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Tsunami Risk Assessment and Reduction in the Global Ocean: Challenges and Prospects

Papadopoulos GA*

International Natural Hazards Society, Greece

***Corresponding author:** Dr. Gerassimos A. Papadopoulos, International Natural Hazards Society, Greece, Email: gerassimospapadopoulos2@gmail.com

Editorial
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Abbreviations: IOC: Intergovernmental Oceanographic Commission; PTRA: Probabilistic Tsunami Risk Assessment; PTHA: Probabilistic Tsunami Hazard Assessment; PSHA: Probabilistic Seismic Hazard Assessment.

Editorial

Tsunamis are gravity sea waves of long period which ranges from a few minutes up to ~1 hour. The main causes of tsunamis are submarine, shallow, strong earthquakes with faulting mechanism that usually involves a significant component of vertical motion. The largest seismic tsunamis are produced along active zones of lithospheric subduction, e.g., in the circum-Pacific belt, in the Indonesian arc, in the Mediterranean Sea and in the Atlantic Ocean offshore SW Iberia. However, tsunamis are also generated from other processes including coastal and submarine landslides, volcanic eruptions and meteorological changes (meteotsunamis) such as fast-moving weather events.

Tsunamis are low-frequency but high-impact waves. In human communities the tsunami impact may include casualties and damage in various assets, such as buildings, infrastructures, life lines, vessels, material of several kinds, and coastal cultivated areas. The tsunami impact may also include social disruption and direct or indirect losses in financial terms. In the natural environment there are several effects caused by the tsunamis, like destruction of flora and fauna, ground erosion, transport and deposition of sediments. The catastrophic potential of tsunamis is exemplified by the devastating events of Boxing Day 2004 tsunami in the Indian Ocean and the 11 March 2011 tsunami in NE Japan.

The term "tsunami hazard" is referring to only the physical phenomenon per se, i.e. the possibility that a tsunami of a particular size may strike a particular section of coast. On the other hand, the concept of "tsunami risk" focuses on the likely destructive effects of the wave.

Tsunami risk is generally adopted as the convolution of three main attributes: hazard, vulnerability, and value exposed to hazard, which is also the definition for the risk related to other physical processes, e.g., earthquakes.

The tsunami risk reduction is based on the synergy of preparedness, operation of early warning systems, public education and awareness, and emergency plans. Better understanding of the generation, propagation and inundation of tsunamis is of crucial importance for developing effective assessments of the tsunami hazard and risk. However, the mode of convolution, of which the risk is composed, does not imply a standardized procedure. The reason is that it depends on the type of risk under consideration, on the availability of relevant data sets and on the types of assets which are exposed to the hazard. Consequently, exposure is an additional component that could be added in the risk convolution scheme. The tsunami risk could be approached qualitatively or quantitatively depending on the data availability and on the kind of risk needed to assess. The risk assessment is a quite complicated issue that requires the assessment of each one of the various components involved.

Efforts for the tsunami hazard assessment are based on deterministic and probabilistic approaches. The first approach is based on the selection of the extreme or the so-called worst-case credible tsunami scenario. Through numerical simulation of the tsunami, which is produced by the largest tsunami causative source for the study area, the procedure concludes with the determination of the inundation area and mapping of the tsunami hazard zone. However, the Probabilistic Tsunami Hazard Assessment (PTHA) has gained ground in the last years. In general, it follows the long experience obtained from the Probabilistic Seismic Hazard Assessment (PSHA) since the 1960's. A PTHA study focuses on the investigation of the seismic (or other) sources that are potentially capable to produce tsunamis threatening the coastal segment of interest. Taking into account the probabilities of activation of each seismic source, with certain earthquake magnitudes in certain time frames, and after numerical simulations of the waves produced by each source, the probabilities of exceedance of certain run-up values in the coast of interest are calculated.

Both the probabilistic and deterministic methods suffer from a variety of uncertainties. The effort for the tsunami hazard determination is characterized by significant gaps in the availability of the data sets needed, such as incomplete knowledge of the dimensions, faulting styles and rates of activation of the seismic sources. Other data gaps concern the limited accuracy of the bathymetry in many parts of the sea bottom, particularly in the near-shore domain, as well as the frequent lack of appropriate digital elevation models needed to map tsunami hazard zones.

Due to the relative sparsity of instrumental tsunami records, hazard estimates are directly derived from historical tsunami records, which often are vastly incomplete. Catalogs of paleoearthquakes and paleotsunamis, which have been identified by geological methods, e.g., by the recognition of tsunami sediment deposits, provide enrichment of the tsunami records and useful input for the calculation of repeat times of large events. However, possible overweighting of large past tsunamis should be treated with caution. Such issues were recently examined in details by a worldwide network of specialists working together in the frame of the European COST tsunami project AGITHAR. Of special interest are approaches developed initially for the PSHA by utilizing incomplete and uncertain earthquake catalogs containing instrumental, historical and paleoearthquake data. Such approaches are suitable for hazard assessment associated with rare events and, therefore, recently were tested for the PTHA too with promising results.

The estimation of tsunami losses is closely connected to damages in buildings and infrastructures. Therefore, physical vulnerability and exposure constitute important components in the convolution scheme for the tsunami risk assessment. Vulnerability is closely associated to damage or fragility functions and relevant data have been collected in the aftermath of the Indian Ocean 2004 and Japan 2011 mega tsunamis. However, a lack of consensus has been noted regarding fragility vulnerability modeling. Of importance are also the data limitation about asset types and the difficulty of "quantifying" social vulnerability. On the other hand, exposure data provide information about the characteristics and the location of people and of various assets at risk but the several techniques for the acquisition of exposure data are characterized by different degrees of resolution and precision.

Although the tsunami risk assessment includes qualitative or quantitative scenario-based methods, the PTHA approaches are becoming progressively a standard basis for the Probabilistic Tsunami Risk Assessment (PTRA). However, less progress has been noted in PTRA with respect to PTHA for the reason that for the hazard assessment only data on the physical parameters of the events are needed, while for the risk assessment vulnerability, exposure and value data are also required. The estimation of financial values exposed to tsunami hazard has been the subject of only a few studies. Relevant losses have been expressed using as metrics either the probable maximum loss for a given return period of the extreme tsunami event or the probabilistic average annual loss and the loss exceedance curve. The several components involved in the tsunami risk assessment are susceptible to a variety of epistemic and aleatory uncertainties making the risk assessment a highly complex procedure. Consequently, no standard methods for the tsunami risk assessment have been reached so far.

International cooperation is of vital importance for an effective tsunami risk reduction policy. The long-term Tsunami Programme of the Intergovernmental Oceanographic Commission (IOC) of UNESCO plays a catalytic role worldwide since the 1960's. Today four major Tsunami Early Warning Systems operate under the IOC coordination in the Pacific and Indian Oceans, in the Caribbean Sea and in the North-east Atlantic and Mediterranean region with the active participation of tenths of national monitoring centers and of hundreds of experts. Since 2001, the US National Weather Service/NOAA has been implementing the recognition programme TsunamiReady® in its states, territory and commonwealths. Since 2015, the UNESCO/IOC started to build its Tsunami Ready Programme based on the experience of USA, first in the Caribbean and later in many other countries around the globe. The UN Ocean Decade Tsunami Programme, launched during 2022, provides an excellent opportunity to note drastic progress in the field of tsunami risk reduction in the years to come. Particular attention is expected to be paid on the possible effects that the climate change may have on the long-term assessment of the tsunami hazard and, consequently, of the tsunami risk assessment.