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Strategic tsunami hazard analysis and risk assessment planning model: A case study for the city of Alexandria, Egypt

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Abstract

Alexandria, a city with a devastating history of catastrophic tsunamis, is extremely vulnerable to a new cataclysmic tsunamic event at any moment, especially with its current high density coastal communities and the rapidly increasing population rates. Most of the city's inhabitants are living in low lying land, even below sea level. The hazard of being attacked by a tsunami has been classified by many scientists as 'likely' and the city has been identified as one of the 'Mediterranean tsunami vulnerable cites,' were there is a great need to implement mitigation and preparedness measures and an advanced tsunami warning system. This paper aims to develop a practical strategic tsunami hazard analysis and risk assessment-planning model, applied on the city of Alexandria. The model will form the basis for sustainable development planners to create and utilise the appropriate tsunami planning measures and emergency evacuation plans for coastal tsunami prone areas. It would also help in calculating and predicting the amount of casualties that would occur in the case of a tsunami attack without any mitigation or preparedness measures.

Keywords: Tsunami Risk Assessment; Tsunami Phenomena; Tsunami in the Mediterranean: Alexandria Historical Tsunami's

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1. Introduction

Tsunami is one of the worlds' largest catastrophic phenomenon (Cochard et al., 2008). Although the hazard duration lasts only a few hours, its impact lasts for life on property and the natural environment (Paris et al., 2009; Cochard et al., 2008). Tsunamis form major geomorphic crises causing changes of coastal lines, beach erosion, sediment transport inshore and offshore only in a few minutes and over hundreds of coastal kilometres (Dawson and Stewart, 2007; Maouche et al., 2007; Camilleri, 2006). Tsunami is a natural phenomenon that is triggered by other natural phenomena such as submarine faulting, submarine slides and slumps triggered by shallow strong earthquakes, submarine volcanic explosions erupting a huge mass of lava into the water, and a falling cosmic from outer space (Todorovska and Trifunac, 2001; Lovholt et al., 2012). When these natural causing phenomena occur, separated or combined, they cause eruption of the seabed and the entire depth of the water column forming tsunami waves. The tsunami waves have very long wave-lengths between 100 and 200 km that can travel all over an ocean basin easily in an excess speed of 500 km/hr (Dominey-Howes, 1998). The height of the wave while travelling in open water is limited causing no or minimal threats; however, when approaching shores of coastal areas it builds up to tens of meters in height (Ozel et al., 2011; Todorovska and Trifunac, 2001).

Until recently, tsunami was not considered a hazard phenomenon; however, following the Boxing Day Tsunami the conscious of the world has changed towards one of the most natural devastating phenomenon. On the 26th of December 2004 the world witnessed "the third largest fast natural disaster calamity recorded in human history and largest to be caused by sea waves" (Cochard et al., 2008:4). The Indian Ocean witnessed the second largest earthquake on record with a magnitude of 9.3 (Paris et al., 2009) triggering one of the world's most violent natural catastrophic tsunami of exceptional dimensions. The 2004 tsunami known as the 'Boxing Day Tsunami' was rated one of the largest and deadliest tsunamis in recorded human history. Waves records on attacked shores were more than 20m high travelling at a speed of up to 800 km/h flushing inward in low lying areas for several kilometres, resulting in an estimated death of over 300 thousand people and left around more than 700 thousand people homeless (Ozel et al., 2011; Pignateli et al., 2009).

Another shocking truth revealed from the 'Boxing Day Tsunami' was that although the government of Indonesia was notified shortly before the tsunami came upon the shores of Sumatra, the political decision was to not issue a warning. They could not really estimate, imagine or speculate the huge human casualties and death rates that could have happened. They decided that a warning might cause chaos among the high-density coastal areas. Since there are no tsunami hazard analysis and risk assessment studies, no evacuation or risk management plans existed; even the minimum community education level of the coastal zone areas required to deal with a tsunami's risk and hazard was not present. Coastal areas, not far ago, have been places of peace with nature and its ecological sensitive ecosystems. The limited number of inhabitants of coastal zones has limited the catastrophic effects of tsunamis in the past (Pignatelli et al., 2009) especially because the preserved natural ecosystems have played an effective role as mitigation and preparedness measures for tsunami impact (UNESCO, 2011; Camilleri, 2006). Today the situation is completely different, although coastal zones make up only 4% of the world's land area, they are inhabited by one-third of the world's population, a percentage which is predicted to increase to over 50% in the coming few years

(Cochard et al., 2008:4). Resulting from the increasing unplanned and unsustainable development of coastal areas, most of the ecological ecosystems have been completely wiped out such as: coral reefs, lagoons, mangrove forests, sea grass beds, sand dunes and other types of coastal vegetation. Considering the current and future high coastal population density, tsunamis must be dealt with as one of the most threatening geological risk factors in coastal areas and cities.

There is a vital need for a strategic hazard analysis and risk assessment model that would prevent people living in coastal cities from being caught by tsunami waves. This would express the crucial and urgent need for careful mapping of potential tsunami hazard areas upon which strategic tsunami mitigation, preparedness and early warning initiatives could be taken (Lovholt et al., 2012; Ozel et al., 2011). The ability to identify the people at risk would allow planners to promote sustainable plans for coastal communities, also planning for emergency and disaster evacuation plans and strategies would be possible. Long term and short term planning mitigation measures for reducing risk and building vulnerability could be carried out. Eisner (2005) listed seven principles for reducing the risk of coastal communities to the tsunami hazard. The first, and the most important of which, is the ability to define the community's tsunami risk; including hazard, exposure and vulnerability (Eisner, 2005). Another astonishing fact was that Eisner's remaining six listed principles are concerned with planning issues as the major source for mitigating tsunami impacts. On reviewing the tsunami and planning literature as a planner expert, the importance of such research field is non-prevalent, if it indeed exists. Tsunami hazard assessment and planning measures have to be identified as a research gap area with high and urgent research priority (Kelman, 2006; Yolsal-Cevikbilen and Taymaz, 2012), especially in developing countries with highly exposed coastal communities.

Egypt, with a wide stretch of coastline communities overlooking the Mediterranean, and thus highly vulnerable to a tsunami threat, needs to trigger an alarm concerning vulnerability of the cities to tsunami risks. The active lithosphere plate classifies the Mediterranean Sea region as a geodynamical high seismic activity and significant volcanisms basin (Papadopoulos and Fokaefs, 2005). Ten percent of all tsunamis worldwide occur in the Mediterranean, with an average of one catastrophic event occurring every century. With the current (130 million) and rapidly growing coastal population exposure to a large tsunami would be catastrophic (Papadopoulos and Fokaefs, 2005).

The paper's methodology for developing the practical model for strategic tsunami hazard analysis and risk assessment of coastal communities and regions in tsunami prone areas is based on profound theoretical analysis and studies. The model is composed of four stages. It was then tested through a practical analytical study that applied the model on the city of Alexandria as a case study. The four stages proposed in the model are as follows; the first stage is the mandatory stage where the geographical information system and data set of the coastal community is to be developed; the second stage is the tsunami scenario calculations based on the 'scenario base modelling', the 'probabilistic based modelling' or both of them, during this stage the various run-up heights of the tsunami, for the estimated tsunami scenarios, are calculated. The third stage is to populate the expected tsunami inundation maps and hazard analysis regions and levels (based on the flood management scale developed in the PRIVEW project, 2005). The final stage qualitatively defined the tsunami risk assessment on physical properties; the paper adopted, added and modified the tsunami risk

model on physical properties presented by Jelinek et al. (2009) and Eckert et al. (2012) as the theoretical base for conducting this analytical stage populating the hazard, vulnerability and risk assessments.

2. Tsunami process and stages

Tsunami is a natural phenomenon, lately identified as one of the worlds' most natural cataclysmic phenomenon that is triggered by other natural phenomenon. The best way to define and report on the tsunami process and stages would be through a descriptive analysis of a real tsunami incident, based on several eyewitness tails and scientific expert analysis reports. The selected tsunami to be described is the Dec 26th 2004, tsunami in Sumatra (Indonesia at 7:58AM local time). This tsunami is one of the most catastrophic and deadliest tsunamis in recoded human history, also known as the 'Boxing Day Tsunami.' The descriptions provided were documented by dozens of eyewitnesses in the Lhok Nga Bay, northwest Sumatra (Paris et al., 2009). The tsunami sequences were as follows: a devastating earthquake of a recorded 9.3 magnitude in the Indian Ocean (only 250 km south–southeast of the coasts of Lhok Nga Bay). Ten minutes later, a retreat of the sea for over 1 kilometre was observed. Five minutes after the sea retreat the first wave came in very fast, as described it was dark in colour loaded with sediments and debris. Five minutes later a second wave came in with a height between 15-30 m above sea level (a.s.l). Shortly a third wave attacks; however, there weren't enough eyewitnesses to describe it. The run up recorded was 36m a.s.l. in Lhok Nga Bay. The created inundation reached 4 km inland. Only 5 minutes following the third wave a backwash (traction) occurred loaded with tons of debris, even people, were washed several kilometres inside the ocean water. In a few minutes, over 300 kilometres of Sumatra's coasts were severely affected (Paris et al., 2009). Concluded from the former descriptive analysis, Figure 1 reports on the various processes of a tsunami. As presented the physics of a tsunami usually links the various overlapping but quite distinct processes: generation, propagation, shoaling & run up, inundation, traction and sedimentation (Dawson and Stewart, 2007; Leone et al., 2011; UNESCO, 2011).

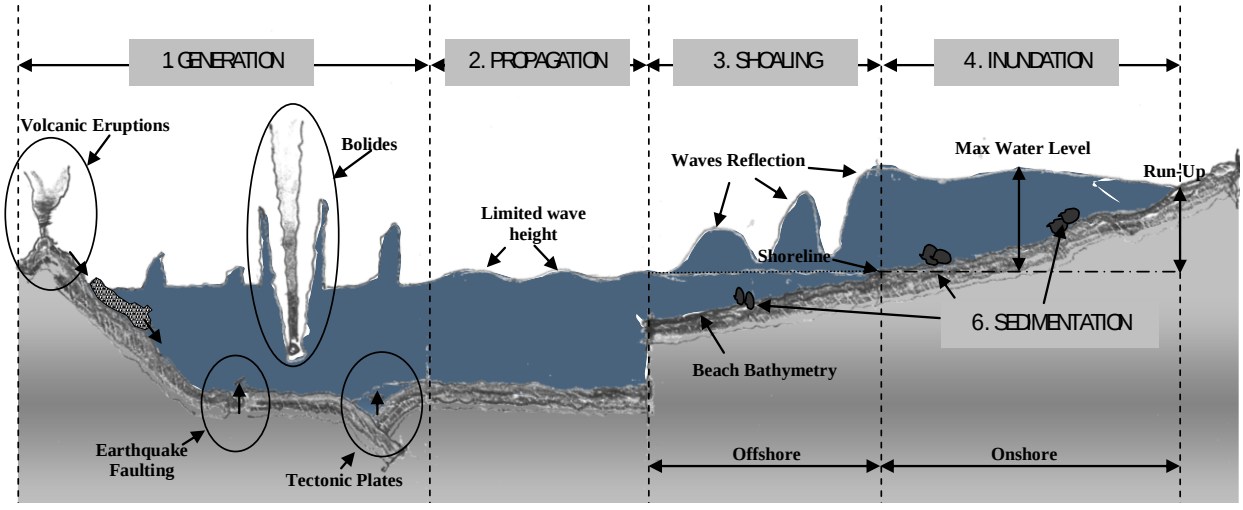


Figure 1. Tsunamis Processes (Source: author based on Dawson and Stewart, 2007; Weiss, 2008; UNESCO, 2011)

2.1. Generation process

A tsunami starts when an underwater disturbance suddenly displaces a complete column of water (Camilleri, 2006). This is called the generation process of the tsunami, among the reported tsunamigenic sources are (Figure 1):

- **Earthquake faulting** vertical earthquakes causing vertical seabed displacement are among the most reported tsunamigenic sources, producing 90 per cent of the recorded tsunamis (Dominey-Howes, 1998). The intensity of the produced tsunami is a factor of both the distance of the quake from the sea bed and the height of the displaced water column (Trodorovska and Trifunac, 2001; Yalciner et al., 2002).
- **Volcanic eruptions** generate destructive tsunamis in most cases. Volcanic debris entering the sea, in the form of large pyroclastic (lava) flows, collapsed volcanic edifices, volcanic air blasts and air cavities cause vertical water displacement of the sea column normally generating a cataclysmic tsunami (Dawson and Stewart, 2007).
- **Tectonic plates** are mega-tsunami sources. Tectonic continental plate's eruptions build up over hundreds of years. The eruption occurs causing a violent landslide uplift which generates a tsunami that can have amplitude of 1 km high. Such mega-tsunami is usually related to the Ocean realm. Unlike earthquakes they are more difficult to determine because the lack of historical documentations (Geist and Parsons, 2009).
- **Bolides impacts** falling bolides (asteroids and comets) in deep Ocean water, from outer space, with diameters of 1km and larger are capable of producing a mega-tsunami. Such an incident's probability in striking Earth is only once every 300,000 years; however, the fact of having a bolides impact tsunami is considerable, as an asteroid or comet having a diameter less than 1 km is likely to fall at any time. Knowing that water covers around 70% of the earth surface the possibility of a tsunami occurrence is high. Bolides of radius less than 500 m may produce a tsunami of around 10 m thousands of kilometres from impact point, with a return period of 3-5 thousand years (Dawson and Stewart, 2007).

2.2. Propagation process

Once the seismic activity occurs and the displacement of the water column occurs, the tsunami propagation process starts. The displacement of the entire water column causes the uniform distribution of the kinetic energy, resulting in very smooth low frequency and very long waves lengths of hundreds of kilometres. The wave length is at least three times greater than the water depth (Dawson and Stewart, 2007). Its speed is usually hundreds of km/hr with an average between 500-800. In open water tsunami waves 'tidal waves' are rarely noticeable with an average height of 10 centimetres in general (Dawson and Stewart, 2007). During the propagation process tsunami waves can travel thousands of kilometres uninterrupted, without dissipating its energy inflicting catastrophic casualties among communities thousands of miles from their generating points (Dominey-Howes, 1998).

2.3. Shoaling process

As a tsunami approaches land it starts converting its kinetic energy, equally distributed along the entire water depth, into enormous potential energy. This turns the tsunami wave into a violent, destructive, onrushing and flooding water movement into the coastal areas (Cochard et al., 2008). This process is known as the tsunami shoaling process. During the process, the tsunami wave height is reflected and amplified into several times to that of its open water height. The degree of amplification and cataclysmic of the wave impact is determined based on the characteristics of the wave and the shore bathymetry of the exposed coastal area. The bathymetry of a coastal area refers to (Figure 1) offshore bathymetry, coastal profile and onshore features (Camilleri, 2006). Just before the wave reaches the shoreline, a withdrawal of the seawater occurs. A few minutes later, the first tsunami wave reaches the coastline. Once a tsunami reaches the coastline it builds up a maximum wave-height (Figure 1), causing a high run-up level (Leone et al., 2011).

2.4. Inundation process

The main factors influencing the tsunami inundation level are the tsunamigenic generating source, distance and the coastal geomorphology (Cochard, et al., 2008). The tsunami reaches the coastline after being amplified hampering its' run-up height in one of three forms: a. laminar flow, flood the landscape without breaking like a sudden sea level rise; b. a train of breaking waves; c. a turbulent water hammer (Pignatelli et al., 2009:13). All forms have a destructive nature on buildings and human life; however, types (b) and (c) bare the most destructive and catastrophic effects that a tsunami could have on buildings- capable exploding and breaking of pillars and walls, pulling out and destruction of roofs and structures, bending and breaking of structures, uprising of floors, burial of the structures and tearing out foundations (Leone et al., 2011:368). The inundation can flood several inland kilometres, until it reaches its maximum run-up height, lasting for hours with very aggressive potential energetic powers.

2.5. Traction process

Following the last wave of the inundation process the water body starts to calm down reaching a point of zero velocity and then changes its direction generating a huge backwash current from inland into deep-waters (Dawson and Stewart, 2007). The backwash current is so powerful and violent in a way that it washes debris, building and people several kilometres in deep water. Backwash flows are routed by coastal morphology they are usually more erosive, powerful and deadlier than inundation flows (Paris et al., 2009).

2.6. Sedimentation process

The process is the imprint of any tsunami that has on nature, it is the tsunami signature, carrying geological records of past tsunamis that can reveal the scientific mysteries and realities concerning a tsunami event (Weiss, 2008). Tsunami sedimentation exists both onshore and offshore, resulting from the inundation and traction processes consecutively (Leone et al., 2011; Paris, 2011).

2.7. Tsunami scaling process

Most of the tsunami scaling or measurements are derived from tsunami run-up, the maximum on-shore wave height above sea level. One of the most widely used tsunami scales is that of Iida measuring tsunami magnitude on a scale from -2 very light to 10 large asteroid impact. The second famous scale is Ambraseys measuring the intensity of tsunami on a 6 level scale from 'I' very light to 'VI' Disastrous (Camilleri, 2006). Papadopoulos and Fokaefs (2005) proposed a new 12-point tsunami intensity scale that is consistent with the 12-point seismic activity scale established and used in Europe and America. It defines the effect a tsunami could have on humans, objects, vessels, nature and buildings (Papadopoulos and Fokaefs, 2005: 168-170).

3. Mediterranean sea and tsunami's risk

The history of tsunami in the Mediterranean is well documented. The Mediterranean Basin is often regarded as an active geodynamical seismic laboratory, encompassing the active lithospheric plate convergence (Papadopoulos and Fokaefs, 2005). Many scientific research and historical documentation confirm the reliability of having a Mediterranean catastrophic tsunami every 140 years. Recently, until the world's largest human catastrophe that took place on Boxing Day 2004, tsunami affect in the Mediterranean Sea has been neglected. Tsunamis were not considered as a threat to the Mediterranean coastal communities. Large tsunami recurrences are of several decades that are short lived or remembered. However the reality of the Mediterranean totally contradicts the previous vision of the Mediterranean being a low impact tsunami prone area. The complex tectonic nature of its basin is responsible for intense earthquake activity, deformation and various types of faulting mechanisms and volcanic activities (Yolsal-Cevikbilien and Taymaz, 2012). Ten per cent of the world's tsunamic activities were found to have happened in the Mediterranean Sea (UNESCO, 2011).

Most of the coastal communities of the Mediterranean are exposed to a tsunami threat within a time range from, a few minutes to a maximum of two to three hours. Figure 2, reports on the most tsunamigenic sources in the Mediterranean with direct impact on the Egyptian coasts. The Mediterranean is at a much higher risk than previously expressed, a major earthquake that struck hundreds of years ago triggering a huge tsunami that wiped out Crete lifting up 360 km of the coast line of western Crete aprox. 10 m a.s.l., tilting Crete to the north east, and devastated far coastal regions of Egypt, and Sicily. Studies estimated that similar earthquakes could strike in a return period of 800 years as stresses and strains build up along a period of time. According to the calculated return period, the east Mediterranean might encounter a devastating destructive earthquake at anytime. Add to that over the past century and precisely the last 40 years most of the coastal areas of the Mediterranean have encountered vast unsustainable forms of development (Kelman, 2006). Preparedness and mitigations measures are now a must to reduce, in a reasonable manner, the effects of being unexpectedly caught or exposed to a tsunami wave.

Knowledge of the past catastrophic affect of the Sumatra tsunami has driven the European Commission and the UNESCO to make a commitment to the scientific community by the creation of the North East Atlantic and Mediterranean Tsunami Warning System (NEAMTWS) (Olivieri and Scognamiglio, 2007). Its main aim

would be to provide the adequate warning system and facilities necessary to mitigate a tsunami's impact on coastal communities of the European and North Africa countries.



Figure 2. Mediterranean Tsunamigenic Sources with possible impact on Alexandria City

The NESMTWS project was set to be affectively fully operational by 2011. Cities and communities in hazard exposed countries through the regional NESMTWS project should be prepared to the extent that the (UNESCO, 2011):

- Stakeholders, political and decision makers have been forced to consider the tsunami hazard as a reality or a factor for coastal zone managements and development;
- Local communities are already aware of the local nature hazard and limits of inundation to be expected from credible tsunami scenarios on their coasts;
- Local communities are aware of their vulnerabilities and risks in respects of tsunami inundation; and
- Having emergency plans and procedures in place to deal with evacuation, shelters, vertical and horizontal shed points and safeguarding of life services in the event of an inundation.

One of the main reasons that motivated the author to conduct such a study is the similarity of the issue of Indonesia to that of Egypt. In Indonesia the government was aware of the threat and the requirement to raise funds for research and mitigation planning measure for coastal zones; however, due to the country's daily economic requirements they decided that the tsunami threat is not a major threat compared to other priorities. A decision that has lead to the world's most devastating natural human catastrophe of the loss of around 300 thousand lives in addition to materialistic losses estimated to be over 16 billion dollars. In Egypt the situation is similar, although the country is a delegate within the NESMTWS, having a Tsunami National Contact (TNC) represented by the National institute of Oceanography and Fisheries (NIOF) and having also an assigned Tsunami Watching Focal Point (TWFP) represented by the National Research Institute of Astronomy and Geophysics (NRIAG). Nevertheless, none of the above four crucial tsunami mitigation measures has been achieved yet.

4. Egypt history and future of tsunamigenic event

The East Mediterranean is regarded as the most hazardous seismic region of the Mediterranean Sea, classified by Yolsal-Cevikbilen and Taymaz (2012) to include three major seismic fault sources: "1. focal mechanisms of the earthquakes exhibiting E-W extension within the overriding Aegean plate; 2. earthquakes related to the Africa-Aegean convergence; and 3. focal mechanisms of earthquakes lying within the sub-ducting African plate" (Yolsal-Cevikbilen and Taymaz, 2012:61). Egypt is located only 500 km from the Hellenic arc, one of the most active seismic devastating tsunamigenic sources of the Mediterranean Sea. The Hellenic subduction zone poses a viable threat on all the east coasts of the Mediterranean including Crete, Rhodes islands, SW Turkey, Cyprus and Nile Delta Egypt regions (Yolsal-Cevikbilen and Taymaz, 2012), causing around 10% of the tsunamigenic activities in the Mediterranean. Studies estimated a return period of around 800 years for stress and strain to build up causing a cataclysmic tsunamigenic event. A recent study by Yolsal-Cevikbilen and Taymaz (2012) also reveals that the tsunami waves of the East Mediterranean Sea to have non-uniform wave propagation correlating to the complex sea bottom and coastal bathymetry (Yolsal-Cevikbilen and Taymaz, 2012).

4.1. Egyptian catastrophic historical tsunami's events

Identifying Egypt as a country with a possible tsunami threat is confirmed based on the historical search of the tsunami events on the Egyptian Coasts. Conducting a profound research of the literature and the available data banks, two catastrophic historical tsunami events were recorded on Egypt they are: 1. the 21 of July 365 AD tsunami; and 2. the 8 of August 1303 tsunami.

4.1.1. The 21 of July 365 AD Tsunami

The documented tsunamigenic source was an earthquake that occurred on the western Hellenic arc, SW of Crete. The magnitude was estimated at 8.5 producing a significant landslide that lifted coastal areas of western Crete up to 9m high a.s.l. and caused heavy destruction to the whole of Crete (Yolsal-Cevikbilen and Taymaz, 2012; Flouri et al., 2013:4). Before the event the coastal areas of western Crete were rocky steep cliffs, following the seismic sequences a distribution of coastal lowland of up to 500 m wide of beaches appeared (Scheffers and Scheffers, 2007). Resulting from the seismic activities a destructive tsunami was generated that propagated reaching the coastal regions of Egypt. The tsunami arriving at Alexandria totally wiped out the city destroying it with recorded death casualties around 50, 000 people in Alexandria and the surrounding regions. It flooded most of the coastal regions of the Nile Delta and inundated in land for tens of kilometres (UNESCO, 2011; Stanley and Jorstad, 2005). The high rate of death can be explained as a result of several factors including the community's lack of tsunami knowledge where, as described, when the sea water retreated prior to the inundation people did not recognise what was going on and they wondered on the sea bed gathering fish and objects when they were suddenly attacked by the rush flow of water killing thousands. Archaeological excavation in 1995 discovered the ruins of the old city of Alexandria that was said to have completely disappeared following the 365 AD tsunami permanently changing the city's shoreline.

There is no precise recorded wave height or run up height on the coast of Alexandria; however, an estimation based on the documenting literature naming the wave as devastating, catastrophic and mega tsunami may give a scientific round-up estimation of the wave height to between 15 and 30 m high.

4.1.2. The 8 of August 1303 tsunami

The seismic activities of 8 August 1303 proved to be one of the best-documented events in the history of the Mediterranean (Yolsal-Cevikbilen and Taymaz, 2012; Ozel et al., 2011). An earthquake of a magnitude around eight and possible epicentre located near the eastern part of Crete occurred at a shallow focal depth at the eastern Hellenic arc. El-Sayed et al. (2000) put forward the best scientific explanation for the seismic activities of the event, being mainly composed of two different sources. The first event is an earthquake, mentioned above, in the Hellenic arc felt in Alexandria after 30 seconds (Hamouda, 2006) destroying high, poor quality buildings, causing difficulty of movement for a long time, killing a number of people, partially collapsing the ancient lighthouse, and it shook the Nile Delta alarming the people there. The second event is a local earthquake occurring to the southeast of Cairo more likely beneath the Nile River causing the water to shake badly in the river, boats thrown on the river banks and sever damage to buildings in the Nile Valley with no reported life casualties (El-Sayed et al., 2000).

The first event, which is an earthquake in the eastern Hellenic arc, generated a tsunami that propagated to the coasts of a number of countries among them are: Crete sweeping the city and killing all its inhabitants, Acre where the sea receded about 12.8 km was flooded by huge devastating waves, and finally Alexandria at the coast of Egypt where the sea first receded then rushed in crashing into the city and flooding it till the ancient city walls of Alexandria. The tsunami arrived within 35-45 min with an estimated run up height of 9 m and an average height between 2-7 m along the rest of the Egyptian coasts (Hamouda, 2006:42).

4.2. Alexandria and the future hazard of a tsunami's events

Alexandria is the second capital of Egypt and the first port of the country accommodating around 6 million people as permanent residence and hosting around a million national guests during the summer season. Also, it contains about 40% of the national industry and 50% of the petroleum industry (Frihy et al., 1996). The city is between 2 ridges nearly parallel to the sea shore with a maximum elevation of 12 m. Most of the city lies on low land only 1-2 m a.s.l. with many residential areas below sea level. The coast of the city has been extended as a result of unsustainable coastal development to reach around 50 km nowadays. Most of the city is developed in the narrow coastal areas. The city suffers very poor building quality, especially in the low income low lying residential districts. Every year the city witnesses the collapse of several buildings as a result of accumulated rain water and high underground water levels with a very limited capacity sewage and stream water drainage system.

Natural disaster destructions usually depend on the ability of humans to interact with natural forces. Therefore economical, social and educational factors are major determinants of the degree of hazard the community is exposed too. The city's local community, in its existing context, is below any requested interaction level of the various stated dimensions. Add to that the hazardous fact of the city, Figure 2, lying

between two fault lines, the Suez-Cairo-Alexandria Line and the Qattara-Eratosthenes Line (Hamouda, 2006; Papadopoulos and Fokaefs, 2005; Eckert et al., 2012), proves the great vulnerability and community risk level that the city is to face if being exposed to a tsunami hazard. Most of the tsunami research studies conducted on the city confirmed such hazardous situation and confirmed a return period (seismic stress building period) of a major tsunami occurring in the Hellenic arc propagating to the city of over a period of 800 years. In simple words the city is considered to have a high potential of encountering a tsunami at any time. The question here is: is the city ready to deal with such an event or simply millions of people will be left uneducated to be caught unaware by a tsunami wave? The answer is very simply the city is not ready, although the country is involved in the NESMTWS project, as previously explained, none of the four basic requirements of the project, previously stated, have been fulfilled although the set fully operational date of 2011 is overdue. Instead of being aware of such risk the country spent around 16 million dollars on researchers dealing with the impact of the rise of sea water on the coastal cities of the Nile delta regions reaching a final conclusion that proper coastal management is required. Another catastrophic project proposed to save the beaches of Alexandria city, with a capital of 170 million dollars, by building sea breakers with a total length of 7 km on three successive stages. Such sea breakers' construction stones would provide any tsunami with huge disastrous debris that would increase the vulnerability of the coastal buildings.

To conclude there is a lot to be done in the city to mitigate the effect and the hazard of any future tsunami event. What is obvious is that the situation is ignored and the city is ready to offer the world a new devastating event.

5. Tsunami hazard analysis and risk assessment planning model

The precious seven principles defined by Eisner for mitigation of tsunami impacts on coastal communities', stated early in the research, all emphasise the importance of the planning discipline's role in preparedness and mitigation for tsunami impact on coastal communities. In order to effectively apply any planning mitigation measures and contingency planning, the ability to define the tsunami hazard areas and risk assessment is required. The paper proposed an effective tsunami hazard analysis and risk assessment planning model based on computerised geographical information system (GIS). The model is composed of four stages. The first stage is the mandatory stage where the GIS and dataset of the coastal community is to be developed. The second stage is to define and compute the expected height of the tsunamic event. The third stage is to populate the expected tsunami inundation maps and hazard analysis regions and levels (based on the flood management scale developed in the PRIVEW project, 2005). The final stage qualitatively defined the tsunami risk assessment on physical properties: the built environment. The paper adopted, added and modified the tsunami risk model on physical properties presented by Jelinek et al. (2009) and Eckert et al. (2012) as the theoretical base for conducting this analytical stage based on which 5 level allocation themes were used to define the hazard, vulnerability and risk of the case study's physical properties.

5.1. Building a credible GIS dataset: First stage

The success of the model and the credibility of its results are based on the ability to build an efficient and accurate GIS for the impact coastal area. The most accurate GIS model of an area is built based on field survey data. If obtaining field survey data is not feasible, then remote sensing data can be used for driving spatial information to assess physical vulnerability; this is carried out by utilising satellite image data. One final requirement of the built model is its ability to present a three dimensional physical surface model. The most accurate model is that built on topographic maps of the area. If those maps were not available, commercial satellite sensors, such as IKONOS or QuickBird, offer the possibility of presenting this three dimensional physical surface model based on the remote sensing technology.

5.2. Tsunami event modeling: Second stage

For expressing the potential of a tsunami impact there are two approaches used: the 'Probabilistic Tsunami Hazard Analysis' and the 'Scenario Based Tsunami Hazard Analysis.' The target to be achieved through this stage is to predict and define the expected tsunami's maximum run-up height on the inundation region or coastal area (Flouri et al., 2013). The credibility of each approach depends on the characteristics of the tsunami source, depth of the sea in the generation area, the factors of the propagation process, the bathymetry of the impact area and the uncertainties in these parameters (Geist and Parsons, 2009; Lovholt et al., 2012; UNESCO, 2011).

5.3. The tsunami hazard analysis and inundation maps: Third stage

The tsunami inundation maps are a simple model for populating and defining the tsunami hazard zones and regions. For generating tsunami hazard maps a wave, with the defined scenario height, is allowed to flow inland until it reaches an elevation equal to the wave start height (Eckert et al., 2012). Therefore, an advanced inundation map, setting the hazard areas and zones of the tsunami prone areas and regions, can be obtained based on the estimated possible impact of the water height on land elevation. The flood Magnitude scale, which predicts the expected damage on infrastructure in relation to the water level, was developed and used in the PREVIEW project on buildings (Eckert et al., 2012). According to this scale the expected damage to buildings caused by a flash flood is: for water level on buildings less than 0.5 m very low hazard (VL); over 0.5 m to 1m is low (L) hazard with limited damage to buildings; over 1m up-till 1.5m medium (M) hazard danger and destruction for masonry wall bearing buildings and concrete buildings with surface foundations; from over 1.5m to 2m high (H) hazard destruction for skeleton buildings with deep foundations; over 2m very high (VH) hazard dangerous for all. The author added the safe level (S) for those dry areas which will not be affected by the tsunami, Table 1 (after Eckert et al., 2012).

5.4. Tsunami risk assessment: Final stage

Risk management is an important issue in modern societies. Risk planning schemes and tsunami mitigation measures were introduced by industrial countries, such as Japan and the USA, that have been affected by

earlier tsunamis. It is a complex process of quantifying probabilities or a chain of probabilities. Risk levels can be calculated for populations, built environment or the natural environment. For this paper, risk assessment is carried out for the built environment (physical properties) calculated by the equation:

$$\text{Risk} = \text{Hazard} * \text{Vulnerability}$$

where *Hazard* is the process or a phenomenon that might occur with a certain probability and causes a damaging effect, and *Vulnerability* is a condition of process resulting from physical, social economic and environmental factors that determine the likelihood and scale of damage from the impact of a given hazard (Coachard et al, 2008:6).

The paper adopted and modified the tsunami risk model on physical properties presented by Jelinek et al. (2009) and Eckert et al. (2012) as an applicable tested approach which bears the ability to classify the risk of the coastal communities at tsunami prone areas.

5.4.1. Hazard (assessment for Buildings in tsunami prone areas)

The hazard levels are defined for the tsunami impact areas based on the inundation and hazard maps, showing the wave run-up height, populated in the model's second stage. The assessment uses the flood magnitude scale developed by the PREVIEW project, described earlier and presented in Table 1.

Table 1. Flood magnitude scale developed by the PREVIEW project

Hazard Classes	Hazard Category	Water Height (m)	Description
Safe (S)	-	Zero	Dry Land levels, no inundation or flooding
Very Low (VL)	1	$H \leq 0.5$	No damage
Low (L)	2	$0.5 < h \leq 1.0$	Limited damage
Medium (M)	3	$1.0 < h \leq 1.5$	Damage to light constructions and wall bearing buildings
High (H)	4	$1.5 < h \leq 2.0$	Damage to concrete buildings with shallow foundations
Very High (VH)	5	$2.0 < h \leq 3.0$	Damage to all buildings with a Hazard value 5

(Source: author based on flash-flood magnitude scale of the PREVIEW project and Eckert at el., 2012)

5.4.2. Vulnerability (assessment for Buildings in tsunami prone areas)

The probability of building damage is intimately related to vulnerability. Vulnerability can be calculated for buildings based on a number of physical, social and economic parameters that can influence the level of the potential damage. The credibility of the vulnerability analysis results is a factor of the number of utilised parameters and the accuracy of the parameters' data (Camilleri, 2006).

5.4.3. Risk (assessment for Buildings in tsunami prone areas)

The risk assessment is the final outcome of the model's second stage, defining the risk level of buildings (built environment) based on the outputs of the hazard and vulnerability analysis. The hazard levels were assigned according to findings of the hazard assessments, while the vulnerability values were assigned according to the number of utilised parameters available for the study area through the developed GIS package. The final tsunami risk on the built environment was computed in a quantitative way utilising the risk matrix, with 5 x 5 classes relating hazard and vulnerability, with a risk range: Very Low (=1); Low (2-4); Medium (5-9); High (10-16); Very High (17-25) (Jelinek et al., 2009: 32).

6. Strategic tsunami risk assessment for the city of Alexandria

The main goal of strategic tsunami risk management is sustainable risk reduction in coastal areas. Risk reduction is achieved through preventing people from being caught unaware by a tsunami wave. By careful mapping of potential hazard and risk areas risk reduction can be attained. Due to the changes in style of development, occupation, utilisation and accommodation of high density districts in low unprotected coastal areas over the past 40 years, the hazard degree among the Mediterranean coastal areas are highly devastating. The potential impacts of future tsunamis are expected to be even more devastating than in the past. In order to sustainably develop coastal cites there is a vital need to determine: the hazardous population zones and buildings, the vulnerable zones and districts and risk assessment concerning the number of death and injuries so that planners can initiate appropriate planning mitigation levels. Lately the city of Alexandria witnessed unsustainable development in most of its regions, which lead to the current situation where around 35% of the city's inhabitants are found to be living in slums located in low lying areas, some of which are even below sea level.

According to UNESCO (2011) "Much of the city's population, its buildings and its economy are vulnerable to major tsunamis through their exposure on low-lying coastal land as well as the challenges posed by the mass evacuation of such a densely populated inundation zones" (UNESCO, 2011). Add to that the fact that based on a number of tsunami experts the calculation of the return period of the Hellenic arc (main tsunami generation source with impact on the city) shows that the city is vulnerable to a tsunami attack at any time (UNESCO, 2011; Hamouda, 2006; Eckert et al., 2012). Figure 3 presents a base map for Alexandria city's main districts and municipalities boundaries.

6.1. Building the GIS model for Alexandria city

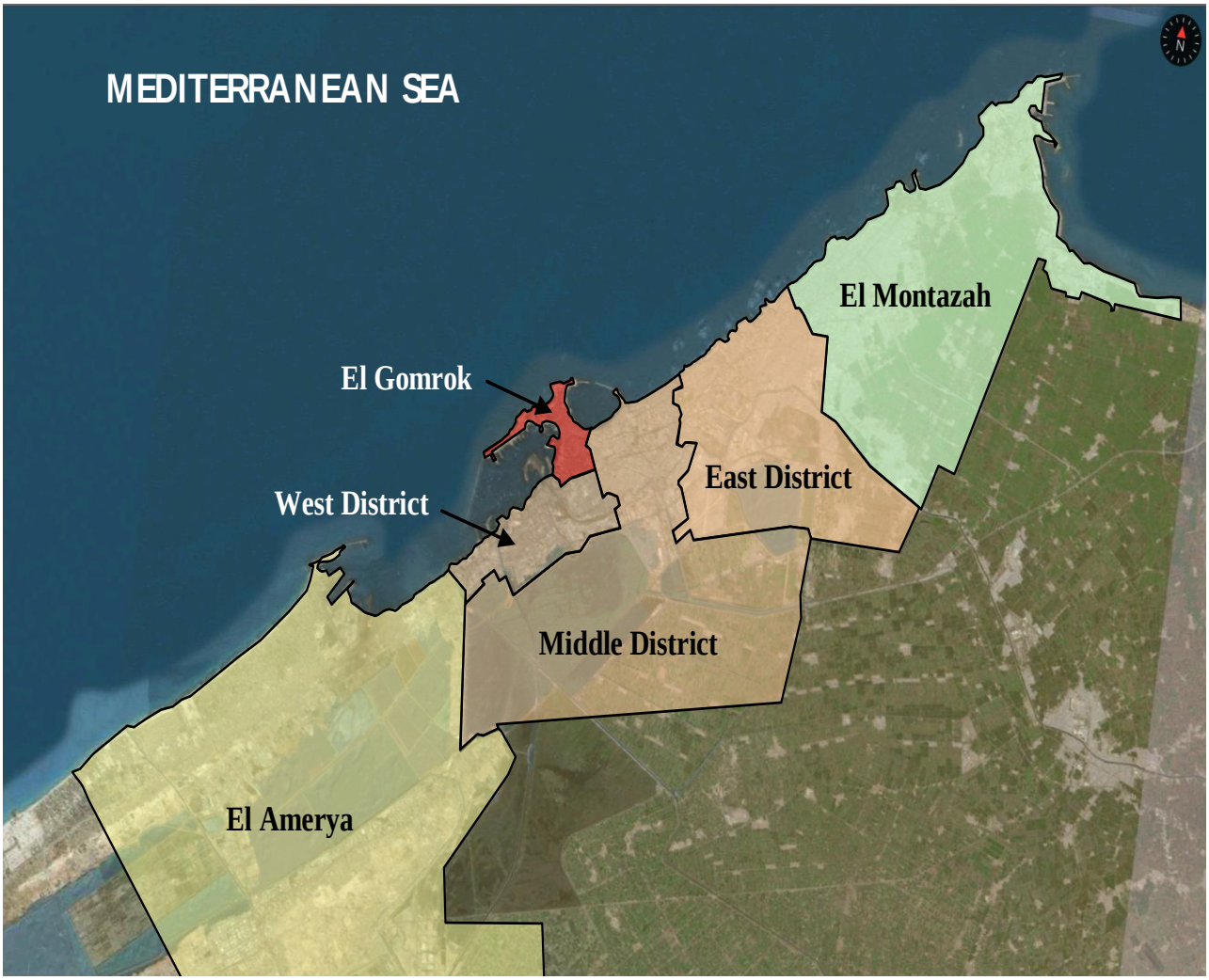


Figure 3. Alexandria City Main Districts (Source: author based on GOPP project GIS Dataset)

The GIS database used in building that model is provided from the Egyptian Ministry of Housing through the General Organisation for Physical Planning (GOPP). The GOPP is carrying out a leading program that enables the provision of an updated database for most of the Egyptian cities. The GOPP provides a complete GIS database for the city of Alexandria based on a field survey conducted only a couple of years ago, which represents high credibility for the model findings and results. Also the dimensional surface 3D model of the data was built by a GIS expert based on topographic survey maps of the city. This model was revised by the author and a GIS expert through comparing it to a VHR satellite remote sensing dataset and digital surface model, credibility is estimated to be around 80%.

6.2. Tsunami event modelling (stage 1)

The paper utilises the event modelling built up by Hamouda (2006) for future tsunami events that attack Alexandria propagating from the eastern Hellenic arc. The expected time of tsunami arriving was found to be between 35-45 min with an expected computed run-up height of 9 m (Hamouda, 2006). Eckert et al. (2012) defined the 5 m scenario as possible but unlikely, while the 9 m scenario as unlikely (Eckert et al., 2012). Accordingly based on the scenario based model we have 2 expected scenarios for tsunamis at Alexandria which are the 5m and 9m scenarios. The author, utilising the probabilistic modelling, based on the analysis of the historical literature review of tsunami events, proposed a third scenario of 20 m based on the generation of the 'worst case scenario' model (Alvarez-Gomez et al, 2011; Lovholt et al., 2012). Concluding, the paper is to conduct a three scenario comparative analytical study on the coastal city of Alexandria assessing the 5m, 9m and 20m scenarios.

6.3. Alexandria tsunami hazard analysis and inundation map (stage 2)

Figure 4 presents the various tsunami scenario's inundation maps for the city of Alexandria. Hazard level analyses were conducted for the three scenarios based on the flood management scale

Fig. 4.1 Inundation Levels Analysis for the 5 m Scenario

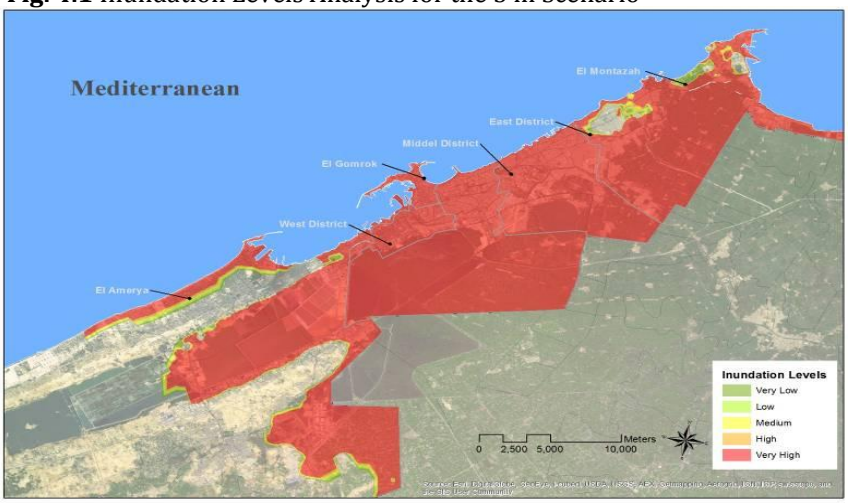


Fig. 4.2 Inundation Levels Analysis for the 9 m Scenario

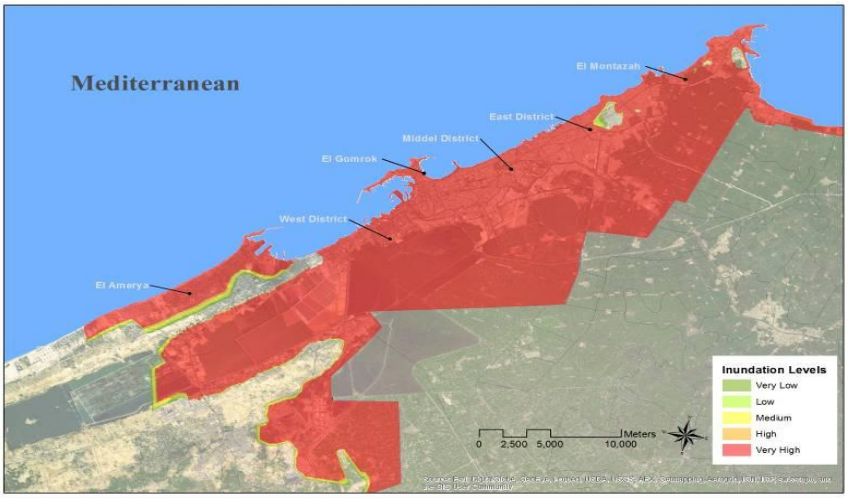


Fig. 4.3 Inundation Levels Analysis for the 20 m Scenario

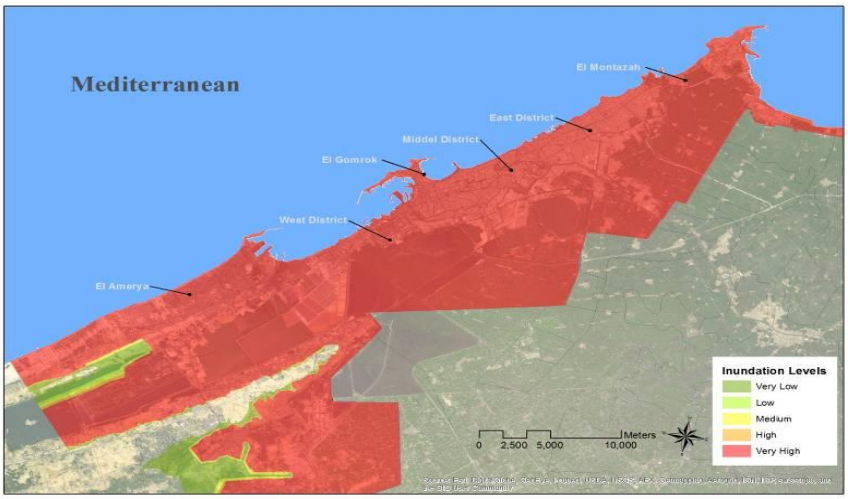


Figure 4. Alexandria City Inundation Levels Analysis (Source: author based on GIS spatial analysis)

and hazard analysis presented by the PREVIEW project (2005), table 1. As shown in Figure 4 around 54.8% of the city has been inundated by the 5 m scenario, almost 59.3% of the city is flooded in the 9 m scenario and 86.8% flooded in the 20m scenario.

6.4. Alexandria tsunami risk assessment

6.4.1. Alexandria buildings' hazard assessment

The hazard assessment for the buildings under the three scenarios, as shown in Figure 5, are obtained based on the spatial analysis provided in the previous stage, transferred and applied on the scale of the buildings. The water height recorded at each building was determined based on the GIS model and the 3D elevation capacity of the model built based on the topographic survey maps of the city. The analysis was carried out using the 5 identified hazard levels presented in table 1, in addition to the safe level (S) representing buildings above inundation levels. The percentages of buildings' hazard levels calculated for the three scenarios were as follows:

- for the 5m scenario (VH 50%, H 2%, M 1%, L 1%, VL 1%, S 45%)
- for the 9m scenario (VH 55%, H 1%, M 1 %, L 1%, VL 1%, S 41%)
- for the 20m scenario (VH 76.%, H 1%, M 1%, L 1%, VL 9%, S13%)

(Source: author based on GIS spatial analysis findings and results)

Fig. 5.1 Buildings Hazard Levels Analysis for the 5 m Scenario

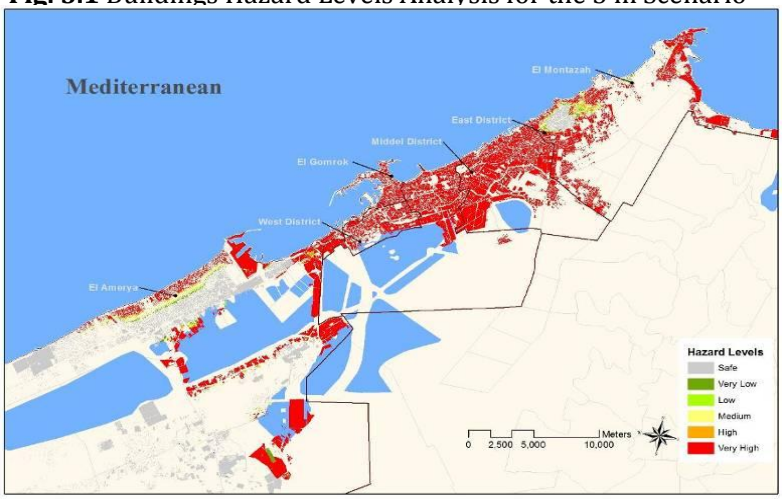


Fig. 5.2 Buildings Hazard Levels Analysis for the 9 m Scenario

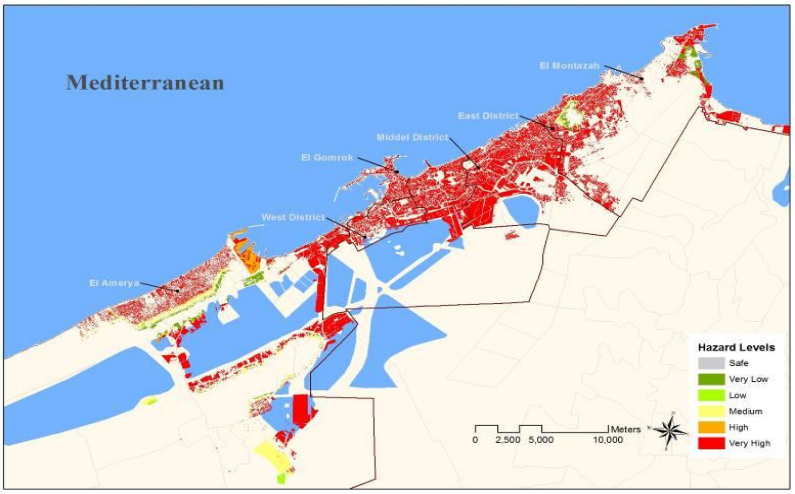


Fig. 5.3 Buildings Hazard Levels Analysis for the 20 m Scenario

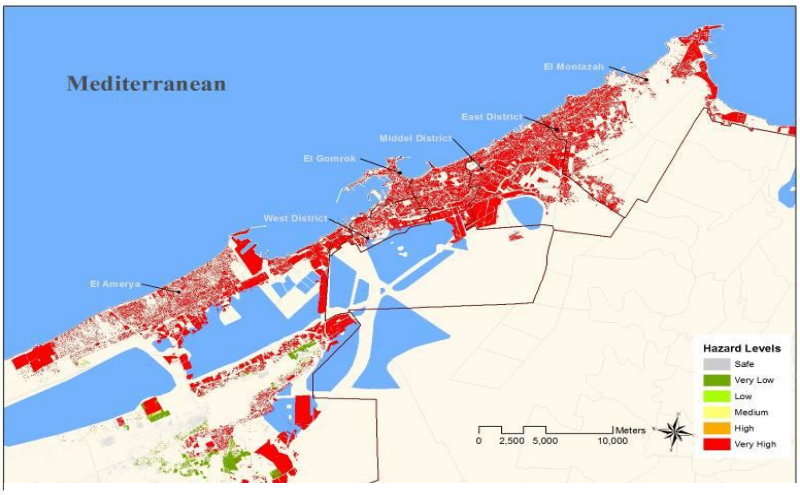


Figure 5. Alexandria City Physical Properties Hazard Levels Assessment (Source: author based on GIS spatial analysis)

6.4.2. Alexandria Buildings Vulnerability Assessment

As brought forward previously, the ability to conduct a valid and reliable vulnerability assessment for buildings in tsunami prone areas is determined based on the ability to encounter as much assessment parameters as possible with reliable data sets that are mainly based on surveys. The paper based its spatial geographic analysis on a provided dataset from the GOPP in Egypt with an assumed estimated degree of certainty, to be over 90%, as it is mostly based on recent field survey. Table 2, presents the assessment parameters for the building's vulnerability calculation and class allocation scheme levels (Low: 1, Medium: 2, High: 3, and V. High: 4).

Table 2. Selected parameters for the physical vulnerability assessment and class allocation scheme

Parameter		Vulnerability Assessment and Class Value				Reference and data source
		Low (1)	Med (2)	High (3)	V High (4)	
P1	Buildings construction Type	skeleton	--	Bearing Walls	Others	GOPP
P2	Buildings Conditions	Good	Medium	Low	--	GOPP
P3	Number of Floors	>12	3-12	2	1	GOPP
P4	Build. Elevation (m)	>10	>5- 10	2-5	<2	after Eckert, 2012
P5	Shore line Distance (m)	>400	>200- 400	100-200	<100	after Eckert, 2012
P6	Social Classes: land-prices pound/m2	>3000	1000-3000	<1000		author based on GOPP

(Source: author based on Jelinek et al., 2009; Eckert et al., 2012)

The author, based on planning and architectural expertise has reclassified some of the parameters and the allocation theme levels to suit the local buildings' construction and planning conditions of Alexandria city. Also, an added parameter with the ability of measuring the social and cultural level of the community was utilised. The author proposed a level named, very high level, which was added to the levelling scheme. A final vulnerability value is summed for

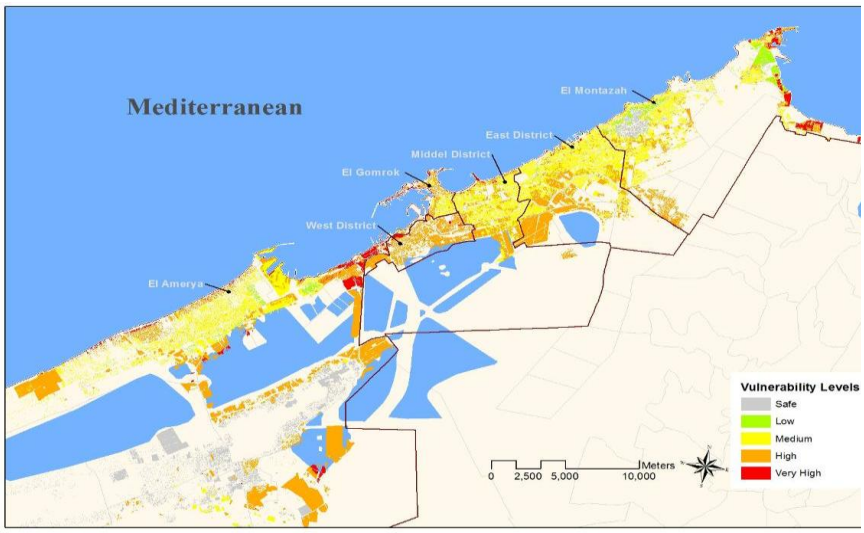


Figure 6. Alexandria City Physical Properties Vulnerability Assessment (Source: author based on GIS spatial analysis)

each building based on the achieved classification level on each parameter. As presented in Table 2, having 6 identified parameters with a possible value varying between 1-4 gives a possible final building vulnerability calculated value between a minimum of 6 and maximum of 24. The final building vulnerability class is defined based on the calculated vulnerability score for each building on a vulnerability scale: Very Low (=1); Low (7-9); Medium (10-12); High (13-15); Very High (16-24).

Figure 6 reports on the vulnerability spatial analysis assessment 5-levels for the buildings of the city of Alexandria. The percentage of the city building's vulnerability levels calculated were as follows:

- Buildings Vulnerability Classes: (VH 12%, H 32%, M 54 %, L 2%, VL 0%).

6.4.3. Alexandria buildings final risk assessment

The risk assessment is the final result of the risk equation, calculated as the product of the equation's other variables: hazard and vulnerability. The final tsunami risk on buildings was qualitatively estimated and classified into levels using the predefined risk matrix (after Jelinek et al., 2009; Eckert et al., 2012). Figure 7 presents the spatial geographic analysis of the risk assessment results for the city of Alexandria on the three estimated tsunami scenarios. The risk assessment is among the most important outcomes of the model upon which the buildings being classified

Fig. 7.1 Buildings Risk Assessments for the 5 m Scenario

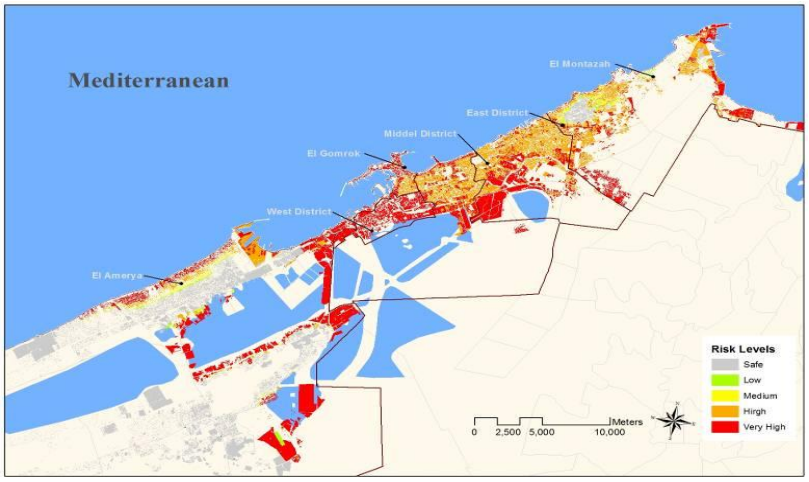


Fig. 7.2 Buildings Risk Assessments for the 9 m Scenario

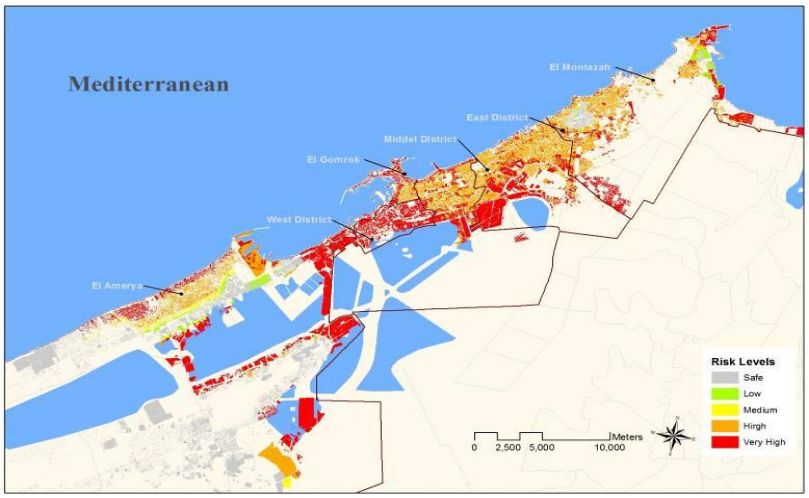


Fig. 7.3 Buildings Risk Assessments for the 20 m Scenario

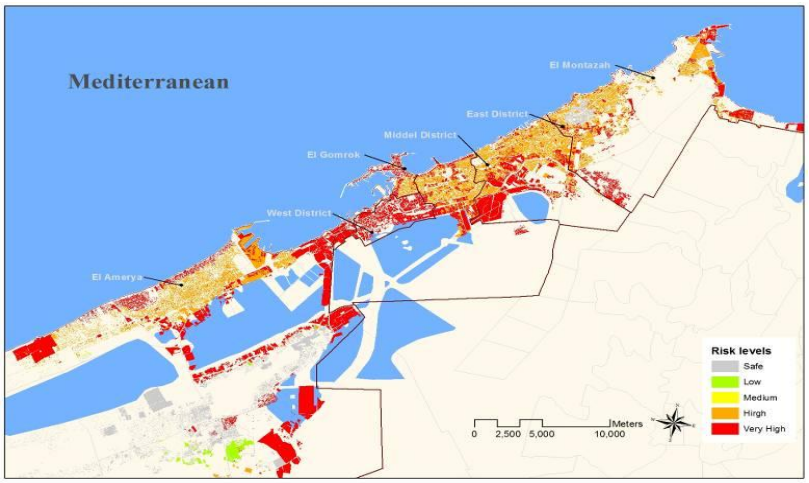
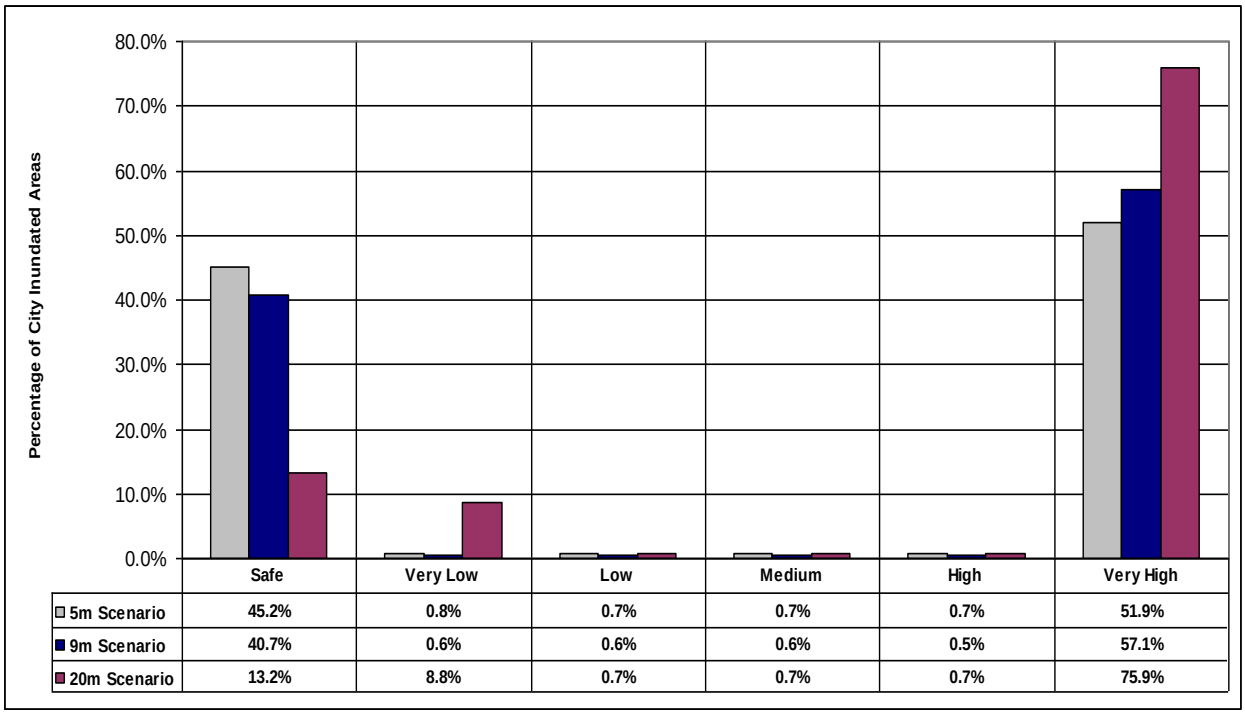


Figure 7. Alexandria City Physical Properties Risk Levels Assessment (Source: author based on GIS spatial analysis)

as VH and H, are expected to be collapsing buildings, thus constituting a direct threat for the lives' of their inhabitants. As shown in Figure 7 starting from the 5m scenario most of the city's buildings are in the H and VH risk categories; this is due to the fact that most of the city lies in low-lying lands only 1 and 2 meters a.s.l. However, the author, based on architectural, construction and soil conditions, has decided to consider the VH class only as collapsing buildings. The VH collapsing buildings would be used for estimating the human casualties and materialistic losses among the 3 tsunami scenarios.

7. Findings and discussion

Figure 8 presents the geographical spatial analysis findings regarding the inundated hazard zones and regions, stage 3, for the three scenarios. The figure presents areas of hazard levels M, H and VH as potential life threatening zones and regions. As shown in Figure 8, according to the 5 m scenario the city's buildings only 1-2 m a.s.l and the other areas below sea level were threatened by being completely wiped out. Under the 9 m scenario most of the city is to suffer being high hazard areas with an average flooding water column of over 6m over most of the city's areas. Under the 20 m scenario the situation is catastrophic where most of the city would be completely flooded with a water column of over 15 m height, triggering the estimated need of completely evacuating the city to nearby high land areas.



	Safe	Very Low	Low	Medium	High	Very High
5m Scenario	45.2%	0.8%	0.7%	0.7%	0.7%	51.9%
9m Scenario	40.7%	0.6%	0.6%	0.6%	0.5%	57.1%
20m Scenario	13.2%	8.8%	0.7%	0.7%	0.7%	75.9%

Figure 8. Inundation Hazard Scenarios Comparative analysis for Alexandria City (Source: author based on GIS spatial analysis)

Figure 9 represents a compound comparative graph for the analytical findings of the risk assessment for the three scenarios. As presented, the percentage of the buildings' risk assessments classified as H and VH

tsunami risk were as follows: for the 5m scenario 52%; for the 9m scenario 54%; for the 20m scenario 81% of the city's total buildings.

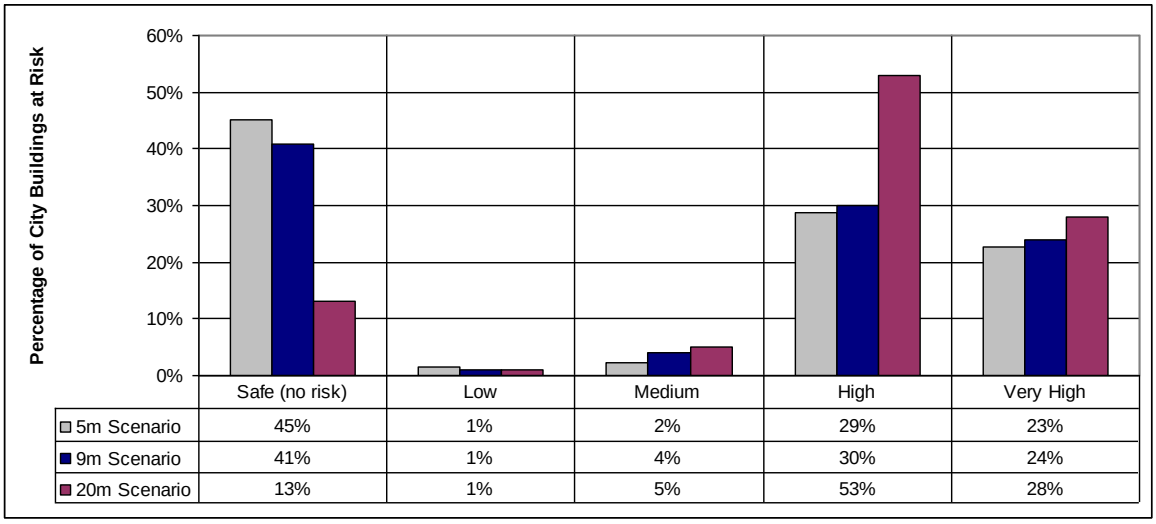


Figure 9. City Buildings Scenarios Risk Assessment Comparative analysis (Source: author based on GIS spatial analysis)

The risk assessment findings can be used to calculate the expected human losses among the three scenarios. Although the VH and H risk buildings are expected/potential collapsing buildings the paper excluded the H and considered the VH risk level only to be collapsing. This assumption was made on the bases that the soil of Alexandria is mainly stones that withhold a higher expected potential of resistance to the tsunami inundation force. The numbers of residential buildings classified by the assessment as VH were calculated and categorized into districts for each scenario. Using the case study GIS dataset and the identified numbers of VH risk level buildings, the number of human casualties was calculated as follows: no. of buildings × relevant no. of floors × average no. of units in each building (based on limited field survey for each district) × average no. of

Fig. 10.1 Calculated Human Casualties

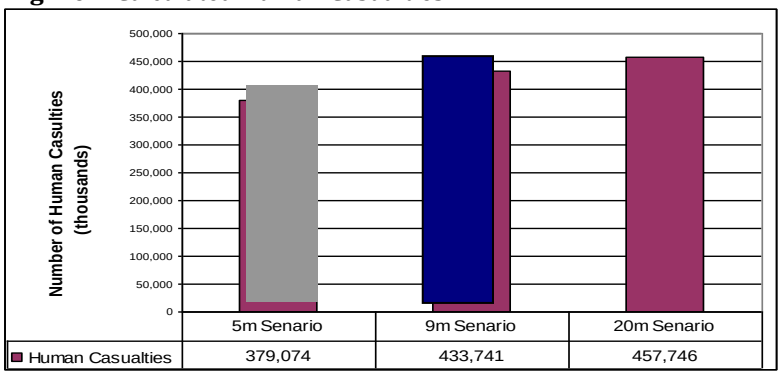


Fig. 10.2 Calculated Materialistic Losses

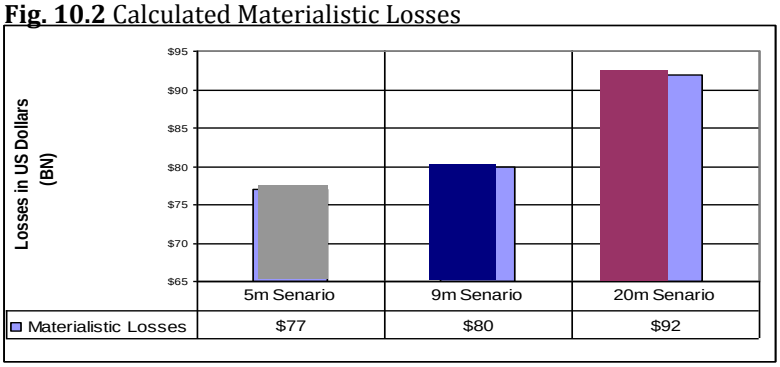


Figure 10. Alexandria City Casualties and Losses for the Various Scenarios (Source: author based on GIS spatial analysis)

family members (based on the 2006 census).

Finally, one of the important outcomes of the model is the ability to estimate the economic loss among the city's built environment; roads, infrastructure and buildings. The economic losses derived by a tsunami can be used as a powerful tool to grasp the attention of politicians and decision makers to start efficient actions regarding the threat of tsunamis on the Egyptian coastal communities.

The achievement of such estimation is to be based upon the findings of the models' third and fourth stages. Based on the inundation hazard analysis the percentage of the city's' roads and infrastructure under the VH hazard level for the three scenarios are defined. VH hazard level areas are areas of potential damage and destruction, by multiplying these areas with the corresponding average cost/m^2 a total amount of materialistic losses could be calculated. For the buildings, the VH risk level for the three scenarios, findings of stage four, were utilised as well as information from the GIS dataset regarding the types, areas and number of floors; using this information a total estimation for the costs of the buildings can be calculated. The calculation is based on the construction price values and rates in Egypt in 2013. Figure 10 reports on the expected human casualties and materialistic losses among the three estimated tsunami scenarios of Alexandria city. As presented in Figure 10 the human casualties were around 379 thousand deaths for the 5m scenario, 434 thousand deaths for the 9m scenario, and half a million for the 20m scenario. For the economic losses, the numbers were as follows $77, $80 and $92 billion among the 3 scenarios respectively.

The paper utilised Papadopoulos and Fokaefs (2005) 12 point tsunami intensity scale's impact on human, objects, vessels, nature and buildings, and the findings and analysis of the model to predict the tsunamis' intensity on Alexandria city. Regarding the 5m tsunami scenario it is expected to achieve an impact between (8) Heavily Damaging and (9) Destructive (with a calculated 52% of the city's total buildings classified as H and VH tsunami risk buildings). The second 9m tsunami scenario is expected to have an impact between (10) Very Destructive and (11) Devastating (with a calculated 54% of the city's total buildings classified as H and VH tsunami risk buildings and an inundation water height of around 6m in most of the city). The third 20 m scenario is expected to have an impact of (12) Very Devastating, with a calculated 81% of the city's total buildings classified as H and VH tsunami risk buildings and an inundation water height of over 15m in most of the city. The achieved scales are scored bearing in mind the community's limited education of tsunami, the demonstrated building quality of most of the city buildings and the expected failure of the government to plan and implement any warning or evacuation emergency plan.

When speaking about tsunami and Egypt, if we stop for a minute and try to ask citizens: what is a tsunami? When and how it occurs? Do you think that Egypt is under a tsunami threat? Are we ready to deal with a tsunami attack? I can predict that over 90% of the Egyptian people will lack the basic knowledge regarding this phenomenon; even those who are aware of the tsunami phenomenon do not think that Egypt is hazard prone. For those who live in tsunami hazard areas, coastal communities, if we can say that they do know what a tsunami is, they lack the knowledge to deal with it. The situation in Egypt is similar to that of India and Indonesia where although the tsunami risk was acknowledged nothing was done because other priorities called for more immediate action. However, that is based on another assumption which is that the Egyptian Government is aware of the threat in the first place. Government awareness is a fact since Egypt has

TNP and TWFP national representatives in the NEAMTWS as of 17 November 2011. Although Egypt is a member of the NESMTWS project, none of the project mitigation measures have been implemented. It has to be noted that dealing with a tsunami event is not a decision to be taken. Even if we have studies that implemented the appropriate hazard analysis and warning systems, still there is a lot to be done. Successful warning systems require investments in a long-term ongoing process including planning, education, research and public awareness.

8. Conclusion

The paper presented a practical model for strategic tsunami hazard analysis and risk assessment of coastal communities and regions in tsunami prone areas. The model was tested through a practical analytical study applied on the city of Alexandria as a case study. The model is composed of four stages; the first stage is the mandatory stage (building the GIS for the study area); the second stage predicts the expected tsunami scenarios and maximum wave heights. The third stage populates the tsunami inundation maps and hazard analysis, defining and classifying hazard flood zones. The final stage qualitatively defined the tsunami risk assessment on physical properties, based on five level allocation themes. Among the most important findings of the model are its ability to populate an estimation of the human casualties and materialistic losses of a tsunami prone coastal community. Such result would grasp the attention of politicians, decision makers and most important of all the local communities to initiate the appropriate tsunami mitigation measures.

The findings of the model can also be utilised by sustainable development planners of coastal areas. The ability to identify the people at risk would allow planners to take precautions and plan sustainable coastal communities, also planning for emergency/ disaster evacuation plans and strategies would be possible. Long term and short term planning mitigation measures for reducing risk and building vulnerability could be carried out. The field of tsunami hazard assessment and planning measures has to be identified as a research gap with high and urgent research priority, especially in developing countries with dense populations and exposed coastal communities such as Egypt. Planning, Urban Design and Architecture disciplines among others have to be encouraged to research and contribute in such an area for the sake of sustainable coastal communities' developments.

The paper, based on the findings of the spatial analysis of the various scenarios, figured out a deficiency in the model. The deficiency was the model's inability to sensitively measure the hazard of a tsunami on physical properties with a flood rate over 2m high. Two meters is the maximum scale adopted by the flash-flood magnitude scale and it posed a limitation. Such deficiency appears in the inability of the model to impose the impact of the hazard assessment factor on the various tsunami scenarios. In order to deal with such an issue a further classification of the VH level to sub-classes is required. This would offer the model with the required sensitivity for measuring the impact of the hazard assessment on the final risk assessment product. This adjustment is a proposed area for further studies.

Acknowledgements

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