level approach**

The RWG considered a number of issues:

- Hazard and risk assessments can be based on either worst case, most credible scenario and/or PTHA.
- Need for agencies to be identified with mandate to be national authority to officially undertake the hazard and risk assessments.
- Need apply existing guidelines in development of inundation and evacuation maps (e.g. IOC Tsunami Evacuation Maps, Plans and Procedures (TEMPP)) to ensure and demonstrate rigour.
- It is hoped Phase 2 of the UNESCAP project will be funded, which includes the development of risk assessments, inundation and evacuation mapping based on the PTHA being developed here under Phase 1.

- While inundation and evacuation maps are being developed, generally accepted rules of thumb should be applied in advice to communities, such as run to high ground or move inland.
- Continual effort is required to develop and maintain community awareness on the tsunami hazard and associated risk, especially as tsunami events are relatively rare but dangerous.

RWG recommended while uncertainty around the maxium credible earthquake threat remains and there are continuing discussions on the seismicity and other potential secondary and atypical sources, it was considered difficult to determine the maximum credible earthquake magnitude for the MSZ. It was therefore suggested the best approach is to undertake a unified Probabilistic Tsunami Hazard Assessment (PTHA) for the region to assist decision makers and alike. Decision makers can then include estimates of the likelihood of certain events occuring into their decision matrices.



7. The Way Forward: agreements and work plans

7.1 Identification of Research and Study Areas to Enhance Scientific Understanding of the NWIO

One of the main objectives of the Expert Meeting was to identify specific fields of tsunami research and studies to be funded by the project to address gaps in current knowledge and understanding to ensure the delivery of enhanced scientific information on the risk of the Makran subduction zone. Rick Bailey summarised the key pathways discussed during the sessions that reviewed and discussed the findings of the Expert Consultation (2019). The meeting split into groupings by Member States to consider the proposed pathways and reported back to plenary. The RWG agreed on the following priority areas:

a) Develop framework and capacity in the NWIO to jointly build a unified PTHA for the region.

b) Document Member State existing assessment methodologies to understand existing capacity and available data.

c) Develop a single unified seismic source model to be used by the PTHA, which will incorporate the latest scientific knowledge of the MSZ.

d) Assess threat of tsunamis for coastlines in the Red Sea & Arabian/Persian Gulf with a view to extending the coverage by the UNESCO/IOC IOTWMS.

e) Assess threat of tsunamis generated by non-subduction zone sources (submarine landslides, landslides due to volcano collapses, meteo-tsunamis)

f) Design optimal monitoring networks to better characterise relevant hazards.

g) Enable data access and sharing to enhance knowledge & warning capabilities.

h) Undertake field surveys to enhance earthquake and tsunami hazard knowledge

The RWG agreed the number one priority with the amount of funds available is the research and study area involved with the joint development of a **unified PTHA** for the NWIO region by regional and international experts. Whilst scientific investigations continue, gaps still remain in our scientific understanding of the complex seismicity and tsunami generating mechanisms in the region, including from other non-seismic effects, and the difficulties therefore in estimating the maximum credible tsunami wave heights that may be generated to inform tsunami hazard assessments. To help quantify these uncertainties and to be able to undertake risk assessment to enable Disaster Management Organisations and other relevant authorities to plan and best respond to the tsunami hazard in the region, it was considered best to take a probabilistic approach in describing the tsunami hazard.

The research and study areas b) through e) were also selected to be undertaken with support from the project, as they are activities that will support the development of the PTHA for the Makran Region.

The research and study areas f) through h) are also important and support this development, but with the limited funds available they will need to be pursued by the TT-MSZ outside of the project.

The RWG decided it was best to propose that the available project funds support four joint activities involving representatives from each Member State and international experts working together on priority issues for the region, rather than support separate studies by each Member State. There was considered more value in this approach, as it encouraged further regional cooperation, capacity development and best leveraged international support and expertise to resolve shared key scientific issues.

In alignment with the agreed Project Plan, a Concept Note will seek co-funding from the project to support the joint development of a unified PTHA and associated activities with the available earmarked resources. The project will then facilitate an international meeting in late 2020 to share the results from the **research and studies in order to achieve an updated and enhanced common understanding** on the tsunami hazard knowledge in the region. This meeting will also be used by the project to evaluate the outcomes of the scientific hazard assessments against the project objectives, as well as ensure they are suitable for the development of risk assessments and communicated in a form that relevant stakeholders are able to understand and act upon.

7.2 Development of Work Plans

The Sub Regional Working Group for the North West Indian Ocean (WG-NWIO) and the Task Team for the Tsunami Hazard Assessment of the Makran Subduction Zone (TT-MSZ) met during the Expert

Meeting . The two groups reviewed the outcomes with respect to their Terms of Reference (ToRs) and developed work plans to include the actions required to facilitate implement the UNESCAP project.

The ICG/IOTWMS Task Team on Scientific Tsunami Hazard Assessment of the Makran Subduction Zone (TT-MSZ) that was established during the 12th session of the ICG/IOTWMS, reviewed the TT's Terms-of-Reference, outcomes of the Expert Meeting and the recommendations from the RWG. Based on the recommendations of the RWG, it decided the following actions will be implemented in close association with the other relevant ICG/IOTWMS Working Groups and Task Teams:

Actions and Timelines:

1. Andrey Babeyko to coordinate a group of international experts (representatives from the Global Tsunami Model (GTM) and regional experts) to draft a framework for the development of a unified Probabilistic Tsunami Hazard Assessment (PTHA) for the Makran region (by end of October 2019).
2. ***Expert Team 1*** (Issa El-Hussain, Mohammad Mokhtari, Sumer Chopra, Carl Harbitz, Emile Okal, Patanjali Kumar, Sunanda Maneela, Gareth Davies, Stefano Lorito, Andrey Babeyko, other invited/nominated experts) to jointly develop a seismo-tectonic model for the Makran region to be used for the unified PTHA. The main outcome should be a catalogue of representative tsunamigenic scenarios with recurrence rates. Principles of model construction will be defined (by end of December 2019).
3. ***Expert Team 2*** (Patanjali Kumar, Mohammad Reza Akbarpour Jannat, Haider Hassan, R. S. Mahendra, Gareth Davies, Stefano Lorito, Andrey Babeyko) to consider and identify tsunami propagation models, existing and required data sets, amplification factors, etc., to be used for the unified PTHA and future inundation modelling (by end of December 2019).
4. ***Expert Team 3*** (Patanjali Kumar, Mehdi Masoodi, Emile Okal, Haider Hassan, Majid Naderi Beni, Khalifa Alebri, Carl Harbitz, Gareth Davies, Stefano Lorito, Andrey Babeyko, other invited/nominated experts) to provide guidance on inclusion of tsunamis generated by non-seismic effects such as landslides, mud volcanoes, etc.) and inclusion of Red Sea and Arabian/Persian Gulf in the proposed PTHA framework, or through other measures to inform risk assessments and decision makers (by end of May 2020).
5. Andrey Babeyko to lead the joint development and implementation of the unified PTHA for Makran region in coordination with all the 3 Expert Teams and to report progress and preliminary results (by November 2020)
6. Issa El-Hussein and Sumer Chopra to develop draft agreements on data exchange (three versions: multi-lateral, bilateral, and with IOTWMS TSPs) (by end December 2019)

A follow up meeting of nominated national experts and invited experts is being discussed for December 2019 (Hyderabad, India) to agree on the framework and course of work to develop a unified PTHA. Follow-up meetings of this team could also be held in May/June (in Iran in conjunction with the second SOP workshop for the other objective for the UNESCAP project) and/or August 2020 (in India in conjunction with the media SOP workshop). The results of the development of a unified PTHA to then be presented and evaluated at a scientific conference at the inter-sessional meetings of the ICG/IOTWMS working groups and task teams, which are proposed for some time between November 2020 and January 2021 in Oman.

The Sub Regional Working Group for the North West Indian Ocean (WG-NWIO) met after the TT-MSZ. The chair Dr Mohammad Mokhtari reviewed the WG-NWIO's Terms-of-Reference and asked asked whether some additonal experts can be added to support the work of the WG, such as geophysicists. Dr Srinivasa Kumar from the IOC Secretariat advised membership is a formal process. Membership for the WG-NWIO is one representative from a NTWC and one representative from a DMO for each Member State. The Vice-Chair of the WG Sunanda Maneela advised specialists are appointed by the WG-NWIO to the TT-MSZ.

Dr Srinivasa Kumar reviewed progress against the Action List for the WG-NWIO. The risk assessment and evacuation mapping actions will hopefully be supported if Phase 2 of the UNESCAP Project is funded.

The work plan of the WG-NWIO was reviewed and further developed. Discussions took place on which activities should be under the WG-NWIO and which should be under the TT-MSZ.

Dr Mohammad Mokhtari acknowledged the leadership of Dr Juma Al-Maskari in driving the TT-MSZ and for supporting this meeting. He acknowledged the important role of Dr Srinivasa Kumar as the engine to keep things going. He thanked Ms Ingrid Dispert for taking the time and interest to attend the meeting and the support of UNESCAP in helping make things happen. He thanked everybody for participating.

8. Acknowledgments

In closing the meeting, Dr Srinivasa Kumar from the IOC ICG/IOTWMS Secretariat in Perth and one of the organisers of the meeting and managers of the project, thanked Dr Juma Al-Maskari, the organising committee and his staff at the Directorate General of Meteorology and Air Navigation, Sultanate of Oman for their wonderful support in hosting the meeting and making it a great success. He thanked all the invited experts from the Member States and partnering international institutions for their contributions. He thanked Ms Ingrid Dispert from UNESCAP for attending the meeting in person and supporting the project. He thanked the chairs of the sessions, and the chair of the WG-NWIO Dr Mohammad Mokthtari and the chair of the TT-MSZ Dr Juma Al-Maskari. He thanked the consultants Rick Bailey and Harald Spahn for bringing their expertise and experience to faciltate a successful meeting. He thanked Ardito Kodijat from IOTIC for his continuing efforts in helping to manage this project and his current efforts towards the International Symposium in Jakartaon the Palu and Sunda Strait tsunami events . He thanked Sella Octavia in UNESCO and Nora Gale at IOC for their ongoing programme support.

Ms Ingrid Dispert thanked everyone for the discussions and vowed to take back to Bangkok the message this important work must go on. She applauded the dedication of the participants and the honesty of discussion to help make this happen. She thanked Rick Bailey and Harald Spahn for their energy in getting everybody successfully through six very productive days.

Dr Juma Al-Maskari closed the meeting with some final personal remarks. He advised every single moment was a learning, including every presentation and discussions over coffee breaks and lunches. He advised he was hesitant we could get everything done in such a short time. But he thanked God we got everybody onboard and in Oman, including experts from the region and internationally. He thanked everybody for coming to Oman and helping the people of the Makran region. He thanked the consultants for doing a hard job and UNESCAP for supporting the project. His final comment was: “This is just the start of the work and there is now much more to do“.

9. References

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UNESCO-IOC. 2019. Summary Statement from the Expert Consultation on Scientific Tsunami Hazard Assessment of the Makran Subduction Zone, 8 March 2019. Perth, UNESCO/IOC Brochure 2019-3. This summary has been prepared by UNESCO/IOC: Srinivasa Kumar Tummala, Nora Gale, Ardito Kodijat and Thorkild Aarup. Printed in Australia (IOC/BRO/2019/3) © UNESCO 2019

10.Annexes

A1: Terms of Reference NWIO-WG

ICG/IOTWMS Sub-regional Working Group
for the North West Indian Ocean
Chair: Dr. Mohammad Mokhtari, International Institute of Seismology and Earthquake Engineering, Islamic Republic of Iran
Vice-Chair: Ms. Vijaya Sunanda Maneela, Indian National Centre for Ocean Information Services, India

Terms of Reference

1. To evaluate capabilities and ascertain requirements of countries in the northwest Indian Ocean region for providing end-to-end tsunami warning and mitigation services within a multi-hazard framework and within the framework of the ICG/IOTWMS.
2. To promote and facilitate tsunami hazard and risk studies and research in the region.
3. To facilitate cooperation in the establishment and upgrading of seismic, sea level and GNSS stations and networks and communication systems in the region.
4. To facilitate improvement of the education programmes on tsunami mitigation in the region.
5. To facilitate capacity building and the sharing of tsunami-related data and information in the region.

The Group will be composed of members representing NTWC and DMO from each of the Member States of India, Iran, Oman, Pakistan, United Arab Emirates, Yemen, other Member States in the North West Indian Ocean region and invited observers, with a Chairperson and Vice-Chairperson to be elected.

Membership Criteria

Following up on a recommendation from the 2nd meeting of the WG-NWIO, Tehran, February 2017 the ICG, in its 11th meeting, Malaysia, April 2017 recommended that each WG-NWIO Member State should nominate two experts representing the National Tsunami Warning Centre and the Disaster Management Organisation to the WG-NWIO

Membership 2019 – 2021
Dr Mohammad Mokhtari, Iran (Chair) - mokhtari@iiees.ac.ir
Ms V Sunanda Maneela, India (Vice Chair) - sunanda@incois.gov.in
Dr Dipankar Saikia, India – dipankar.s@incois.gov.in
Mr AlYaqdhan Al-Siyabi, Oman (DMO) - alsiyabi.y@hotmail.com
Mr Jaifar Al-Busaidi, Oman (NTWC) - jaiferu053151@hotmail.com
Mr Ameer Hyder, Pakistan (NTWC) – free2hyder@yahoo.com
Mr Tariq Ibrahim, Pakistan (NTWC) – t_jaan1@hotmail.com
Mr. Majed Naser Alshkeili, UAE (NTWC) – malsheikili@ncms.ae
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Officer from DMO (DDM, NDMA), India – to be advised
Officer from DMO, Iran – to be advised
Representatives from Yemen - to be advised
Representative from Indonesia - to be advised
Representative from UNESCAP - to be advised

A2: Terms of Reference TT-MSZ

ICG/IOTWMS inter-sessional Task Team on
"Scientific Hazard Assessment of the Makran Subduction Zone"

Chair: Dr. Juma Said Al-Maskari, Directorate General of Meteorology and Air Navigation, Sultanate of Oman
Vice-Chair: Dr. Abdolmajid Naderi Beni, Iranian National Institute for Oceanography and Atmospheric Science, Islamic Republic of Iran

Terms of Reference

1. Draft an agreement document for real-time exchange between Member States of seismic/sealevel/GNSS data in the Makran Subduction Zone (MSZ).
2. Specify optimal number and configuration of seismic/sea-level/GNSS and other observing networks needed for real-time tsunami warning in the MSZ.
3. Investigate and report on the credible maximum earthquake magnitude in the Makran Subduction Zone and define a strategy to develop a unified hazard map.
4. Investigate and report on the seismicity of the Makran subduction zone as well as the potential impact of tsunamis in the Red Sea and Persian Gulf with a view to including those zones in the IOTWMS AoS if there is a threat.
5. Review and report on the status of research into modelling of secondary non-seismic effects tsunamis in Makran for potential use in the IOTWMS.

The Task Team will report to the Steering Group and be composed of members nominated by WG-NWIO Member States (India, Iran, Oman, Pakistan, United Arab Emirates, Yemen), representatives from TSPs and Observers from international institutions involved in research of MSZ (GFZ, GTM, UNESCAP, etc)

Membership 2019 – 2020

Dr. Juma Said Al-Maskari, Oman (Chair) - j.almaskari@met.gov.om
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TSP Representative / Expert Modeller from Australia – no nomination
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Representative from UNESCAP – to be advised

A3: UNESCAP Project component to enhance risk knowledge in NWIO

Strengthening tsunami early warning in the North West Indian Ocean through regional cooperation

Project Objective 1: Better understanding of risk knowledge based on scientific research

Outcomes:

- Availability of latest scientific insights on the tsunami hazard from the MSZ as an input for risk assessment activities in the countries
- Concept and inputs for a unified regional tsunami hazard map

Outputs:

- Gap analysis and strategy for regional cooperation to develop a unified regional tsunami hazard map developed by a NWIO working group on risk knowledge
- Results from studies on critical issues such as maximum magnitude and source mechanism for tsunami modelling implemented by international scientific partner institutions
- Exchange of latest scientific results and studies from international studies on the tsunami hazard in the MSZ

Performance Indicators:

- Presentations of results from studies on critical issues as prioritized by the Regional Working Group at the regional science meeting
- Availability of a concept note for developing a unified regional hazard map by the Regional Working Group

Activities:

- Establishment of a Regional Working Group and working process between NWIO countries on risk knowledge – September 2019
- IOC and external facilitators/consultant provide support and technical assistance for the coordination of the expert meeting and Gap Analysis and Strategy for the Regional Coordination for development of a Unified Regional Tsunami Hazard Map
- Co-funding on studies on critical Issues for Risk Knowledge in MSZ – results from four Study Packages to be presented at the Scientific Meeting (India, Iran, Pakistan)
- Organization of a scientific exchange meeting in Oman – August 2020

Member State Contribution:

- National governments assign staff from relevant institutions to a regional working group on risk knowledge to exchange experiences and discuss concepts and methods for tsunami risk assessment.
- National institutions will consider these inputs for the development of national standards, concepts and policies for risk assessment and collaborate on the development of a unified hazard map
- Organization of a scientific exchange meeting by its hosting country (Oman)

A4: Agenda

UNESCO-IOC Intergovernmental Coordination Group for the
Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS)
Expert Meeting for establishment of a regional working group and working process between NWIO Countries on risk knowledge
Muscat, Oman
03 – 06 September 2019

AGENDA

Day-1: 03 September 2019 (Tuesday)

Time	Topic	Session Chair / Speaker (s)
08:30 – 09:00	Registration	Organisers
09:00 – 10:15	**Welcome and Opening**	
09:00 – 09:15	Welcome Remarks	Juma Al-Maskari
09:15 – 09:30	Introduction of Participants	
09:30 – 09:45	Status of the IOTWMS and Scope of the UNESCAP Project	IOTWMS Secretariat and UNESCAP
09:45 – 10:00	Sub regional working Group for the North West Indian Ocean [ToR, Members, Activities]	Mohammad Mokhtari
10:00 – 10:15	Task Team on Scientific Tsunami Hazard Assessment of the Makran Subduction Zone [ToR, Members, Activities]	Juma Al-Maskari
10:15 - 11:00	Tea Break and Group Photo	
11:00 – 12:30	**Workshop Organisation and Introduction**	
11:00 – 11:15	Objectives of Workshop and Session Organisation	Project Consultant, Hazard Assessment
11:15 – 11:45	General Presentation on Tsunami Hazard Assessment [Importance, Methods, Data Needs, Outputs]	Stefano Lorito
11:45 – 12:00	Experiences from Palu and Sunda Strait Tsunamis	Ardito Kodijat
12:00 – 12:30	Importance of Hazard and Risk Assessment from Last-Mile Perspective - Recommendations from the Expert Consultation Meeting (08 March 2019) and High-level Workshop (01-02 Sep 2019)	Project Consultant, Warning Chains
12:30 – 14:00	Lunch Break	
14:00 – 15:30	**Session-1: National Initiatives on Tsunami Hazard and Risk Assessment of the MSZ and their application for planning, emergency response, evacuation mapping, etc.**	Chair – Mohammad Mokhtari
14:00 – 14:30	India	
14:30 – 15:00	Iran	
15:00 – 15:30	Pakistan	
15:30 - 16:00	Tea Break	
16:00 – 17:30	**Session-1: Continued**	
16:00 – 16:30	Oman	
16:30 – 17:00	UAE	
17:00 – 17:30	Discussions	

Day-2: 04 September 2019 (Wednesday)

09:00 – 10:30	**Session-2: Seismicity of the MSZ and Credible Maximum Earthquake**	Chair – Issa El-Hussain
09:00 – 09:15	Recommendations from the Expert Consultation Meeting (08 March 2019) including current status, gaps and future priorities in Makran	Presentation by Issa El-Hussain
09:15 – 10:30	Invited Presentations/Discussions • Historical Earthquakes in Makran and Seismic data acquisition initiatives in MSZ – Mohammad Mokhtari, • Paleo tsunamis in the MSZ – Sumer Chopra • Probablistic Seismic Hazard Assessments and Credible Earthquake Magnitude in the MSZ – Ahmed Dief (tbc)	Invited Experts, National Experts
10:30 - 11:00	Tea Break	
11:00 - 12:30	**Session-2: Continued**	
	Discussions	
12:30 – 14:00	Lunch Break	
14:00 - 15:30	**Session-3 Optimal Observing Networks in the MSZ**	Chair - Juma Al-Maskari
14:00 – 14:15	Recommendations from the Expert Consultation Meeting (08 March 2019) including current status, gaps and future priorities in Makran	Presentation by Juma Al-Maskari
14:15 – 15:30	Invited Presentations/Discussions • Observing Networks in the NWIO Member States – National experts • Seismic Data Sharing Arrangements in the region – Yousuf Al-Shijbi / Zaid Al-Habsi (tbc) • Optimal Observing Network Design – Andrey Babeyko	Invited Experts, National Experts
15:30 - 16:00	Tea Break	
16:00 - 17:30	**Session-3: Continued**	
	Discussions	

Day-3: 05 September 2019 (Thursday)

09:00 – 10:30	**Session-4: Tsunami Hazard and Risk Assessment in the MSZ**	Chair – Andrey Babeyko
09:00 – 09:15	Recommendations from the Expert Consultation Meeting (08 March 2019) including current status, gaps and future priorities in Makran	Presentation by Andrey Babeyko
09:15 – 10:30	Invited Presentations/Discussions • Review of PTHA studies in the region – Andrey Babeyko • Global Tsunami Model – Sefano Lorito • Australian PTHA – Gareth Davies (remote) • Modelling the impact of tsunamis in Pakistan coast due to earthquakes in the MSZ – Haider Hasan	Invited Experts, National Experts
10:30 - 11:00	Tea Break	
11:00 - 12:30	**Session-4: Continued**	
	Discussions (i) methods, data availability, gaps, cooperation framework, timelines for development of unified regional tsunami hazard map and (ii) Risk Assessments	
12:30 – 14:00	Lunch Break	
14:00 – 15:30	**Session-5: Non-seismic tsunamis in the MSZ and Tsunamis in the Arabian/Persian Gulf and Red Sea**	Chair – Emile Okal
14:00 – 14:15	Recommendations from the Expert Consultation Meeting (08 March 2019) including current status, gaps and future priorities in Makran	Presentation by Emile Okal
14:15 – 15:30	Invited Presentations/Discussions • Non-seismic tsunamis (Volcano, Landslide) – Carl Harbitz (remote) • Non-seismic tsunamis (Mud Volcano, Landslide) – Mehdi Masoodi • Response of a basin to a tsunami incident through a small aperture: Application to the Straits of Hormuz – Emile Okal • Modelling the source of Sep 2013 Makran tsunami, and Possible tsunamis in the Arabian/Persian Gulf and Red Sea - Patanjali Kumar	Invited Experts, National Experts
15:30 - 16:00	Tea Break	
16:00 - 17:30	**Session-5: Continued**	
	Discussions	

Day-4: 06 September 2019 (Friday)

08:30 – 09:30	**Session-6: Last Mile**	Project Consultant, Warning Chains
	Discussion on Making hazard knowledge usable for practical application: • The political dimension: science meets politics, worst case or most credible scenarios • Early warning: warning chains, SOPs, timelines, warning-levels, etc. • Evacuation planning: from hazard & risk maps to evacuation plans • Institutional aspects: roles & responsibilities of institutions in partner countries to provide or support the development of official hazard & risk maps • DRM: hazard knowledge and risk assessments as a basis for contingency & disaster response plans • Public knowledge: education and training, mock drills	
09: 30……	Working Tea Break	
09:30 - 11:30	**Session-7: Way Forward**	Project Consultant, Hazard Assessment
	• Review of all potential studies to be considered for funding as part of the UNESCAP Project • Discussions on the Strategy for: 1) Regional cooperation for the development of national standards, concepts and policies for risk assessment; 2) Collaboration on development of a unified regional hazard map developed by a NWIO working group on Risk Knowledge • Summary of recommendations from the Workshop: Future activities, focal points, timelines, working mechanism, etc.	
11:30 – 14:00	Lunch Break	
14:00 – 15:30	**Meeting of the Task Team on Scientific Tsunami Hazard Assessment of the Makran Subduction Zone (TT-MSZ)**	Chair - Juma Al-Maskari
	Development of Work plan 2019-20	
15:30 - 16:00	Tea Break	
16:00 - 17:30	**Meeting of the Sub-regional Working Group for the North West Indian Ocean (WG-NWIO)**	Chair - Mohammad Mokhtari
	Development of Work plan 2019-20	
17:30 – 18:00	**Conclusion and Closing**	
	Concluding remarks and official closing of the meeting	IOTWMS Secretariat, UNESCAP and Juma Al-Maskari

A5: Participants

Member State Participants

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