



Tsunami risk assessment a mitigation planning tool

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Abstract

The risk assessment model has been considered lately as one of the most efficient approaches having the ability of quantifying probabilities or a chain of probabilities concerning natural hazards. Risk planning schemes and tsunami mitigation measures were introduced by the most technologically advanced countries that have been effected by earlier tsunamis. These nations have the required technologies and resources for applying advanced techniques for achieving the required tsunami mitigation plans. The authors, in a previous paper, invented a sustainable tsunami mitigation tool utilizing the risk assessment model; the tool was named 'Strategic Tsunami Risk Assessment and Planning Model' (STRAPM). The novelty of the tool was mainly based on the ability of having an efficient tsunami risk assessment mitigation planning tool that could be applied proficiently within the context and limitation of developing nations. The tool was designed to provide coastal communities, of developing countries, with an applicable proactive tool that would allow these communities to define tsunami risk zones and buildings; thus having the ability to initiate the appropriate mitigation planning and evacuation plans. Applying the STRAPM has proved the tool's efficiency; however, a major deficiency has been noticed. Thus the authors aim, through this paper, to present a required refinement and to practically reexamine the efficiency of the STRAPM.

Keywords: Tsunami; Risk Assessment; Mitigation Planning; Mitigation Tools

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1. Introduction

Tsunamis have been identified since the famous catastrophic 2004 incident of the 'Boxing Day' among the most hazardous natural phenomena of the world (Leone et al., 2011; Cochard et al., 2008). In a few minutes the world witnessed the tragedy of over 300 thousand human casualties and materialistic losses worth billions and billions of dollars. Wave heights attacking coastal communities have varied from 20m to 50m with speeds reaching over 800 km/hr causing inundation depth for several kilometers onshore. The waves left over 700 thousand people homeless, it destroyed and eroded everything in its path resulting in thousands of barren coastal areas (Ozel et al., 2011; Pegnatelli et al., 2009; Paris et al., 2009). Figure 1 demonstrates the catastrophic effect that tsunamis could have on coastal areas.

Such an incident changed the consciousness of the world regarding the ways of treating and dealing with tsunamis as a natural phenomenon (Dawson and Stewart, 2007; Maouche et al., 2007; Camilleri, 2006). The world started to identify the phenomenon among the most hazardous phenomenon effecting the sustainability of the coastal communities all over the world (Todorovska and Trifunac, 2001; Lovholt et al., 2012). This incident started the real science of tsunami hazard and mitigation measures. Among one of the most important tsunami mitigation programs was the North East Atlantic and Mediterranean Tsunami Warning System (NEAMTWS program) (Olivieri and Scognamiglio, 2007) initiated by the UNESCO 2011. The UNESCO program made a commitment to the scientific and coastal communities of the world through creating the NEAMTWS to provide the adequate warning systems and facilities necessary to mitigate any tsunamic impact on the coastal communities of the European and the North African countries. The project's target date for fulfilling its objectives was 2011. Among the objectives of the project were that stakeholders, politicians and decision makers should be forced to consider the tsunami hazard as a reality or a factor for coastal zone management and development. Local communities should be aware of the nature hazard and limits of inundation to be expected from credible tsunami scenarios on their coasts and of their own vulnerabilities and risks in respects of tsunami inundation. 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 inundation is also among the UNESCOs objectives (UNESCO, 2011). As mentioned before the program should have fulfilled all its objectives by 2011, Egypt as a participant country in this program should by now have developed and implemented the appropriate mitigation plans for most of its coastal communities. None of the objectives have been achieved. Not only that, but the program has even failed to trigger awareness among the Egyptian local coastal communities. A situation similar to that of the Indonesian case, where the political administration of the country refused to understand and consider the real threat that a tsunami could have on the country (Pignatelli et al., 2009). Although there was an on going scientific community oriented program, the Indonesian political administration aborted the program on the premise of its unimportance and for the lack of funds and resources compared to other urgent issues. A few months later the country was attacked by the famous 2004 tsunami. Egypt nowadays is facing the exact same situation (Paris et al., 2009). The county's political and executive administrative bodies refuse to consider the threat that a tsunami could pose to the country. The threat is disregarded and seen as non-urgent in comparison to

what the country is currently facing from unstable economic, security and political situations; accordingly, the possibility of directing any funds to deal with such a situation is out of the question.



Figure 1. Tsunami's Impact on Coastal Communities (Source: satellite image)

The authors, in a previous paper (El-Barmlegly, 2014), invented a proactive tsunami mitigation planning tool that has the ability to be implemented within the limitations of developing countries. The tool can overcome the scientific gap and the funding problems by providing the required tsunami mitigation data with an acceptable efficiency rate (El-Barmlegly, 2014). The tool was named 'Strategic Tsunami Hazard Analysis and Risk Assessment Planning' (STRAPM). Applying the tool on a practical case study (Alexandria City) clarified a deficiency in the tool's scientific model that affects its credibility. Accordingly, the aim of this paper is to refine the STRAPM and retest it through a practically applied case study. Finally, the results of the model before and after refinement are to be compared reporting on the final efficiency of the tool.

2. The notion of the STRAPM tool

In one of the world's finest contributions to the tsunami mitigation scientific research fields Eisner defines seven principles. Eisner (2005) stated that among the most prevalent tsunami scientific mitigation challenges are:

- 1- The ability to identify a community's tsunami risk, i.e. hazard, exposure and vulnerability values;
- 2- to avoid new developments in tsunami prone areas;
- 3- to locate and configure new developments to minimize future tsunami losses;
- 4- to design them to minimize tsunami damage;
- 5- to protect existing development from tsunami losses (various measures);
- 6- to take special precautions with regard to critical infrastructure; and
- 7- to plan for evacuation.

An analysis of Eisner's predefined points clarified the fact that six of the listed principles are concerned with urban planning and architecture issues. The seventh principle and the most important one is the first principle. It deals with the ability to define people at risk and the tsunami prone areas of coastal communities. Such an issue is the most challenging issue for the tsunami science nowadays. Calculations for the purpose of saving human lives and properties are based on this incremental step. Even, in the most advanced societies where resources and scientific calibers are available the first principle is still met with struggle. The United States of America, with half of its citizens living in coastal communities, has managed to develop the worlds most advanced warning program and mitigation measures. NOAA (National Oceanic and Atmospheric Administration) advances its tsunami warning capabilities through building robust sensors, increased staffing and greater public awareness. NOAA has managed to create the fourth generation DART/buoy (tsunami sensing stations) that will be able to: measure a wave up to a 1 cm height, measure and sense local tsunamis, and provide data that is used to forecast tsunami intensity and expected flood potentialities on coastal communities. Now there are more than sixty darts/buoys that are distributed all around the world compared to the six darts that were existing before 2004 (<http://www.noaa.gov/>...last accessed online on 22/8/2016). Based on the data obtained from local topography and historical tsunami records, comprehensive flood forecasting models were built that have the ability to define tsunami flood zones and levels (Flouri et al., 2013). The models can predict the tsunami's inundation levels and expected inundations scenarios onshore for almost all of the USA's coastal areas.

The situation is extremely different in developing countries. Refusal to recognize a threat, deniability, is among the first challenges. In addition to the lack of available resources and scientific calibers. STRAPM can play a very important role in providing developing countries with an efficient model that can deal with the limitations and the political and scientific contexts of these countries while offering an applicable model able to efficiently identify tsunami hazard prone areas among coastal communities.

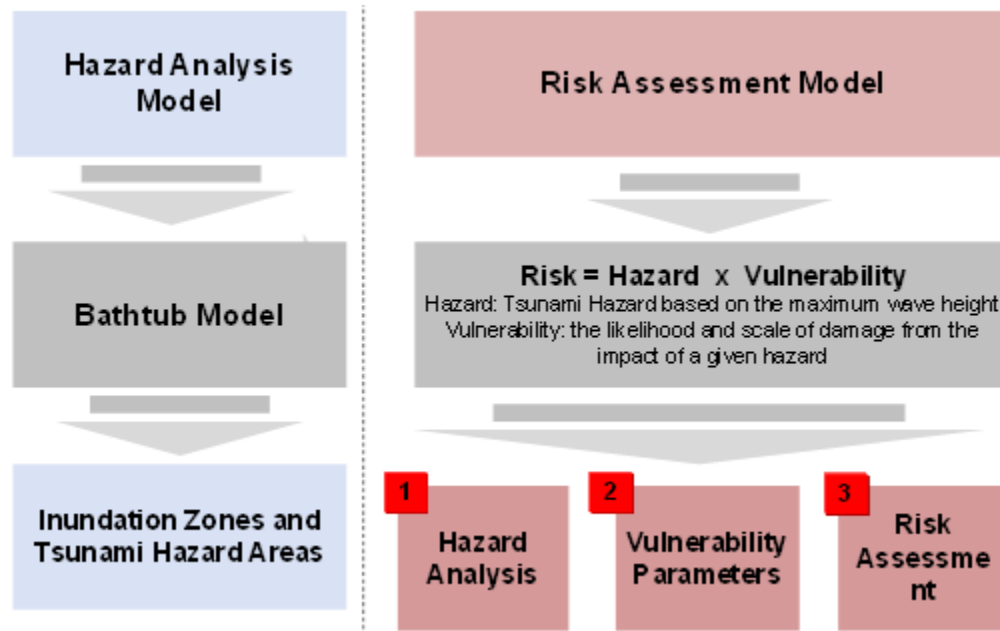


Figure 2. The STRAPM Tool: Stages and Levels

2.1. The STRAPM stages and levels

As presented in Figure 2 the STRAPM is mainly composed of two stages.

2.1.1. First stage: Hazard analysis

The aim of this stage is to define tsunami prone areas at coastal communities and the various hazard levels. The model, based on the Bathtub Model and its 'Flood Magnitude Scale' (Eckert et al., 2012), populates inundation and hazard analysis maps (Figure 3). The hazard analysis maps define the levels of inundation zones and water run up heights, based on which tsunami prone areas can be defined.

The required data includes topographic cadastral surveying maps for any specific coastal community area and the expected tsunami run-up scenarios. The scenario forecasting models for calculating the expected run-up scenarios, as presented in Figure 4, are mainly based on three different models. The first model is called the 'Scenario Based Model,' which builds up a scientific model for the expected run-up height based on scientific evidence and advanced computer simulating techniques (Hamouda, 2006; El-Sayed et al., 2000); the second model is called the 'Probabilistic Scenario' where, based on historical data of tsunamic events in a certain area, the inundation levels and run-up height of the area are calculated (Sorensen et al., 2012). The final scenario is known as the 'Worst Case Scenario,' based on historical evidence of similar coastal areas, a worst case scenario can be built up for the required coastal area (Hassan et al., 2013; Yalciner et al., 2002).

By running the expected tsunami run-up height scenarios on the coastal area, contour maps, inundation levels and hazard analysis maps can be generated (Stanley and Jorstad, 2005; Papadopoulos and Fokaefs, 2005). The inundation maps (Figure 3) define the maximum expected levels of on-land inundation for the

corresponding tsunami scenarios. The hazard analysis maps measure the hazard degree of coastal communities and districts. The maps also classifies the areas and districts inside the tsunami hazard prone zones. The key importance of these maps, besides informing the residence of these zones about the kind of hazard they are exposed to, is their ability to guide the creation of a tsunami evacuation plan for coastal communities.



Figure 3. Tsunami's Impact on Coastal Communities (Source: Queensland Evacuation Guidelines, 2010: 69-71)

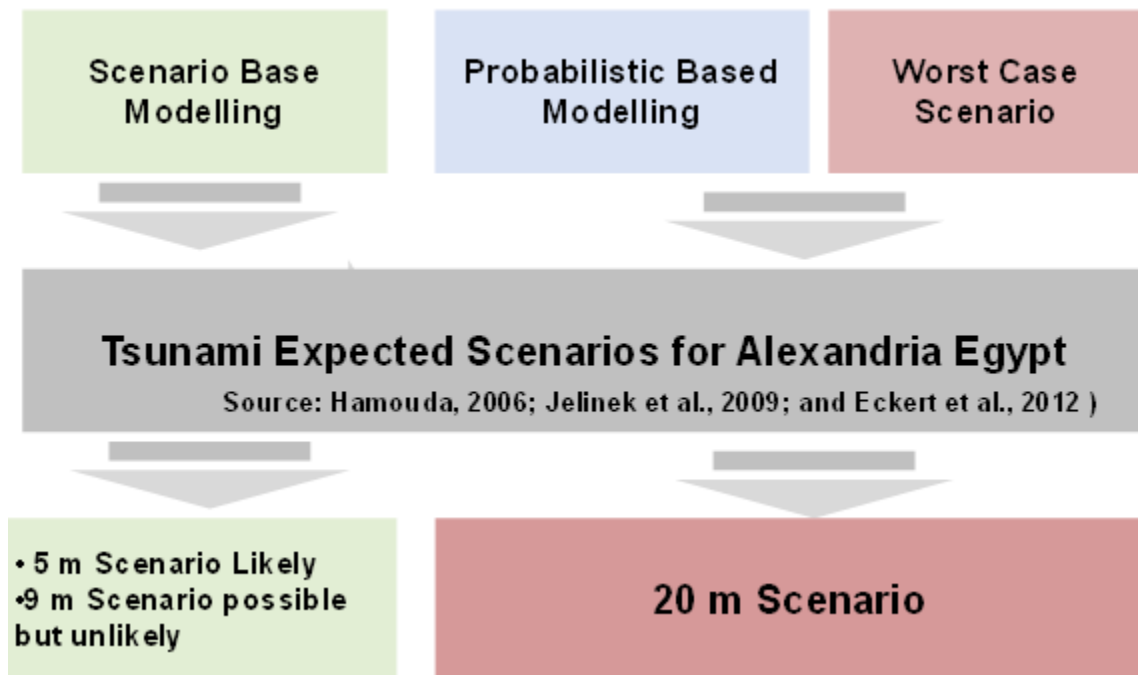


Figure 4. Tsunami's Run-up Heights Forecasting Models

2.1.2. Second stage: Risk analysis

The main aim of this stage is to run the risk assessment model on the coastal communities. The risk assessment model is among the most important models for tsunami risk planning and mitigation in the next coming years. The model is a complex process for quantifying probabilities or a chain of probabilities based on different parameters like population, built environment or the natural environment (Coachard et al., 2012). This paper utilizes the model for calculating the risk levels on the physical properties of the coastal communities (Jelinek et al., 2009). The final outcome of this stage in the model is a risk assessment map for the physical properties of the coastal communities.

This stage of the model is an advanced stage, it requires the involvement of a GIS expert beside the basic tsunami and planning knowledge of the coastal community. The main steps of this stage are summarized in the list below.

- 1- Building a credible GIS dataset for the tsunami impact coastal community.
- 2- Having complete, updated and accurate data for the parameters of the physical properties for the impact area.
- 3- Building a 3D physical surface model of the area based on either topographic maps or remote sensing technology presented by satellite maps provided by I`KONOS or QuickBird.
- 4- Producing the hazard assessment map as presented in Figure 5.1. Figure 5.1 is based on running the tsunami run up scenario on the coastal area's GIS dataset and calculating, based on the flash flood magnitude scale, the water level for every building of the coastal community.
- 5- Building up the vulnerability map for the physical properties of a coastal area is based on the available and the most effective parameters for each coastal community (Figure 5.2).
- 6- Finally, by applying the risk assessment matrix (Eckert et al., 2012) risk assessment maps for the physical properties can be populated as presented in Figure 5.3.

The most important contribution of the risk assessment is the ability to estimate the human casualties and the materialistic losses for the tsunami impact areas and communities. This is estimated based on the outcome of the risk assessment maps for an area's physical properties. For further details regarding The STRAPM stages and levels, refer to El-Barmelgy, 2014.

3. The deficiency of the tool

The authors, in a previous research entitled "Strategic tsunami hazard analysis and risk assessment planning," invented the tool as an effective proactive tsunami planning mitigation tool (El-Barmlegy, 2014). The tool was practically applied on Alexandria City, Egypt. The output of the case study has proven the efficiency of the tool on the first stage being able to accurately define tsunami prone zones and hazard levels. However, when applying the second stage of the tool, it has shown some limitations. Figure 6, presents the inability of the tool to accurately define the risk values of the physical properties for the applied case study, Alexandria City (Frihy et al., 1996).

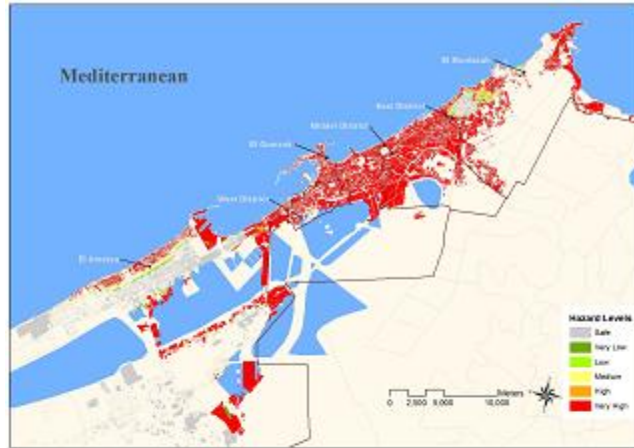


Fig 5.1. Tsunami Hazard Analysis Map

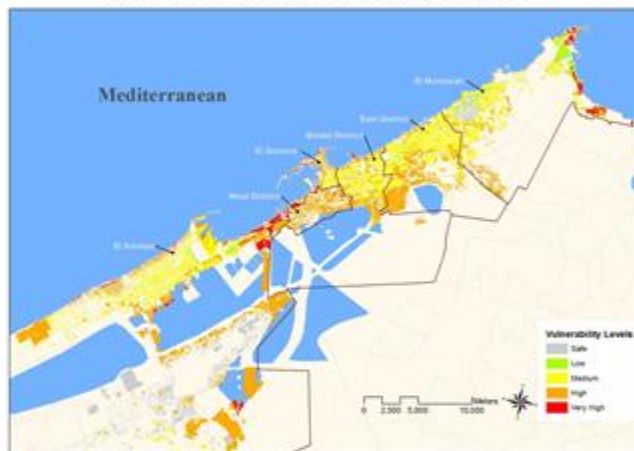


Fig 5.2. Tsunami Vulnerability Analysis Map



Fig 5.3. Tsunami Risk Analysis Map

Figure 5. The STRAP Tool - Stage 2: Output (Source: GIS analysis applied on Alexandria City)

Based on a comprehensive examination of the tool, it was found that the tool failed to accurately present risk values for the city’s buildings, among the various expected city tsunami impact scenarios. It is not possible for a building to have the same risk value for a water column that varies between 3m and 17m. The tool was not able to record and accurately calculate the appropriate hazard value for a tsunami wave over 3m due to the limitation of the utilized 'Flash Flood Magnitude scale' based on which the hazard values were calculated.

Table 1. Bathtub Model: Flash-Flood Magnitude Scale before and after Refinement (Source: Authors based on mathematical calculations utilizing the bathtub model original scale and notion

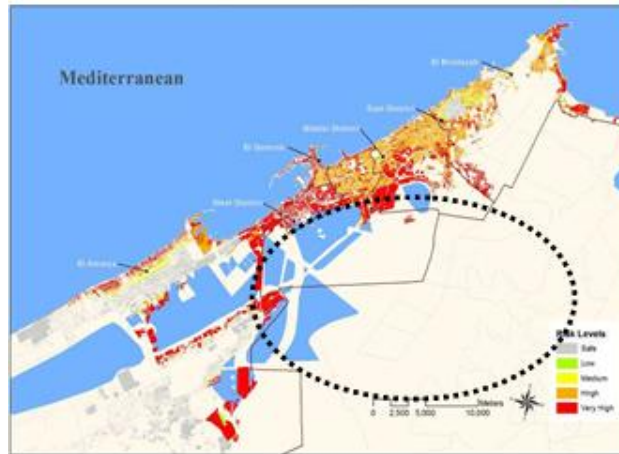
Hazard Classes	Hazard Category	Water Height (m)	Description
Safe (S)	-	Zero	Dry Land levels, no inundation or flooding
Very Low (VL)	1	$H \leq 0.5$	No damage
Low (L)	2	$0.5 < h \leq 1.0$	Limited damage
Medium (M)	3	$1.0 < h \leq 1.5$	Damage to light constructions and wall bearing buildings
High (H)	4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

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High	4	$1.5 < h \leq 2.0$	Damage to concrete buildings with shallow foundations	
Very High	(1)	5	$2.0 < h \leq 3.0$	Damage to all buildings with a Hazard value 5
	(2)	6	$3.0 < h \leq 4.0$	Damage to all buildings with a Hazard value 6
	(3)	7	$4.0 < h \leq 5.0$	Damage to all buildings with a Hazard value 7
	(n)	(n+4)	$(n+1) < h \leq (n+2)$	Damage to all buildings with a Hazard value n+4

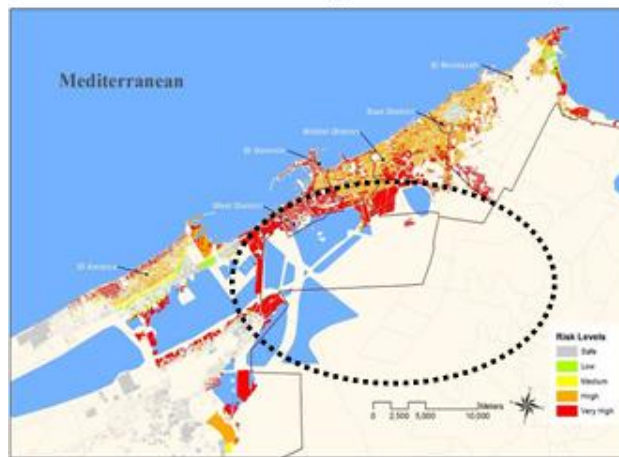
The number of VH hazard classes utilised in the model should be a factor of the run-up height of the tsunami scenario decreased by 2m which is already measures by the other Hazard classes (VL, L, M, and H). i.e, in case of the 5m scenario we should VH classes = to $5 - 2 = 3$, VH classes: VH (1, 2 and 3 as presented in the table) – for the 9m tsunami scenario: VH classes should be $= 9 - 2 = 7$, VH classes (1,2, 3, 4, 5, 6, and 7)

4. The model refinement

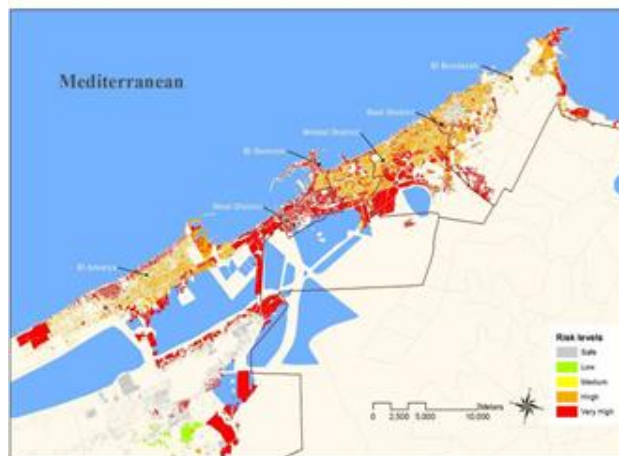
The risk value for the physical properties is calculated based on the international risk assessment model, where Risk = Hazard x Vulnerability. The calculation of the hazard values are based on the Flash Flood Magnitude scale. The model as presented in table 1, lacks the sensitivity/potentiality to calculate the hazard value for the physical properties attacked by a tsunami wave with a water column height over 3m corresponding to the physical property to which the risk value is calculated (Figure 6).



5m Scenario Alexandria City Risk Assessment Map



9m Scenario Alexandria City Risk Assessment Map



20m Scenario Alexandria City Risk Assessment Map

Figure 6. Alexandria City Risk Assessment Maps - Output of the STRAP Tool before Refinement (Source: GIS analysis applied on Alexandria City)

The authors extended the Flash Flood Magnitude Scale with a statistical n term equation that has the ability to interact with any expected tsunami wave height scenario. Table 1, presented the modification the authors applied to the scale. The adjustment of the scale was carried out on the last level of the scale, the Very High (VH) level. This level was further divided into minor layers so called (VH1, VH2, VH3.... etc.) The number of the VH hazard classes on the scale were designed to be a factor in the tsunami scenario run-up height, decreased by 2m which is already accurately measured by the other hazard classes (VL, L, M, and H) as presented in Table 1.

5. Testing the tool on the coastal community of Alexandria City

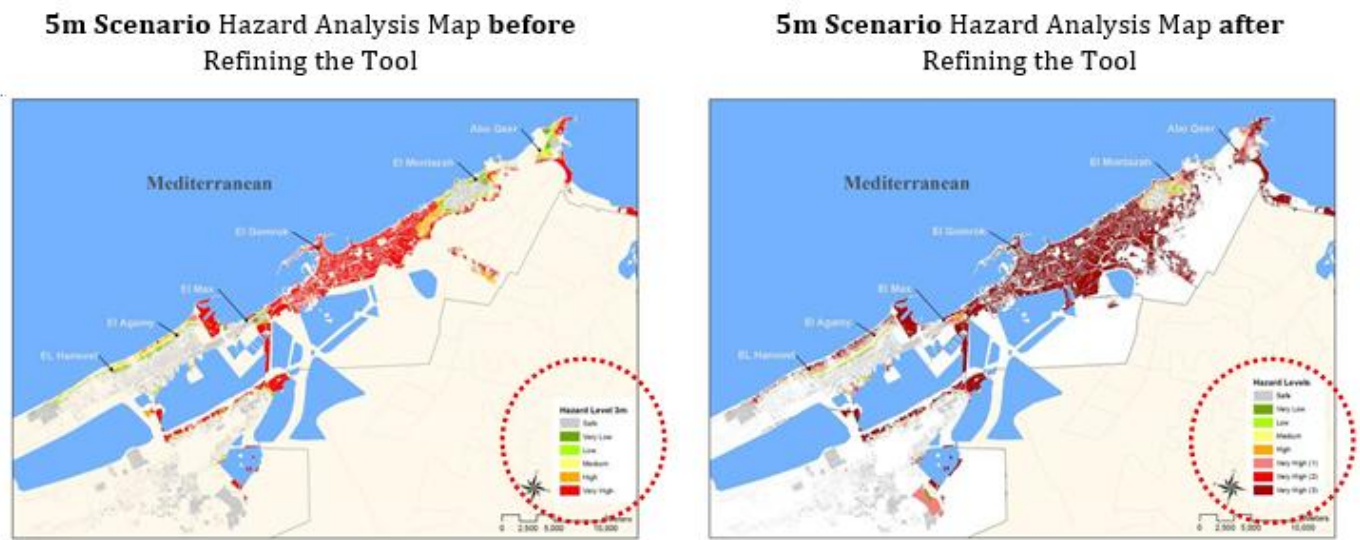


Figure 7. Alexandria City Hazard Analysis Maps - Output of the STRAP Tool before and after Refinement (Source: GIS analysis applied on Alexandria City)

By refining the model, a practical test of the tool was required, similar to the authors’ previous study El-Barmelgy 2014, the tool was applied on Alexandria City. The GIS expert utilized the refined model of the 'Flash Flood Magnitude Scale' as presented in table 1. The tool now was ready to be retested and the first output of the Model stage 2, was populated. Figure. 7 presents the difference between the tools output for the building’s hazard assessment after and before refinement. By running the tool the final output of stage 2 was achieved and presented in Figure. 8 where the final risk assessment values of the case study’s physical properties were calculated and populated. As shown in Figure 7, parts (a) and (b) now the model, after refinement, has proven the ability to calculate the accurate risk values for the corresponding/relevant expected tsunami run-up heights. Part (a) shows the central districts of the city where most of the buildings are to reach the maximum risk level facing a tsunami threat from 5 to 9m high. Part (b) reports on Al-Amriah district of the city being located on high ground. The efficiency of the tool is clearly shown as the risk levels of

the physical properties were affected relevant to the corresponding tsunami threat, by reaching the 20m tsunami threat scenario most of the city’s physical properties would be facing the VH level of risk.

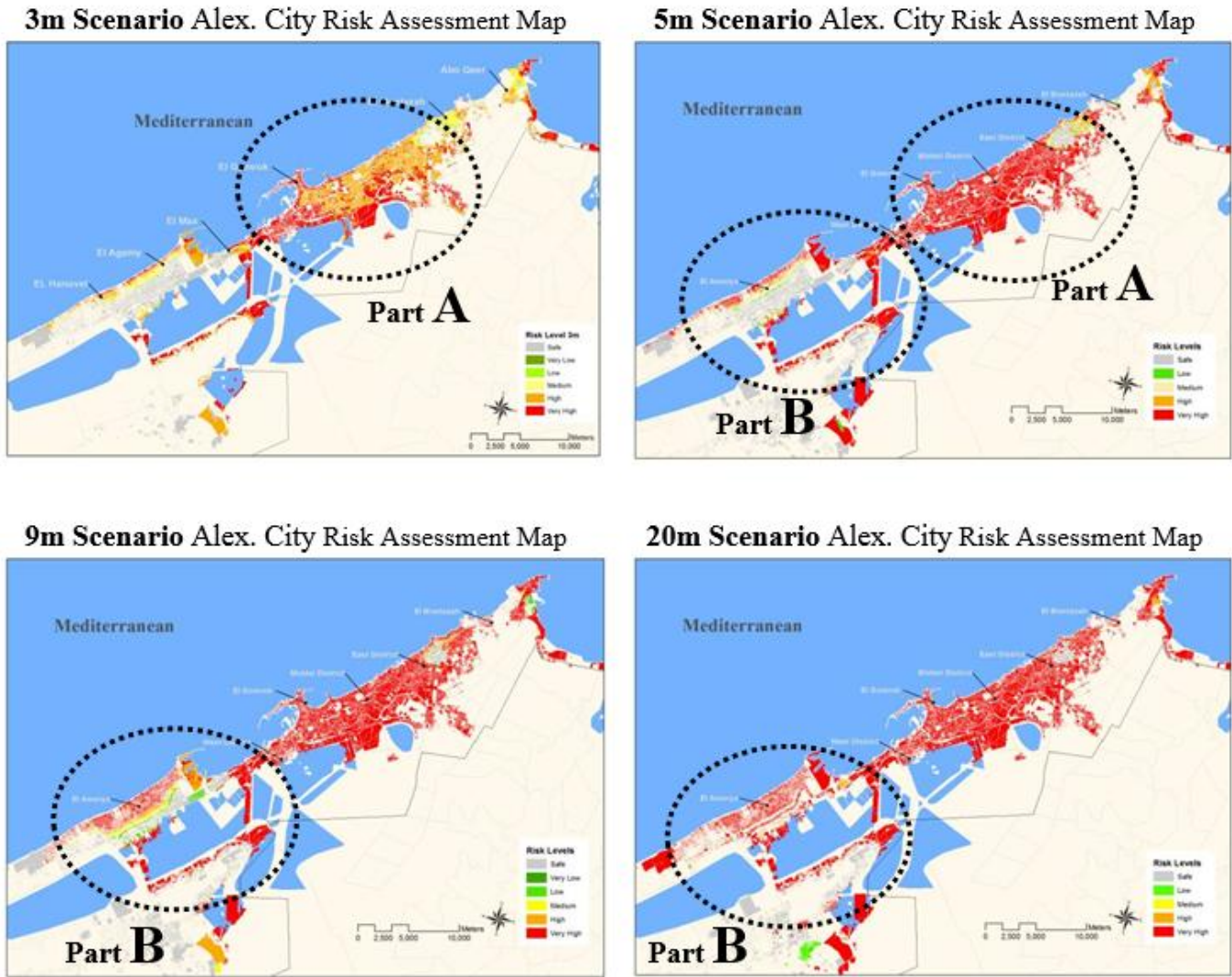


Figure 8. Alexandria City Risk Assessment Maps - Output of the STRAP Tool after Refinement (Source: GIS analysis applied on Alexandria City)

6. The model outputs concerning the ability to define human casualties

The authors utilize the output of the tool’s second stage, concerning the physical properties risk assessment, for calculating the expected human casualties. The idea of calculating a number for the expected human casualties is to create and to gain the required attention to this eminent threat that faces coastal communities, from both the residence and the political decision makers.

Table 2. Human Casualties Calculations for the 3m Tsunami Impact Scenario (source: authors based on field survey and scientific calculation)

Variables	Districts	Gomrok District	Amerya District	Montazah District	East District	West District	Middle District	Total
Number of buildings with VH value / Building		412	1805	1621	529	1357	555	
Corresponding Building height / Floor		2-15	1-4	2-15	1-10	2-9	1-13	
Average number of units in each floor / Unite		4	3	3.5	3	3.5	4	
Average Number of family members / People		4.5	4.5	4	4.5	4.5	5	
Total /People		44928	86522	117922	29363	106533	32740	

The calculations for the expected human casualties were based on a mathematical method that is to maximize the validity and reliability of the achieved figures. The method is based on a number of variables such as: the number of buildings defined as VH (based on the risk assessment), the relevant height for each building, the number of units in every floor, the expected number of families living in each unit, and the expected number of family members. The defined variables were obtained and set for each district of the case study (Alexandria City). The required data for the utilized variables were obtained as follows:

- The number of expected damaged buildings according to the relevant tsunami scenario is based on the output of the STRAPM tool's second stage where the risk values for every building were calculated,
- The heights of the buildings are obtained from the GIS dataset (the dataset is obtained from The Egyptian General Organization for Physical Planning GOPP),
- The number of units in each floor and the number of families living in each unit (obtained based on random survey and sampling for the various districts of the city),
- The number of family members (are obtained from the official population censuses conducted in 2006 for Alexandria City).

The equation used is:

$$\text{Estimated no. of human casualties} = \text{no. of buildings with VH risk values} \times \text{corresponding building height} \times \text{average no. of units in each floor} \times \text{average no. of family members}$$

Based on the equation and the defined variables' data, the expected number of human casualties was calculated for the four forecasted tsunami impact scenarios. Table 2, represents the calculation for the 3m tsunami impact scenario. As presented, the table calculates the estimated number of casualties based on the urban form of the districts. Finally figure 9, presents the number of the estimated human casualties for various city districts based on the urban pattern and fabric of each district. Utilizing the same method in Table 2 the estimated numbers were calculated for the 5m, 9m and the 20m tsunami impact scenarios.

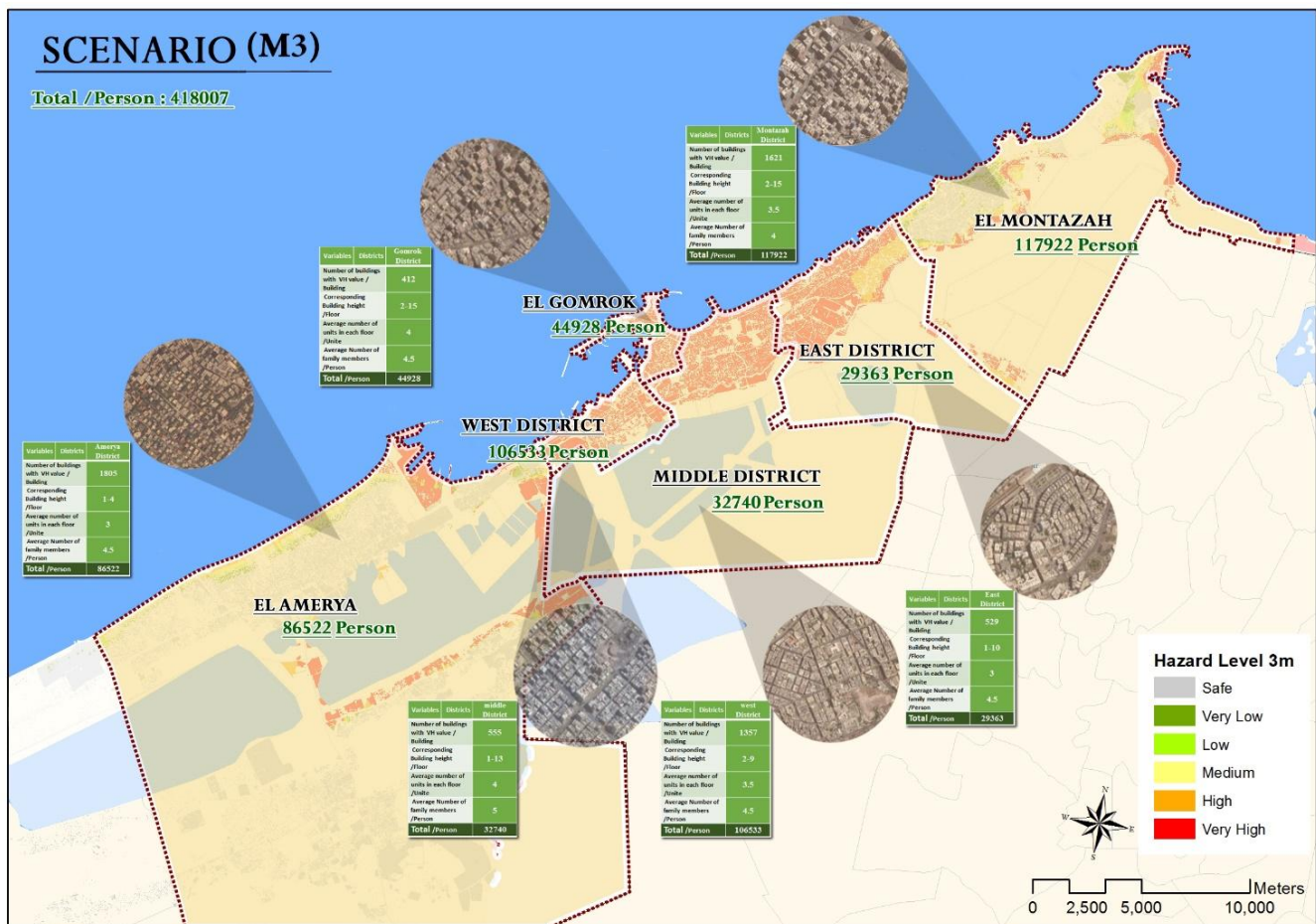


Figure 9. Alexandria City Human Casualties Calculations for the 3m Tsunami Impact Scenario (Source: GIS analysis applied on Alexandria City)

7. Findings and conclusions

The paper adopted an applied method for the refinement of a tool that is initiated by the authors to have the ability to report on the hazard degrees and impact of the tsunami threat on coastal communities. In a previous research the authors invented a tool named STRAPM. The tool has the ability, utilizing very simple data forms and affordable resources that would match the situations of most developing countries, to provide an efficient analysis and assessment of the degree of threat among coastal communities against tsunami threats. However, running the tool has highlighted a deficiency. The tool was not sensitive for cases where the hazard levels for tsunami scenarios are over 2m depth. Accordingly, the authors in this research have managed to add the required scientific refinement to the tool. Testing the tool through an applied case study (city of Alexandria, Egypt) has proven the efficiency of the tool in dealing with various tsunami expected scenarios (Figure 7 and 8). Accordingly, the paper declares that the tool is an effective and efficient proactive tool that can be applied within the scientific and resource limitation of the developing countries, while still having the ability to provide efficient and accurate results. The findings and results of the tool are argued by the authors to be between 80% and 90% accuracy based on the authors’ strategy of adopting the most efficient parameters and variables and depending on the ultimate levels of physical and materialistic resistance.

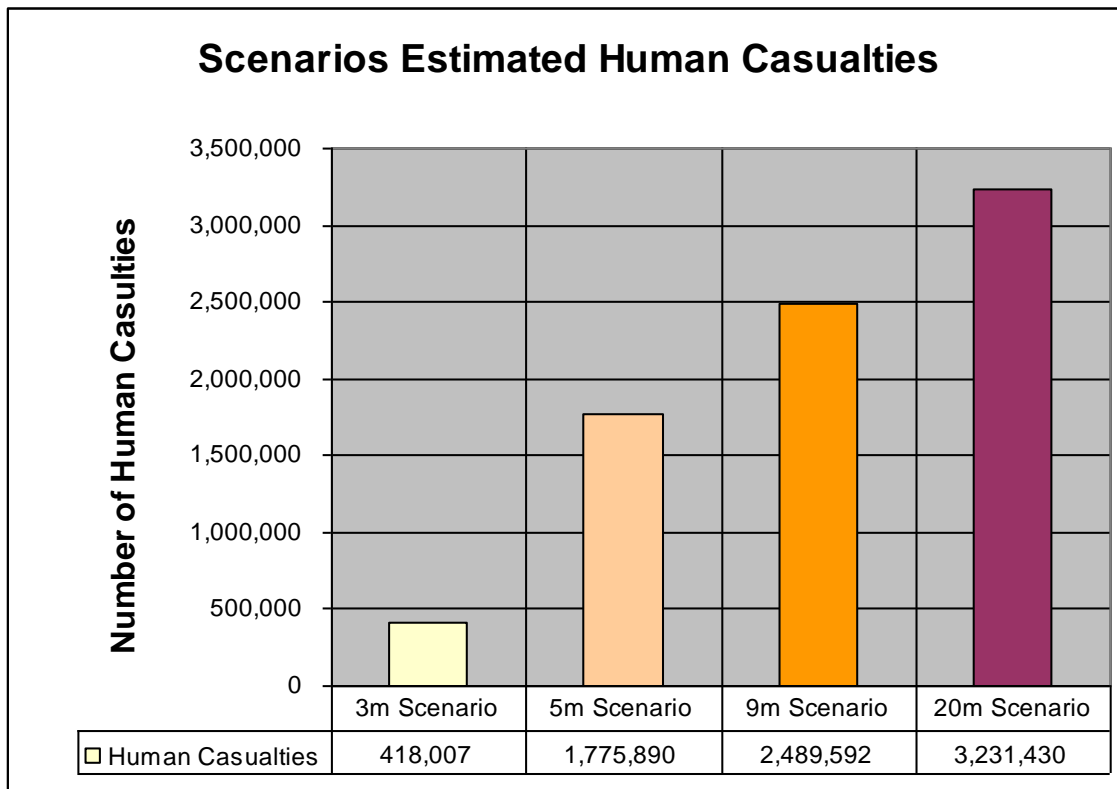


Figure 10. Alexandria City Tsunami Expected Human Casualties (Source: output of running the tool on Alexandria City)

The most important outcome of the tool's second stage is the ability to define the degree of risk on the physical properties of coastal communities. The paper used the findings of the tool and adopted a mathematical method for estimating the number of human casualties for one of Egypt's most important cities, the city of Alexandria. The results of the calculation for the city's expected tsunami impact scenarios are presented in Figure 10... For the 3m scenario the expected human casualties are around 7.7% of the city's population (418 thousand people); for the 5m scenario, 32.7% of the city's population (1.8 million people); for the 9m scenario, 45.8% of the city's population (2.5 million people); and for the 20m scenario, 59.5% (3.2 million people). The estimated numbers show the catastrophic situation the city is facing. In addition, the city is the first summer destination for Egyptian citizens, accommodating around a million national tourists every year. If the tsunami is to strike the city during the summer, then the estimated numbers are expected to increase by at least 300 thousand; offering the world the most catastrophic incident in its current history. Furthermore, among the outcome of the tool, stage 1 can provide the people of coastal communities with the required data regarding the tsunami prone areas and degrees of hazards; based on which tsunami evacuation plans and mitigation measures can be planned. The paper offers this as a point for further practical research.

References

- Camilleri, D.H. (2006), "Tsunami construction risks in the Mediterranean – outlining Malta's scenario", *Disaster Prevention and Management*, Vol. 15 (1), pp. 146-162.
- Cochard, R., Ranamukhaarachchi, S.L., Shivakoti, G.P., Shipin, O.V., Edwards, P.J. and Seeland K. T. (2008), "The 2004 tsunami in Aceh and Southern Thailand: A review on coastal ecosystems, wave hazards and Vulnerability", *Perspectives in Plant Ecology, Evolution and Systematics*, Vol. 10, pp. 3-40.
- Dawson, A.G. and Stewart, I. (2007), "Tsunami deposits in the geological record. Sedimentary", *Geology*, Vol. 200, pp. 166-183.
- Eckert, S., Jelinek, R., Zeug, G. and Krausmann, E. (2012), "Remote sensing-based assessment of tsunami vulnerability and risk in Alexandria, Egypt", *Applied Geography*, Vol. 32, pp. 714-723.
- Eisner, R.K. (2005), "Planning for tsunami: reducing future losses through mitigation", *Natural Hazards*, Vol. 35, pp. 155-162.
- El-Barmelgy, H.M. (2014), "Strategic tsunami hazard analysis and risk assessment planning model: A case study for the city of Alexandria, Egypt", *International Journal of Development and Sustainability*, Vol. 3 No. 4, pp. 784-809.
- El-Sayed, A., Romanelli, F. and Panza, G. (2000), "Recent Seismicity and realistic waveforms modelling to reduce the ambiguities about the 1303 seismic activity in Egypt", *Tectonophysics*, Vol. 328, pp. 341-357.
- Flouri, E.T., Kalligeris, N., Alexandrakis, G., Kampanis, N.A. and Synolakis, C.E. (2013), "Application of a finite difference computational model to the simulation of earthquake generated tsunamis", *Applied Numerical Mathematics*, Vol. 67, pp. 111-125.

- Frihy, O.E., Dewidar, K.M. and El-Raey, M.M. (1996), "Evaluation of coastal problems at Alexandria, Egypt", *Ocean & Coastal Management*, Vol. 30 (2-3), pp. 281-295.
- Hamouda, A.Z. (2006), Numerical computations of 1303 tsunamigenic propagation towards Alexandria, Egyptian Coast, *Journal of African Earth Sciences*, Vol. 44, pp. 37-44.
- Hassan, H. M., Yalciner, A. C., Badawy, A. A., and Abd El Hafez, N. A. (2013) "Tsunami hazard assessment of the Mediterranean-Egyptian coastal zone by using the Worst Case Credible Tsunami Scenario Analysis, available online at <https://www.researchgate.net/publication/272676286> (accessed August 2017).
- Jelinek, R., Eckert, S., Zeug, G. and Krausmann, E. (2009), "Tsunami Vulnerability and Risk Analysis Applied to the City of Alexandria, Egypt", European Communities, Italy, available online at: http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/11532/1/2009_08_alexandriatsunamivulnerability%26risk.pdf (accessed 10 September 2013).
- Leone, F., Lavigne, F., Paris, R., Denain, J.C. and Vinet, F. (2011), "A spatial analysis of the December 26th, 2004 tsunami-induced damages: Lessons learned for a better risk assessment integrating building vulnerability", *Applied Geography*, Vol. 31, pp. 363-375.
- Lovholt, F., Glimsdal, S., Harbitz, C.B., Zamora, N., Nadim, F., Peduzzi, P., Dao, H. and Smebye, H. (2012), "Tsunami hazard and exposure on the global scale", *Earth-Science Reviews*, Vol. 110, pp. 58-73.
- Maouche, S., Morhange, C. and Meghraoui, M. (2009), "Large boulder accumulation on the Algerian coast evidence tsunami events in the western Mediterranean", *Marine Geology*, Vol. 262, pp. 96-104.
- Olivieri, M. and Scognamiglio, L. (2007), "Toward a Euro Mediterranean tsunami warning system: The case of the February 12, 2007, M_l = 6.1 earthquake", *Geophysical Research Letters*, Vol. 34, pp. L24309.
- Ozel, N.M., Ocal, N., Cevdet, Y.A., Dogan, K. and Mustafa, E. (2011), "Tsunami hazard in the Eastern Mediterranean and its connected seas: Toward a Tsunami warning center in Turkey", *Soil Dynamics and Earthquake Engineering*, Vol. 31, pp. 598-610.
- Papadopoulos, G.A. and Fokaefs, A. (2005), "Strong Tsunamis in the Mediterranean Sea: A Re-Evaluation", *Journal of Earthquake Technology*, Vol. 42 (4), pp. 159-170.
- Paris, R., Wassmer, P., Sartohadi, J., Lavigne, F., Barthomeuf, B., Desgages, E., Grancher, D., Baumert, P., Vauiter, F., Brunstein, D. and Gomez, C. (2009), "Tsunami as geomorphic crises: Lessons from the December 26, 2004 tsunami in Lhok Nga, West Banda Aceh (Sumatra, Indonesia)", *Geomorphology*, Vol. 104, pp. 59-72.
- Pignatelli, C., Sanso, P. and Mastronuzzi, G. (2009), "Evaluation of tsunami flooding using geomorphologic evidence", *Marine Geology*, Vol. 260, pp. 6-18.
- PREVIEW, (2005), PREvention, Information and Early Warning preoperational services to support the management of risks, Damage assessment based on damage intensity scales: service specification, available online at: <http://www.preview-risk.com> (accessed 10 September 2013).
- Sorensen, M. B., Spado, M., Babeyko, A., Wiemer, S., and Grunthal, G. (2012) "Probabilistic tsunami hazard in the Mediterranean Sea", *Journal of Geophysical Research*, Vol. 117, pp. B01305.

Stanley, J.D. and Jorstad, T.F. (2005), "The 365 A.D. tsunami destruction of Alexandria, Egypt: erosion, deformation of strata and introduction of allochthonous material", Geological Society of America, Annual Meeting Salt Lake City, report 2005.

Todorovska, M.I. and Trifunac, M.D. (2001), "Generation of tsunamis by a slowly spreading uplift of the sea floor", *Soil Dynamics and Earthquake Engineering*, Vol. 21, pp. 151-167.

UNESCO (2011), "Reducing and Managing the Risk of Tsunamis", Intergovernmental Oceanographic Commission: Manuals and Guides, 57, United Nations Educational, Scientific and Cultural Organisation, available online at: <http://unesdoc.unesco.org/images/0021/002147/214734e.pdf> (accessed 10 September 2013).

Yalciner, A.C., Alpar, B., Altinok, Y., Ozbay. I. and Imamura, F. (2002), "Tsunami in the Sea of Marmara Historical documents of the past, models for the future", *Marine Geology*, Vol. 190, pp. 445-463.