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Dealing with Local Tsunami on Pakistan Coast

Ghazala Naeem

Abstract

Tsunami originating from a local source can arrive at Pakistan coastline within minutes. In the absence of a comprehensive and well-coordinated management plan, the fast-approaching tsunami might wreak havoc on the coast. To combat such a threat, a wide range of short- and long-term mitigation measures are needed to be taken by several government and private sector organizations as well as security agencies. Around 1000-km coastline is divided administratively into two provinces of Baluchistan and Sindh and further into seven districts. Most of the coastal communities were severely affected by an earthquake of magnitude 8+ on 28 November 1945 followed by a devastating tsunami. In contrast to the level of posed hazard and multiple-fold increase in vulnerabilities since then, the risk mitigation efforts are trivial and least coordinated. It is important to provide stakeholders with a set of prerequisite information and guidelines on standardized format to develop their organizational strategies and course of action for earthquake and tsunami risk mitigation in a well-coordinated manner, from local to the national level.

Keywords: local tsunami, hazard and risk assessment, mitigation, preparedness, standardized format, stakeholders' coordination

1. Introduction

Tsunami being a less frequent hazard has not yet gained due attention in the national hazard mitigation and preparedness program within Pakistan. However, disastrous impacts of 1945 Makran Tsunami, which occurred in the Arabian Sea merely 70 years ago, cannot be ignored and urge need of comprehensive and sustained tsunami resilience efforts.

In recent decades, 2004 Indian Ocean and 2011 Japan Tsunamis have revealed destructing powers of tsunami and the level of unpreparedness with regard to hazard assessment, warning and response planning, public awareness, mitigation, and research, not only of developing but developed countries as well.

Since 2006, in the aftermath of 2004 Indian Ocean Tsunami, significant efforts have been made in the country; however, there is much more to do for developing tsunami-resilient communities in Pakistan.

There are several multi-tiered stakeholders having inter-reliant responsibilities and mandates for earthquake and tsunami risk reduction, working in the coastal region of Pakistan. There is a need to support those stakeholders in dealing with tsunami and earthquake risks in a well-coordinated and comprehensive manner. This chapter recommends policy guidelines for determining strategic significance of

posed tsunami threat to the Pakistan coast and ascertaining the underlying risks in comparison to the current capacities and preparedness measures. The chapter also suggests desirable research work, establishing timely warning system and structural and nonstructural mitigation measures including effective outreach to the public level and international coordination to combat local tsunami threat.

2. Recommended policy guidelines for local tsunami

The Arabian Sea region is threatened by earthquake and tsunami hazards, mainly because of the presence of the Makran subduction zone (MSZ). An earthquake of magnitude 8+ had wreaked havoc along the Pakistan coastline on 28 November 1945 followed by a devastating tsunami. In contrast to the level of posed threat and multiple-fold increase in vulnerabilities since then, the risk mitigation efforts are trivial and least coordinated. There is need for stakeholders to provide a set of prerequisite information to develop their organizational strategies and course of action for earthquake and tsunami risk mitigation in a well-coordinated manner, from local to the national level. Most important and immediate tasks include:

- Develop standardized and coordinated tsunami hazard and risk assessments for all coastal regions of Sindh and Baluchistan provinces.
- Improve tsunami and seismic sensor data, infrastructure, and standard operating procedures (SOPs) for better tsunami detection and warning.
- Enhance tsunami forecast and warning dissemination capability along the coastline.
- Promote the development of model mitigation measures, and encourage communities to adopt resilient construction, critical facilities protection, and land-use planning practices to reduce the impact of future tsunamis.
- Increase outreach to all communities, including all demographics of the at-risk population, to raise awareness, improve preparedness, and encourage the development of tsunami response plans.
- Develop a strategic plan for earthquake- and tsunami-related research especially within Arabian Sea region.

The required mitigation measures in a standardized manner are divided into three main categories including hazard assessment, risk evaluation, and mitigating measures to guide national level stakeholders in developing a long-term comprehensive tsunami response and risk reduction plan for Pakistan.

Establishing a technical committee to perform a role of central coordination and advisory under the National Disaster Management Authority can be supportive for stakeholders interested in and mandated for planning and implementation of earthquake and tsunami response and preparedness measures.

3. Assessing tsunami hazard

This section is based on the review of scientific and historical evidences of various potential sources of tsunamis which have affected and are likely to affect the Arabian Sea region and are described below.

3.1 Potential tsunami sources

3.1.1 Subduction zone earthquake

The most important source of earthquake-generated fast-approaching tsunamis (a local tsunami) in the Arabian Sea is the Makran subduction zone (**Figure 1**) adjacent to the coasts of Iran and Pakistan [1]. Recent event, known as 1945 Makran Tsunami, was caused by the earthquake in eastern part of this zone.

Another potential subduction zone lies from the northern tip of the Bay of Bengal, through the western margin of the Andaman Sea, and skirting the southern coasts of Sumatra, Java, and the islands of Lesser Sunda and is underlain geologically as Sunda subduction zone [1]. However, a tsunami generated by a potential earthquake event within Sunda subduction zone may reach Pakistan coast in hours, categorized as distant tsunami. A devastating event like 2004 Indian Ocean tsunami created disturbance on Pakistan coast after several hours of the incident occurred near Indonesia.

It is difficult to evaluate the accurate level of tsunami hazard these subduction zones pose for near and distant regions. The record and likelihood of earthquake occurrence in these zones and the implications for tsunami generation are the only basis for such estimations.

3.1.2 Submarine landslides

Within the Arabian Sea region, submarine landslides have the potential to produce large, local tsunamis owing to steep seafloor slopes and rapid sedimentation.

Tsunami waves (≤ 1 m) were observed in the Arabian Sea on 24 September 2013 along several beaches in Oman and Pakistan during low tide period. The event was caused by a secondary effect of an earthquake of magnitude 7.7, which occurred

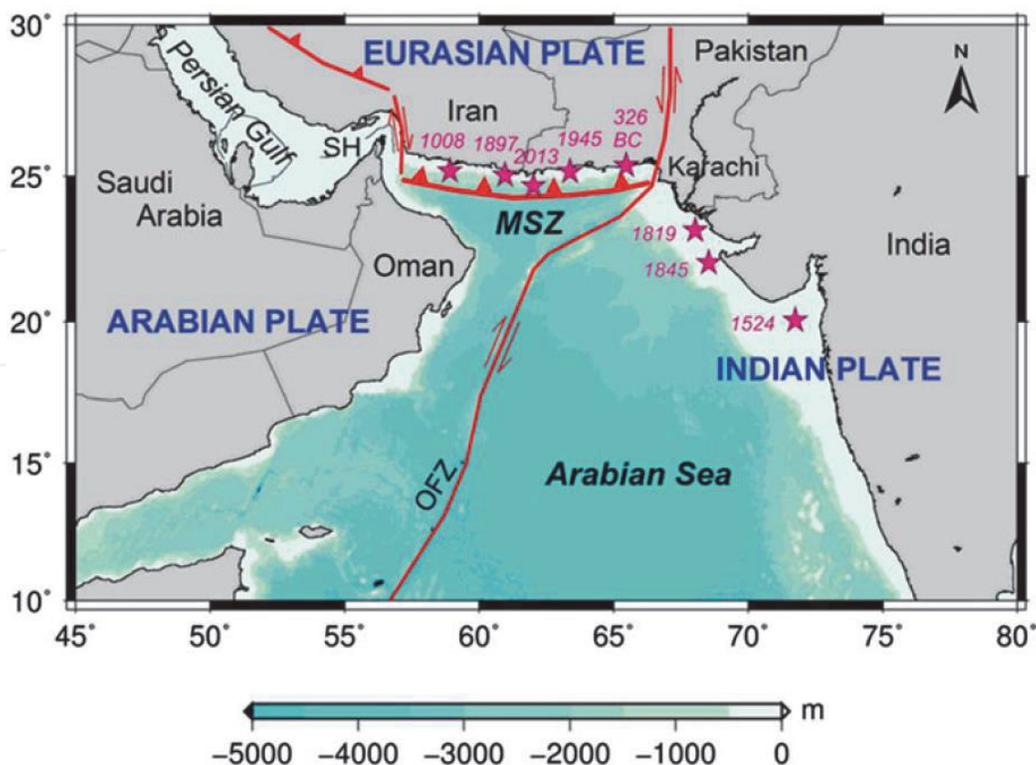


Figure 1. General location map of the Makran subduction zone (MSZ) at the northwestern Indian Ocean showing locations of past tsunamis in the region. Source tsunami risk, preparedness and warning system in Pakistan by Heidarzadeh [2].

inland in southwestern Pakistan at 11.29.47 UTC (local time is UTC +5) on the same day, but after several hours, the earthquake's epicenter was a couple of hundred kilometers inland. Hoffman et al. [3] suggest the waves must have been triggered by a submarine landslide.

3.2 Guidelines for tsunami hazard assessment

Tsunami hazard assessment at local level is important to understand the locally imposed threat and to deal with the posed hazard accordingly. The creation of local hazard maps is a key step in the tsunami risk assessment procedure and is needed to:

- Develop evacuation plans
- Land-use planning within a defined coastal management area
- Determine the exposure parameters that will be used in the assessment of vulnerability of the coastal community and of their supporting assets and systems

The organizations, institutions, and experts mandated or interested to conduct directly or support to carry out earthquake and/or tsunami hazard assessment along the Pakistan coastline are suggested to follow standard parameters or guidelines, led by any national agency like the National Disaster Management Authority (NDMA) such as:

- i. Local tsunami hazard maps are usually developed from specified tsunami event scenarios. The parameters defined in Multi-Hazard Vulnerability and Risk Assessment guidelines of the NDMA available at <http://ndma.gov.pk/publications/MHVRA%202017.pdf> are used [4]. Other technical details for modeling tsunami hazard, for example, input data sources, modeling tools, and criteria used by different research institutions and experts, can also be reviewed by the NDMA to make integrated tsunami hazard assessment of the Pakistan coastline on a standardized format. Final output products include:
 - a. Inundation maps
 - b. Flow velocity profiles
 - c. Warning time available for emergency response
 - d. Debris flow profiles at least for ports if possible
 - e. Comprehensive hazard map made by overlaying inundation maps and flow velocity profiles
- ii. The NDMA take the core responsibility of coordination among agencies and implementing partners to develop and facilitate regular update of hazard database. The NDMA collaboration is also required for statistics and information acquisition and sharing among stakeholders, developing and publishing such maps on standardized and easily understandable (for general public) format.
- iii. Interagency coordination for sharing data and information required for comprehensive hazard assessment should be conducted by the NMDA

and PDMAs, for example, onshore, offshore surface data, geological and meteorological scientific information, census and building records, and satellite images and archival records. The NDMA being the central focal organization for disaster management can play a vital role to facilitate data and information sharing among organizations and also with researchers.

- iv. Tsunami caused by undersea landslides should also be accounted for more reliable hazard assessment process.
- v. All possible impacts of any future tsunami event should also be studied and modeled in details. For example, huge quantities of debris brought onshore itself can be a major hazard for ports, fishing harbors, and local environment at any specific location.

4. Assessing tsunami risk

Using the outputs from the hazard assessment, disaster, emergency managers, and other relevant organizations (NDMA, PDMAs, and DDMA of Baluchistan and Sindh Provinces) will need to create a community asset database of maps showing the distribution of population, buildings, infrastructure, and environmental assets in relation to the information on various hazard exposure parameters (inundation limit, run-up, depth of water, proximity to open coast, inundation and drainage flow velocities, etc.) for a particular earthquake and tsunami hazard scenario [1].

4.1 Guidelines for tsunami risk assessment

- i. In addition to following the NDMA's MHVRA guidelines, tsunami vulnerability and capacity assessments are to be carried out in detail. Such risk maps should be interpreted in standardized format of "well-defined categories of risk" from the national to local level.
- ii. Hazard maps developed under the proposed guidelines of the previous section can be used to incorporate vulnerability maps and finally produce tsunami risk maps, and those should be communicated to all stakeholders in a systematic way.
- iii. Levels of risk are presented in geospatial ways: maps showing the extents of areas with defined "risk categories" as high, medium, and low levels of estimated risks as per the NDMA's MHVRA guidelines.
- iv. Coastal cities being hub of economic activities having national life line infrastructure like ports are also densely populated. The NDMA and other relevant national and provincial agencies should encourage research institutions and experts to prioritize conduction of vulnerability and risk assessments of urban areas on priority basis and its incorporation in the national database. For example, detailed exposure database of 1- to 3-km-wide coastal belt in urban, semi-urban, and rural settlements can be maintained and updated annually by the provincial and district disaster management authorities.
- v. To assure uniformity and speed in the risk assessment process, the following data of interest should be maintained for areas in close proximity

to the sea (as suggested above, i.e., 1- to 3-km-wide belt along the coast can be surveyed on priority). Detailed survey should be carried out along the coastal areas to collect data such as:

- Census data (population distribution, income, and other statistics such as age, occupation, disability, education)
- Building classification, construction materials and techniques, ground level elevation
- Critical infrastructure (roads, water, power, sewerage, emergency facilities)
- Economic zones and location (business sectors, industry, ports)
- Environmental services/inventory

The abovementioned information include all required level of onshore, offshore surface data, geological and meteorological scientific information, census and building records, satellite images, archival records, and organizational capacity (to facilitate and contribute in earthquake and tsunami emergency response and preparedness).

- vi. Data and information collection, for reliable and authenticated coastal earthquake and tsunami risks assessment, can be acquired by all the agencies and organization mandated to collect and maintain such database, whereas the NDMA can play a vital role of coordination and support for essential data sharing among agencies and with experts by developing data sharing protocol.

5. Managing tsunami risk

This section covers guidelines for effective earthquake and tsunami risk reduction measure to strengthen coastal communities and infrastructure aiming to reduce impacts of any devastating event in the future.

5.1 Early warning system

Is it critically important to assess whether the current early warning system and practices are effective for the posed tsunami threat to Pakistan coastal communities [5]? A review of critical issues that hindered the efficient and timely operation of early warning systems has led to the identification of four elements [1]:

- Implementation of technically oriented early warning systems, without taking into consideration or without conducting risk assessment
- Weaknesses in monitoring and forecasting of potentially catastrophic events
- Weaknesses in the emission of warnings or in ensuring that warnings reach vulnerable communities
- Weaknesses in local capacities to respond to a warning and to a potentially catastrophic event

5.1.1 Current status

The National Seismic Monitoring Tsunami Early Warning Center (NSMTEWC) of the Pakistan Meteorological Department (PMD) is capable of issuing warning bulletins and messages to identified stakeholders including disaster management authorities, concerned provincial and district governments, and media within 13 min as specified in laid down standard operating procedures [5]. However, there is a lack of further downstream time bound SOPs (13 min onward with reference to PMD's SOPs) of other stakeholders (e.g., disaster management authorities, emergency services, provincial and local governments) to ensure the warning information and messages are communicated to all vulnerable coastal communities and, if needed, to adopt evacuation procedures that are timely completed within available lead time.

5.1.2 Guidelines for effective early warning system

The NDMA being the central coordinating agency of disaster management in Pakistan can take a lead and engage relevant organization including PDMA Sindh, PDMA Balochistan, Army, Pakistan Navy, Pakistan Coast Guards, Marine Security Agency, port authorities, and police to develop consensus on technical issues, set required protocols, and monitor progress on the policy guidelines mentioned below:

- i. End-to-end time bound synergized SOPs for the dissemination of tsunami warning to be developed involving all stakeholders living in remote coastal villages including islands and creeks.
- ii. Protocol among all national organizations capable of communication (using one or more communication networks such as satellite, HF/VHF, radio, or any wired or wireless network) should be established and made accessible to coastal communities (on- and offshore).
- iii. Develop and enforce SOPs and procedures to ensure that all tsunami and earthquake detection, forecasting, warning communication, and dissemination network/equipment must be kept in operational condition by the organization in charge of the asset. Such equipment and network should be installed and maintained with earthquake-resistant features and techniques.
- iv. Stakeholders and organizations responsible for burden sharing of early warning dissemination can be involved in practicing procedures and equipment operation tests, collectively, at least once a year or on an agreed schedule as a full-scale tsunami exercise in coordination with the NDMA.
- v. Individual government organizations involved in early warning chain and emergency response to arrange tabletop and functional test exercises at least twice a year on a feasible schedule, in coordination with NDMA and/or concerned PDMA.
- vi. Official early warning bulletins should be adapted as easily understandable public messages by relevant PDMA in coordination with the PMD Tsunami Center. The NDMA shall provide central coordination to maintain uniformity and standardization of the public messages.

- vii. Early warning bulletins and messages shall be tested for their level of understanding through a manageable size of survey after each simulation, exercise or drill involving the general public or at least schools in target areas.
- viii. Strengthening of information sharing mechanism among Regional Tsunami Watch Providers and National Tsunami Warning Centers to better receive information and advice to complement national data stream including seismic, sea level, and other geophysical data networks.

5.2 Evacuation planning

Subject to the assessed level of risk in respect of a tsunami event, disaster management authorities and emergency responders should prioritize establishing and implementing a strategic plan (considering available lead time and resources at local level) for the effective and orderly evacuation of the exposed population.

Evacuation planning in each coastal area is directly related to the:

- Geographical size of the management area
- Assessed hazards and vulnerabilities
- Topography
- Demographics
- Size and density of the population
- Number of agencies involved in the planning process
- Resources available

Vulnerability maps derived from the inundation maps (in Section 4) provide key information for evacuation planning. Either voluntary or mandatory evacuation, both can place a significant burden on the resources and emergency managers in terms of caring for the displaced people (**Figures 2–5**).



Figure 2. Pedestrian tsunami evacuation route at Gwadar City, Baluchistan Province. (Left) Red arrows show starting and ending point of the evacuation route. (Right) Tsunami evacuation route, more than 600 steps of a stairs designed with landing at several points to facilitate pedestrian evacuation leading to the proposed evacuation site at the top of the Koh-e-Batil (a 450 high mountain) by the district disaster management authority Gwadar. Photo by Ghazala Naeem.

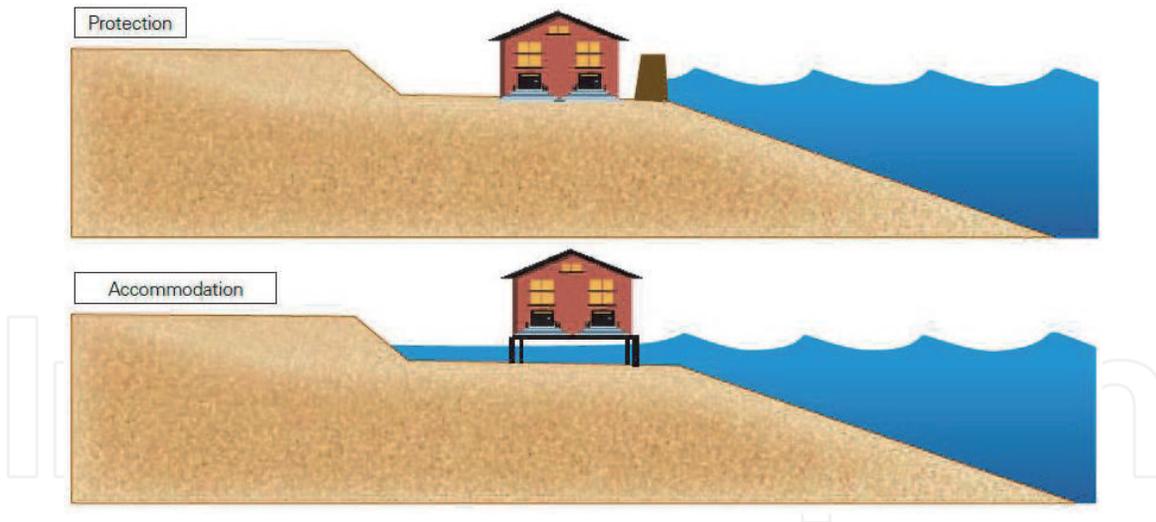


Figure 3. Application of engineering solutions of building a protection wall and accommodating the building by raise on stilts to safeguard against maximum tsunami wave and inundation height. Source: IOC Manual 52 [1].

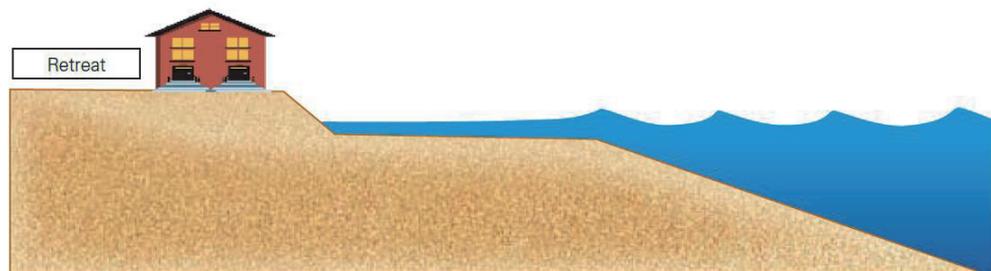


Figure 4. One of the strategic options for tsunami mitigation is “retreat” with reference to general maximum tsunami wave and inundation height. Source: IOC Manuals and Guides 52 [1].



Figure 5. Remote coastal communities settled on small islands in the Indus Creek Sindh Province. Photo by Ghazala Naeem.

5.2.1 Guidelines for tsunami evacuation planning

Disaster management authority of each coastal district, in coordination with concerned stakeholders, should prepare evacuation plans with the following aspects to be addressed:

- i. Identify “at-risk” people/communities who may require evacuation (either through risk assessment (Section 4)). It is recommended that authorities

proceed with mapping based on current locally available information and indigenous knowledge and not wait for the perceived required scientific knowledge. Zone boundary definition can then be refined as knowledge improves, over time.

- ii. Safe evacuation sites or buildings should be identified, clearly marked, and communicated to locals based on the perceived hazard analysis, for example, possible earthquake shaking, inundation height and extent, etc. Such sites and buildings should be pre-examined for safety, security, required space, and facilities to cater for the expected number of evacuees.
- iii. Maps depicting tsunami evacuation zones, escape routes, and tsunami safe areas should be available for display at workplaces, public gathering areas and buildings, holiday homes, and tourist facilities. Particularly, display in all areas subjected to tsunami risk.
- iv. Well-placed evacuation signage (in nationally agreed standardized format) with local perspective is critically important, for example, safety instructions and signage (natural signs) for tsunami events, identification of dangerous areas, safe sites, routes to reach evacuation sites, and other important messages.
- v. Define conditions under which an evacuation may be necessary.
- vi. Elaborate command, control, and coordination instructions (including designation of officials who are authorized to order an evacuation).
- vii. Warning instructions should be issued to the media, public, and businesses.
- viii. Procedures for assisting special categories of evacuees (e.g., vulnerable communities with least communication networks, elderly, children, physically challenged people, school students, patients at hospitals, etc.).
- ix. Specific plans and procedures that address:
 - The circumstances of the emergency
 - Transportation (e.g., arrangements in areas where pedestrian evacuation is not possible or for the patients, etc.)
 - Dealing with community that disregards mandatory evacuation
 - The evacuation of specific locations (UC and village level) facilities (ports, hospitals, schools, large industrial setup, atomic reactors, security agencies set-up) and evacuation routes
- x. Means of accounting for evacuees (and registration).
- xi. Welfare support for evacuees; designated reception areas for vulnerable groups like unattended children, elderly, patients, physically challenged people, etc.
- xii. Security of evacuated areas.

- xiii. Procedures for the return of evacuees.
- xiv. A consistent plan to facilitate common public understanding across communities about tsunami evacuation zones, maps, tsunami evacuation signage, and tsunami response actions.
- xv. Maintaining the plan, conduct drills and exercises, and incorporate lessons learnt in the overall planning scheme.

5.3 Other structural and nonstructural measures

Long-term earthquake and tsunami mitigation measures, other than effective early warning system and efficient evacuation plan, are also important to reduce the damage caused on the shores by expected events. There is a wide range of both structural and nonstructural measures, implemented as pre-disaster mitigations to manage earthquake and tsunami risks in the coastal areas of Pakistan.

Within the framework of a coastal area management plan, measures which mitigate the impact of earthquake and tsunami hazard represent a coherent set of interventions. A project monitoring and control system should also be incorporated within such a plan.

This section describes the management of the earthquake and tsunami risk by strategic mitigation, both through the use of structural methods, including the use of natural coastal resources and engineering approaches, and also by nonstructural initiatives, including regulation and land-use, emergency response planning, and community preparedness.

5.3.1 Coastal engineering solutions

While it is not possible to prevent a tsunami, particularly in tsunami-prone countries, some measures have been implemented and tested to reduce the damage caused on the shores that may have succeeded in slowing down and moderating the impacts of tsunami, for example, construing tsunami in front of populated coastal area, raising ground level for housing near beach by infilling land, and building floodgates and channels to redirect the water from incoming tsunamis. However, their effectiveness has been questioned, as tsunamis are observed there, often higher than the barriers. These engineering options for risk reduction are analyzed, that is, if these are appropriate to the scale of the tsunami threat to the designated coastal area, balancing social and economic pressures against environmental considerations including sustainability, over the long-term.

It is important to have a reliable database of the building stock in coastal areas especially in close proximity of the shoreline to have a reliable vulnerability and thus risk assessment. Strong buildings, safe structures, and prudent land-use policies to save lives and reduce property damage are implemented as pre-disaster mitigation measures.

5.3.2 Hazard-resilient built environment

- i. Relevant disaster management organization and building control authorities should maintain a GIS-based inventory of already constructed buildings with details of construction type, height, use, age, and structural stability at least for the areas in close proximity to shoreline (as a thumb rule, initially this database can be worked out for 1–3-km-wide coastal belt).

- ii. Building control authorities in collaboration with other stakeholders should review and suggest policies to counter underlying challenges in the development of disaster resilient built environment. For example, lack of regulatory frameworks, unplanned cities and urbanization, old building stocks and at-risk infrastructure, unauthorized structures, weak institutional arrangements, inadequate capacities of local administration, lack of funding, inadequacy of qualified human resources, corruption, and unlawful activities are major challenges in this regard [6].
- iii. Although cost may be an impediment, the national/provincial/local authorities should choose to adopt tsunami-resistant structures, stronger buildings, and deeper shock-resistant foundations mandatory in areas of high risk. The orientation of buildings with respect to the ocean is another factor for consideration. Mandated organizations should develop guidelines, byelaws, regulations, and codes to encourage coastal earthquake and tsunami-resistant infrastructure and housing in a local context. The overall general design guidelines could be developed from the experience gained from post-tsunami impact and damage assessments from different parts of the world as good practices.

5.3.2.1 Retrofitting of critical public buildings/facilities

- i. Important public buildings, for example, schools, hospitals, and government offices, and infrastructure like telecommunication, communication, water supply, roads, and bridges shall be inspected by the concerned authority for evaluation against estimated earthquake and tsunami impacts. These evaluations shall contribute to the vulnerability and capacity assessments mentioned in Section 4 and completed on priority especially for facilities located within 3-km-wide coastal belt on priority, by the concerned government authority/organization.
- ii. A complete framework for strengthening and retrofitting to be prepared and initiated according to available resources and fund generated through public-private partnership schemes.

5.3.2.2 Land-use planning

- i. Information contained in the inundation, vulnerability, and risk maps is to be used as basis to develop policy on land-use planning for new development and to suggest critical measures to make existing land-use better resilient for fast-approaching tsunami [1].
- ii. Hazard maps, particularly inundation maps for tsunami scenarios, are appropriate tools to suggest appropriate measure for land-use planning at any particular location. For example, option of “retreat” with reference to expected inundation extents can be used in land-use planning of high-risk areas [1].
- iii. Coastal communities in Pakistan, especially in rural settings, tend to settle right on the beach without any appropriate set back distance from the shoreline. Thus, making these settlements much more vulnerable to coastal hazard at one end and an environmental hazard on the other, by throwing sewerage and garbage disposal directly into sea. Such settled remotely in small islands within the Indus creek system, these dotted communities are

impossible to be warned in case of approaching local tsunami [5]. Relevant authorities and organization shall establish appropriate land-use management system to ensure a coastal hazard-resilient and environmentally sensitive land-use pattern along the coastline.

5.3.3 Strengthening of natural safeguards

Natural coastal features like high lands, sand dunes, mangroves, and other plantation species have been reportedly protecting the nearby communities in disaster situations. For example, interviews of 1945 Makran Tsunami survivors identified Pasni sand dunes, mangroves in Kalmat village, and Indus Creek system, mountain “Koh-e-Batil” at Gwadar, and tens of feet high rocks at Peshukan and Ganz villages as “savior” [7].

- i. Coastal vegetation can be used to dissipate tsunami energy via turbulent flow through the media. The effectiveness of dissipation is dependent on the density of vegetation, its overall porosity, and its tortuous characteristics of porous matrix. It is important to consider that the vegetation itself is resilient against tsunami propagation and has a root structure that can resist the high velocity regime at the floor bed. Planting mangrove at appropriate locations can also serve to dissipate extreme wind wave energy.
- ii. Sand dunes can provide natural full barriers against tsunami inundation. When overtopped, sand dunes tend to fail progressively by erosion. Dune-cladding vegetation provides reinforcement to the dunes, thus impeding erosion.
- iii. Engineering solution for protection of coastal communities such as offshore breakwaters, dykes, and revetments can be used in hybrid way, i.e., with natural features, harnessing the full potential of coastal ecosystems including coral reefs, sand dunes, and coastal vegetation such as mangrove forests.
- iv. Coastal development authorities, forest department, building control authorities, and local and provincial governments need to maintain a database (preferably GIS based) of such natural safeguard features in coastal belt and develop guidelines and regulation to protect and strengthen such features.

5.3.4 Continuity of operation plans for ports and other major facilities

- i. Authorities of ports, large- and medium-scale industrial setups, and major facilities, including hospitals, schools, etc., both on- and offshore, need to prepare respective continuity of operation plans in response to estimated earthquake and tsunami impacts mentioned in Sections 3 and 4.
- ii. The plan can include [8]:
 - Conducting business impact analysis.
 - Identifying recovery time objectives for business processes.
 - Identifying recovery point objective for restoration.

- Define business continuity strategies and requirements.
 - Work out procedures, resource requirements, and logistics for execution of all recovery strategies.
 - Describing detailed procedures, resource requirements, and logistics for relocation to alternate work sites.
 - Deciding detailed procedures, resource requirements, and data restoration plan for the recovery of information technology (networks and required connectivity, servers, desktop/laptops, wireless devices, applications, and data).
- iii. National security agencies and port authorities also pay high attention to develop continuity of operation plan.

5.3.5 Debris clearance and management plan

Tsunamis of even small wave heights can bring huge quantities of debris and waste on the coast. Severe public sanitation and environmental concerns are also associated with earthquake and tsunami debris clearance and the management of municipal solid waste:

- i. District government and municipal committees to develop tsunami debris clearance and waste recovery plan for expected tsunami derived waste estimation made either through numerical modeling or national and international case studies.
- ii. National security agencies' infrastructure and ports need high-level consideration and debris clearance plan.

5.3.6 Emergency response, search, and rescue plan

- i. All agencies and organization including civil defense, fire brigade, Rescue 1122, NDMA, PDMA, Pakistan Army, Navy, Pakistan Coast Guards, Marine Security Agency, and health department mandated and/or capable of emergency response and rescue operations (even only in case of any critical situation) shall develop or adapt (already available) plans, SOPs, manuals, and guides as per estimated hazard of earthquake and tsunami with reference to Sections 3 and 4.
- ii. The abovementioned plan and procedures shall be developed considering lead time availability of only "minutes" before a tsunami can hit the coast. To efficiently act upon the plans, strong coordination (inter and intra department) is to be assured through practicing envisaged plans and participating in scheduled drills and simulations coordinated by the NDMA and PDMA.

5.4 Community preparedness

5.4.1 Database of tsunami knowledge

Tsunamis being infrequent phenomena could have gained least focus of all stakeholders in Pakistan; however, mega events of 2004 Indian Ocean tsunami and

2011 Japan tsunami created a sense of realization among national- to local-level organizations and experts to work on tsunami risk assessment and preparedness measures.

Within little more than a decade's period, significant pilot initiatives on community preparedness have been implemented based upon adaptation of international knowledge products and "Information, Education and Communication" (IEC) material. The adaptation strategy included not only the interpretation of those IEC products in national and local languages but also inclusion of indigenous knowledge and social and cultural traces. Tsunami safety tips, guidance for evacuation, observing natural signs of tsunami, protection, and conservation of natural safeguards of coastal region are delimited in handouts, pamphlets, information boards, booklets, videos, and through radio programs.

- i. The NDMA in collaboration with PDMA Baluchistan and Sindh need to maintain a database of all available IEC material for earthquake and tsunami community preparedness and education.
- ii. The NDMA to support PDMA in finalizing standardization of available knowledge products and further adaptation including translation into local languages.

5.4.2 Public awareness campaign

- i. At local level, DDMA need to plan and conduct tsunami awareness campaign on yearly basis through training of various community groups (volunteers, teachers, medical staff, local elected representatives, students, women, etc.) and of every Union Councils (UCs).
- ii. At national level, NDMA needs to design and implement public awareness campaigns focusing on earthquake and tsunami through national electronic channel and local FM radio channels using the tsunami knowledge database in the coastal region. The NDMA can collaborate with the Pakistan Electronic Media Regulatory Authority (PEMRA) to broadcast such information on electronic media channels under Section 20 (e) "Terms and Condition of License" of PEMRA Ordinance [9].

"Broadcast, if permissible under the terms of its license, programmes in the public interest specified by the Federal Government or the Authority in the manner indicated by the Government or, as the case may be, the Authority, provided that the duration of such mandatory programmes do not exceed ten percent of the total duration of broadcast or operation by a station in twenty-four hours except if, by its own volition, a station chooses to broadcast such content for a longer duration."

- iii. The NDMA in collaboration with the Pakistan Telecommunication Authority (PTA) can be vital to design and implement tsunami awareness campaigns for general public in coastal region through social media and cellular phone networks.
- iv. The NDMA, in collaboration with PDMA and other government and nongovernment organization, can manage (if already available) and develop (if not readily available) knowledge products on a standardized format for public awareness campaign on the following subjects:

- Observing natural signs of tsunami
- Receiving and responding official warnings
- Identification and recognizing evacuation centers and routes
- Information about hazard-resistant construction, land-use, byelaws, regulations and codes to ensure safety against earthquake, tsunami, flooding, and fire impacts
- Evacuation procedures and guidelines
- Importance of participating in evacuation drills and training
- Conservation and strengthening of natural safeguards of tsunami like mangroves, high land, sand dunes, and coral reef.

The information mentioned above shall be used through electronic, print, and social media campaigns and community training.

- v. Evacuation drills must be conducted to ensure training of the community on disciplined evacuation. A regular schedule of conducting drill shall be planned and implemented at local level (UC and village level) once a year with communities settled on the coastline (at least within 3-km-wide coastal belt). PDMA (Baluchistan and Sindh) shall support respective DDMA to design and implement community-led and sustainable mechanism for monitoring entire processes.

5.4.3 Curriculum development for all levels of academia

- i. The NDMA in collaboration with PDMA should lead the process of finalizing curriculum on earthquake, tsunami, flood, cyclone, and fire hazards and preparedness measures for students of all levels. Education departments shall be a part of this process. Private educational institutions also follow the finalized curricula.
- ii. Schedule of evacuation drill (at least once a year) in all level academic institutions, both public and private, located in coastal districts shall be finalized by respective DDMA and district education department.
- iii. Teachers' training program to be developed by PDMA Baluchistan and Sindh in collaboration with provincial and coastal districts' education departments.

5.4.4 Self-evacuation plan for remote coastal communities

Fishing villages in coastal Pakistan along tidal creeks of the Indus Delta and Makran region would need to respond quickly to escape a tsunami from nearby parts of the Makran subduction zone.

- i. The NDMA in collaboration with PDMA Baluchistan and Sindh should conduct a survey and mapping (using GIS) of all remote coastal communities where means of official warning communication are limited

or not at all available, in estimated available lead time (subject to the estimated tsunami hazard and risks discussed in Sections 3 and 4).

- ii. PDMA (Baluchistan and Sindh) along with respective DDMA should design and implement evacuation planning for such communities including:
 - a. Identification of feasible evacuation site and routes near each individual settlement.
 - b. Awareness campaigns and training of local volunteers to receive official warning to disseminate to other villagers and fishermen.
 - c. Interpretation of bulletins issued by the PMD and DDMA.
 - d. Detection of early warning via natural signs such as abnormal behavior of animals, earthquake shaking, and retreat of sea water.
 - e. Basic emergency response, especially how and where to evacuate, immediate first aid provision to injured, etc.
 - f. Facilitate and manage evacuation of vulnerable groups.
 - g. Ways to manage external communication to get help from outside of the village and emergency responders/organization.
 - h. Knowing, using, and keeping alive the indigenous knowledge.
 - i. Knowledge about different categories of threat and how they should respond to it.

5.5 Risk transfer

The NDMA in collaboration with PDMA (Baluchistan and Sindh) and other organizations should develop a strategy to promote insurance (life and property) for earthquake and tsunami incidents that can play an important role in offering financial protection from the costs of disaster.

5.6 Research and knowledge sharing

Understanding disasters and to find appropriate ways to reduce disaster risk are critically important. Scientific, social, and indigenous knowledge-based researches are direly needed to be undertaken, and result sharing with larger audience including communities at risk has a pivotal role in managing disasters. This role of risk-based knowledge sharing has been recognized in international frameworks, i.e., Sendai Framework for disaster risk reduction (SFDRR) 2015–2030 [10].

- i. At national level the NDMA may facilitate coordination among academia, research institutions, and private sector to undertake scientific and social research initiatives facilitating overall risk assessment of coastal areas of Pakistan on:
 - a. Earthquake and tsunami hazard analysis

- b. Exposure data, vulnerability and capacity evaluations
 - c. Indigenous knowledge
 - d. Preparedness and response
 - e. Related policies, regulations, guidelines, bylaws, and codes
- ii. The Higher Education Commission (HEC), the National Institute of Oceanography (NIO), PMD, NDMA, PDMA Sindh, and PDMA Baluchistan should explore public-private partnership to encourage researchers to undertake the required studies mentioned in this section as well as ensure that the results are shared and available to the end user (including general public) and are incorporated in policies, regulations, and guidelines from national to local level.

5.7 International cooperation and coordination

International cooperation on tsunami warning and mitigation is envisaged to assure international compatibility and interoperability for rapid exchange of data and information. Pakistan is actively engaged in exchange of data and resources and capacity building initiatives through bilateral and global commitments. Pakistan is a member state of the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), established in 1960 as a body with functional autonomy. The Pakistan Meteorological Department is the focal agency mandated to coordinate with UNESCO-IOC, ocean-wide tsunami warning providers for data sharing and capacity building regional and global initiatives.

1. The PMD in coordination with disaster management authorities at national and provincial level should ensure to participate in all capacity building initiatives and ocean-wide simulations and drills.
2. Effective participation in research, knowledge sharing, and capacity building should be ensured, and the PMD being the focal agency should play a lead role.
3. The PMD should also play a lead role in appropriate follow-up of global and regional collaborations from national to local level.

6. Conclusion

Coastal area residents in Baluchistan and Sindh provinces can experience a local earthquake—the most common cause of tsunamis—and a local tsunami generated in Arabian Sea can approach the coast within minutes.

Limited information regarding Pakistan coastline's vulnerability is available to assess tsunami risk. Database is not appropriately maintained for social, physical (structural), economic, and environmental dimensions of exposure analysis, making the situation more critical. Since 2006 (in the aftermath of 2004 Indian Ocean Tsunami), some limited but focused efforts on tsunami hazard and risk assessment, mitigation, and preparedness have been piloted in the country since 2006 serious and consistent efforts of all stakeholders at policy and implementation level.

This chapter suggests earthquake and tsunami risk assessment and mitigation roadmap for Pakistan's coastal areas with a vision of acquiring required deposit of

information to plan and implement coherent and synergized earthquake and tsunami risk reduction measures. The guidelines for in various sections of the chapter are proposed for:

- i. Determining the earthquake and subsequent local tsunami threat, in terms of hazard and risk assessment all along the coastline on a standardized pattern on priority basis, involving all levels of stakeholders.
- ii. Ensuing federal and provincial agencies utilize earthquake monitoring systems, tide gauges, deep ocean buoys, and other capabilities (international/regional information sharing systems to gather as much information as possible about a potential tsunami). Essential data is then used by forecasting and analysis centers for the assessment of the immediate tsunami threat. Timely and accurate warnings must then be disseminated in clear and actionable terms to emergency managers and a ready public.
- iii. Identifying mitigation strategies that involve sustained actions taken to reduce or eliminate the long-term risk to human life and property based on earthquake and tsunami risk assessments.
- iv. Aiming at tsunami-resilient communities that have plans, enhanced communications, and heightened awareness of the citizens to ensure resilience to earthquake and tsunami events, reduced economic losses, and shorten recovery periods.
- v. Encouraging continued broad scientific and social research efforts needed to improve all-purpose understanding of tsunami processes and impacts and then to develop more efficient and effective risk assessment, risk communication, prediction and warning, preparedness, and mitigation measures.
- vi. Strengthening partnerships with international organizations and other countries persuade bilateral and multilateral agreements to better understand and reduce the common threat and impact of earthquake and tsunami in the region.

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