Earth Sciences
2023; 12(4): 111-115
http://www.sciencepublishinggroup.com/j/earth
doi: 10.11648/j.earth.20231204.14
ISSN: 2328-5974 (Print); ISSN: 2328-5982 (Online)

Applying the Fundamental Principles of Natural Hazards to the Study of Tsunamis: Case Study of the 2004 Tsunami in Sumatra

Sule Ayannor Issaka

Institute of Geography, Faculty of Mathematics and Natural Sciences, University of Cologne, Cologne, Germany

Email address:
aisule09@hotmail.com

To cite this article:
Sule Ayannor Issaka. Applying the Fundamental Principles of Natural Hazards to the Study of Tsunamis: Case Study of the 2004 Tsunami in Sumatra. *Earth Sciences.* Vol. 12, No. 4, 2023, pp. 111-115. doi: 10.11648/j.earth.20231204.14

Received: May 10, 2023; **Accepted**: May 29, 2023; **Published**: July 31, 2023

Abstract: For the past seven decades, researchers of natural environmental hazards have been trying to find answers to fundamental questions answers to which will lead to a better understanding of the characteristics, impacts, and responses to hazards. This has led to the development of five fundamental principles of natural hazards as discussed in the literature. Research on the fundamental principles of natural environmental hazards is far from being described as rudimentary with a vast amount of literature to warrant this claim. However, the so-called principles of natural hazards are being discussed in the literature in isolation, without relating them to a particular hazard to facilitate a practical understanding and applicability and this is the gap in the knowledge that this paper seeks to fill. This paper applies the five fundamental principles of natural hazards to help explain tsunamis based on the review of relevant and related literature. The analysis of the findings of the different works in this area shows that all the fundamental principles of natural hazards are applicable in the explanation of the causes, characteristics, impacts, and reducing vulnerability to not only tsunamis but also other related hazards such as earthquakes and floods. These findings highlight the relevance of the use of scientific methods in studying natural hazards as it facilitates a better understanding of the nature and characteristics of natural environmental hazards which will aid in reducing vulnerability to and the impacts of such hazards.

Keywords: Natural Hazards, Fundamental Principles, Tsunamis, Sumatra, Impacts

1. Introduction

The world has witnessed varied forms of natural hazards with devastating effects on lives and economic losses as well in the past decades [3]. For instance, increasing global temperature has either directly or indirectly led to increases in the number and frequencies of certain hazards with their accompanied effects on the lives of humans and property as well. It has been argued that though earth disturbances in the likes of mudflows, droughts, flooding, earthquakes, landslides, and many others have been there right from the existence of the planet Earth, however, not all natural disturbances qualify to be described as hazards until they have an impact or affects the lives of human beings [11]. Natural hazards in this context have been defined as naturally occurring processes or events that occur outside of the influence of man but pose a serious threat or danger to human lives and property [11]. This implies that the events themselves qualify not to be called hazards, not until lives and property are at risk or being affected. Crozier & Glade [5], also defined hazards as either in the form of an action or inaction, situation, or a process with the ability to harm, damage, or adversely affect both humans and property. A natural hazard has again been defined as "*the potential interaction between humans and extreme natural events*" [18]. Disasters on the other hand have been defined as hazardous processes or events that cause damage to the host communities, disruptions, casualties, and in the end leaving affected communities in a state where they are unable to function well without external support [19]. Disasters can also be defined as processes or events with greater or very large impacts or effects on the recipient society [18]. This is to say that a natural hazard that took place within the boundaries of a certain confirmed place or area and also

within a specific period then becomes a disaster [11, 18]. For catastrophes, these are always massive or very large-scale disasters that will certainly require very huge sums of money to handle with relatively longer recovery periods, they will cost their host nations or localities dearly and with severe impacts [18]. A catastrophe is a process or event that could lead to at least the loss of 500 lives or at least $10 million worth of damages to property [18]. Some notable natural hazards have led to the loss of lives and property within the last century. For instance, in the last century up to the end of 1990, an estimated number of 1.52million people were reported to have died due to earthquakes, and almost 50% of this figure occurred in China alone as a result of the ever-devastating 'Tangshan earthquake' in 1976 which took the lives of 242, 000 people (Blaikie et al., 2014). The last century has witnessed a series of volcanic eruptions that took the lives of up to some 75, 000 people, an example of which is the 1902 volcanic eruption of Mount Pele in which 29,000 lives perished [1, 18]. Second in terms of magnitude was the 23, 000 lives that were lost as a result of the Nevado del Ruiz volcanic eruption in Columbia that took place in 1985 [1]. Again, landslides in the past century alone claimed the lives of about 280,000 people with the most deadly leading to 200, 000 deaths in the Gansu province of China in 1920 [1]. In the case of earthquakes, the 1985 Mexican earthquake also led to 20, 000 deaths [18]. Still, in 1985, 11, 000 people were killed in a landslide in Bangladesh and another landslide in Vietnam also took away 670 lives [18]. Coming down to the 21st century, the 2004 Indonesian tsunami has gone down in history as one of the deadliest events that the world has ever witnessed with a recorded death toll of at least 283,000 [16]. The Sumatra tsunami which took place on Boxing Day of the year 2004 also injured thousands of people with millions displaced [16]. The heat waves of 2003 that hit several countries in Europe is yet another terrible incident that will ever be remembered across the length and breadth of Europe. Up to 70,000 lives were lost in the whole of Europe due to the heat waves [14]. Considering the devastating impacts of natural environmental hazards on lives and property, it is therefore incumbent the understanding of the characteristics of these hazards as this will help mitigate their impacts on lives and property. The main of this paper, therefore, is to find out how applicable the fundamental principles of natural hazards are in understanding tsunamis. The following are the two main research questions that will help archive the above-stated aim of the study: 1. What are the implications of the fundamental principles of natural hazards as outlined by Keller & DeVecchio [11]? 2. How can these fundamental principles of natural hazards help explain tsunamis (with a focus on the 2004 tsunami in Sumatra)?

Finding answers to the above-stated research questions will not only help us understand the characteristics of tsunamis but also other natural environmental hazards as well.

2. Application of the Concepts in the Study of Tsunamis (a Reference to the 2004 Sumatra Tsunami)

Keller et al. [11] has outlined five key or fundamental concepts or principles that are not only meant to help us understand natural hazards but also enable us in our bit to conceptualize hazards. These are explained below;

1. The predictability of hazards through scientific methods is one key concept of natural hazards. Every particular natural hazard has specific properties which include the frequency or rate, type, pattern, and many others that make it possible for the scientist to be able to predict or calculate their future occurrence or activity, map, and then monitor them as well through the use of scientific methods. Key examples of this concept are the two methods that have been devised for the estimation of the potential peak discharge of water from dams that could lead to flooding [20]. According to Shuto & Matsutomi [15], the two primary ways through which the features of a tsunami could be expressed are by the intensity and the magnitude of the tsunami. The intensity of a tsunami tells us about the local or in other words, the specific areal strength of a tsunami. It tells us about the strength of a tsunami at a particular point in time. The magnitude of a tsunami on the other hand refers to the total energy carried by the tsunami. On the boxing day of the year 2004, a record-setting tsunami with very severe effects on lives, which happens to be one of the deadliest single events in recent times struck the Indonesian coast of the Indian Ocean, Sumatra to be specific [7]. According to Titov et al. [18], the tsunami occurred at exactly 07: 59 local Indonesian time with a magnitude of (M) 9.3. The tsunami is said to have occurred in three different waves around the area of 'Banda Aceh', [13]. The first wave which was about five meters high and very fast came from the southwestern part exactly three minutes later, the second and largest wave originated from the west-southwestern part with an average height of between fifteen to thirty meters around the coast [2, 13]. Though not enough observations are available for the third wave, it is said to have occurred around five minutes after the backwash with the topographic features of the area such as lagoons and rivers helping to control the spatial distribution of the wave [13]. It is still very difficult for scientists to able to predict a tsunami before it occurs, if at all, then this could, however, be too late before the tsunami sets in because most of the triggers of a tsunami are either very difficult to predict or could only be predicted just some few seconds before they occur. For instance, it will certainly be impossible for scientists to be able to predict comets before they fall which is one of the causes of a tsunami. Again, earthquakes which are the major causes of tsunamis can only be predicted just for a few seconds before they

occur which is always almost too late for anything to be done except to press the button of an early warning system. The lack of reliable early warning systems made it difficult for predicting the 2004 tsunami in Indonesia [12].

2. Another fundamental concept of natural hazards is that knowing the risk associated with hazards helps people in decision-making. In this regard, the analysis of risk is keen in enabling us to comprehend the negative effects of hazards. This is to say that natural hazards are in one way or another aligned to the analysis of risk, thereby making it possible to estimate the possibilities of an event occurring and the accompanying consequences as well. Contrary to this point, there is the notion that "*risks are conceptually uncontrollable*" [8]. Meaning no one can be able to determine whether he or she has made enough effort to help prevent the occurrence of a hazard or not. This also confirms the assession that there has never been a straightforward, single, and universal understanding or comprehension of risk, as different people from different backgrounds perceive risk differently [8].

The history of natural hazards has shown that tsunamis have been among the list of severe hazards due to their effect on lives and property, with the latest tsunami (the 2004 Indonesian tsunami) being one of the single deadliest disasters in human history after taking more than 200, 000 lives [9]. The impact of the Sumatra tsunami was very catastrophic not only to Indonesia but to many countries worldwide and has taken the lives of thousands of people with also several billions of dollars in damages to property [18]. One of the severely hit destinations by the 2004 tsunami around 'Sumatra' was the area of Banda Aceh, in the northwestern region of 'Sumatra' [2; 13]. This, and many other record-breaking effects of tsunamis help us understand the threat tsunamis pose to human lives and livelihood and thus will guide societies in their preparations for, during, and after tsunamis. This principle, therefore, applies to tsunamis in the sense that our analysis of the harm caused by previous tsunamis is enough to make us understand the threat tsunamis pose to both lives and property. Indonesia is said to be at risk of a tsunami in its North-eastern territories in areas such as the Banda Sea, Sulawesi, and Molucca Sea prompting the installation of early warning systems in those areas with their data merged with the central one located in Jakarta [12].

3. The third fundamental concept of natural hazards is the existence of linkages or connections between natural hazards. For instance, persistent drought can cause wildfires just as flooding will cause both soil and coastal erosions as well. Along the same line, earthquakes can produce fires, tsunamis, and landslides. Extremely hot or cold temperatures can lead to heat waves or cold waves respectively. Several causal agents or events could lead to the development of, or trigger a tsunamis. It could either be as a result of a collapsing part of a volcano that eventually slides inside of the sea, massive earthquakes with the potential of subsiding the seafloor, the effects of extra-terrestrial bodies in the likes of comets and asteroids from space, volcanoes that occur beneath the sea and also as a result of a landslide that occurs underwater and that might have been influenced by an earthquake [11]. However, among the many causes of tsunamis as stated above, the most common causes of tsunamis are earthquakes [11]. A tsunami most often occurs when an earthquake takes place either just below, or even closer to the ocean floor [10]. Scientists have also tried to differentiate a tsunami from a mega-tsunami. The term mega-tsunami has been defined as the type with an initial height or in other words, wave amplitude that is sometimes up to several hundreds of meters and which, at least, is more severe, strong, and destructive than the normal one [10]. Erosion as a result of tsunamis will affect the structure and quality of the soil. The sweeping away of trees by tsunamis could also lead to desertification in the long run.

The Sumatra tsunami occurred when a mega earthquake struck the western part of Sumatra, the island of Andaman, and Nicobar [17; 18]. According to Paris et al. [13], the harm caused by the 2004 tsunami in the area of 'Lhok Nga' alone includes the massive erosion of the coast, an inundation of the bay around the east, the absolute sweeping away of both buildings and trees, complete demolishing or at least damaging of bridges, and the taking away of 7, 000 lives.

4. Human factors have the potential to turn disasters into catastrophes. The increasing magnitude of hazards to disasters and even catastrophes can be linked to an increasing global population in the sense that population growth means an intensification of agriculture, spreading of urbanization, wealth creation, and exposure of many more people and assets to hazards, which will all sum up to increases in the impacts of natural hazards [16]. In relation to this, and in an attempt to analyze the relationship between disasters and urban centers, [4] have noted that most of the larger megacities we have in the world today are facing lots of problems from not only everyday hazards but also disaster risk as well. They have noted that the inhabitants of smaller urban centers like those in Sub-Saharan Africa are most likely to face numerous challenges than the megacities due to a lack of social amenities [4]. Human-induced factors such as poor or bad land use habits or practices and population hikes have the potential of either directly or indirectly influencing the rate, frequency, and size or magnitude of a hazard and as a result, previous disaster-causing events are now becoming catastrophic [21, 22].
5. Climate change can also be blamed for changes in the dimensions of hazards such as floods and droughts.

The total number of people who lost their lives as a result of tsunamis between the period of 1975 to 1998 (58,571) is not up to the number of people who died from the tsunami of Indonesia in 2004 alone (230,000) [11; 21; 9]. This could partly be associated with increased population coupled with

increased human interaction with the natural environment. It has been found that human activities along the coast of Sri Lanka exacerbated the impacts of the 2004 tsunami [6]. The results indicate that the destruction of the mangrove forest by humans for varied purposes such as construction, medicine, and firewood exposed the bare coastline to the wrath of the strong waves of the tsunami [6].

6. The possibility of minimizing the consequence or harm caused by hazards. Lastly, there is the possibility of minimizing the consequence or harm caused by hazards. The possibility of minimizing the impacts of natural hazards, however, depends on factors such as proactive and not reactive preparation for disasters, good land use culture, appropriate and functioning laws, and a proper understanding of the scientific basis of disasters among others. The thick forest along the coast also has the potential of reducing the share force of tsunamis and thus in a way reducing its impact on lives and property. This was evident in the 2004 Indonesian tsunami [11]. Furthermore, the worst impacts of tsunamis on lives can be averted when early warning systems are immediately accompanied by swift evacuations and systems of public education on the risk associated with tsunamis [21]. Other measures include the construction of sea defense walls and breakwaters to reduce the force of the wave emanating from tsunamis [21].

It was evident that the impact of the 2004 Sumatra tsunami could have been less with the existence of a better warning system in Indonesia. Based on this, the German government offered to install a warning system for tsunamis in Indonesia and other neighboring countries [12]. Also, the protection of mangrove forests along the coastlines of the affected countries would have minimized the impact of this tsunami [12].

Table 1 below gives a breakdown of the total number of people from some of the countries around the Indian Ocean who either died or went missing due to the tsunami in Indonesia in 2004.

Table 1. *Recorded casualties from the 2004 tsunami.*

Country	Number of people dead or missing
Indonesia	163,795
Sri Lanka	35,399
India	16,389
Thailand	8,345

Source: [9].

3. Discussions

The first research question that this paper seeks to answer is what are the implications of the various fundamental principles of natural hazards? The result has shown that these principles provide for the use of scientific methods in analyzing and assessing natural hazards. The analysis of the features and trends of natural hazards can help predict the occurrence of such hazards. The knowledge of the risk of hazards is keen in decision-making towards such hazards. This enables adequate preparation for the hazard which leads to prompt response and immediate recovery from the hazard. Also, there is the tendency for one natural hazard to lead to or trigger the occurrence of another. This is common in the case of tsunamis which in the first place are caused by either an earthquake that happens in the ocean, volcanic eruptions, and many others as elaborated above. Tsunamis themselves also lead to other hazards such as flooding and erosion of the coastline among others. This however depends on other factors such as the nature of the vegetation cover along the coastline, the nature of settlement, and other human activities. This is because of the potential of human actions in turning disasters into catastrophes. This ranges from deforestation of coastal vegetation, land use patterns, agriculture, and population growth. Despite all the above features of natural hazards discussed above, the findings also indicate that it is still possible to minimize the impacts of natural hazards on both lives and property. Good land-use practices, afforestation, and the construction of protecting structures such as sea defense walls can help minimize the impacts of some natural hazards.

The second research question that this paper seeks to answer is how the above-stated principles of natural hazards can help in understanding tsunamis. The findings above have indicated that almost all the five-stated principles of hazards are applicable in the analysis of tsunamis, though with variations in the degree of applicability of the various principles. For instance, the causes, impacts, and nature of tsunamis can be explained through the application of scientific methods, as science enables us to understand the various causes of tsunamis which have already been elaborated in the previous chapters. Also, knowing the risk of certain human activities such as deforestation of village vegetation, agriculture, and settlement pattern along the coastlines susceptible to tsunamis will serve as a guide in the formulation of policies and decision making will reduce vulnerable to tsunamis. This is important because human actions contribute to worsening the impacts of hazards on lives and property which also includes tsunamis as exhibited in the 2004 tsunami whose impacts was worsened by deforestation of coastal mangrove in affected areas. This also depends on other factors such as the nature of the population of the area and political will. When people are aware of their vulnerability and the risk posed by natural hazards, they can indulge in good practices such as afforestation, and good farming practices to help reduce their vulnerability rate to hazards such as tsunamis.

4. Conclusion

The fundamental principles for explaining natural hazards can be said to apply to the study and understanding of tsunamis. This is important in helping us explain not only the causes, dynamics, vulnerability, impacts, response mechanisms, and recovery from tsunamis but also other related hazards as well such as earthquakes, floods, and

coastal erosion. Some of the reasons for more casualties due to hazards in most communities due to lack of awareness of those hazards, inadequate response capacities, and poor infrastructure. There is, therefore, the need for periodic public sensitization in disaster-prone areas on the causes, signs, and impacts of these disasters. There is also the need for the installation of modern early warning systems in disaster-prone areas to help in early evacuations. Finally, there is the need to develop the capacities of the people living in disaster-prone areas to boost their coping strategies as this will enable them to respond immediately to the impacts of hazards even before the arrival of external support.

References

[1] Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2014). At risk: natural hazards, people's vulnerability, and disasters.

[2] Borrero, J. C. (2005). Field survey of northern Sumatra and Banda Aceh, Indonesia after the tsunami and earthquake of 26 December 2004. Seismological Research Letters, 76 (3), 312–320.

[3] Botzen, W. J. W., & Van Den Bergh, J. C. J. M. (2009). Managing natural disaster risks in a changing climate. Environmental Hazards, 8 (3), 209-225.

[4] Bull-Kamanga, L., Diagne, K., Lavell, A., Leon, E., Lerise, F., MacGregor, H.,... & Yitambe, A. (2003). From everyday hazards to disasters: the accumulation of risk in urban areas. Environment and Urbanization, 15 (1), 193–2004.

[5] Crozier, M. J., & Glade, T. (2005). Landslide hazard and risk: issues, concepts, and approach. Landslide Hazard and Risk, 1–40.

[6] Dahdouh-Guebas, F., Jayatissa, L. P., Di Nitto, D., Bosire, J. O., Seen, D. Lo, & Koedam, N. (2005). How effective were mangroves as a defense against the recent tsunami? Current Biology, 15 (12). https://doi.org/10.1016/j.cub.2005.06.008

[7] Danielsen, F., Sørensen, M. K., Olwig, M. F., Selvam, V., Parish, F., Burgess, N. D.,... & Suryadiputra, N. (2005). The Asian tsunami: a protective role for coastal vegetation. Science. 310 (5748), 643–643.

[8] Douglas, M., & Wildavsky, A. (1983). Risk and culture: An essay on the selection of technological and environmental dangers. Univ of California Press.

[9] Fujii, Y., & Satake, K. (2007). Tsunami source of the 2004 Sumatra–Andaman earthquake inferred from tide gauge and satellite data. Bulletin of the Seismological Society of America, 97 (1A), S192–S207.

[10] Goff, J., Terry, J. P., Chagué-Goff, C., & Goto, K. (2014). What is a mega-tsunami? Marine Geology, 358, 12-17.

[11] Keller, E., & DeVecchio, D. (2015). Natural hazards: earth's processes as hazards, disasters, and catastrophes. Pearson Higher Education AU.

[12] Lauterjung, J., Münch, U., & Rudloff, A. (2010). The challenge of installing a tsunami early warning system in the vicinity of the Sunda Arc, Indonesia. Natural Hazards and Earth System Science, 10 (4), 641–646. https://doi.org/10.5194/nhess-10-641-2010

[13] Paris, R., Wassmer, P., Sartohadi, J., Lavigne, F., Barthomeuf, B., Desgages, E.,... & Gomez, C. (2009). Tsunamis as geomorphic crises: lessons from the December 26, 2004 tsunami in Lhok Nga, west Banda Aceh (Sumatra, Indonesia). Geomorphology, 104 (1-2), 59–72.

[14] Robine, J. M., Cheung, S. L. K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J. P., & Herrmann, F. R. (2008). (n.d.). Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies, 331 (2), 171–178.

[15] Shuto, N., Matsutomi, H. Field survey of the 1993 Hokkaido Nansei-Oki earthquake tsunami. PAGEOPH 144, 649–663 (1995). https://doi.org/10.1007/BF00874388

[16] Smith, K. (2013). Environmental hazards: assessing risk and reducing disaster. Routledge.

[17] Szczuciński, W., Chaimanee, N., Niedzielski, P., Rachlewicz, G., Saisuttichai, D., Tepsuwan, T.,... & Siepak, J. (2006). Environmental and Geological Impacts of the 26 December 2004 Tsunami in Coastal Zone of Thailand--Overview of Short and Long-Term Effects. Polish Journal of Environmental Studies, 15 (5).

[18] Titov, V., Rabinovich, A. B., Mofjeld, H. O., Thomson, R. E., & González, F. I. (2005). The global reach of the 26 December 2004 Sumatra tsunami. Science, 309 (5743), 2045-2048.

[19] Tobin, G. A. (1997). Natural hazards: explanation and integration. Guilford Press. Guilford Press.

[20] Twigg, J. (2007). Tools for Mainstreaming Disaster Risk Reduction, Social Impact Assessment. International Federation of Red Cross and Red Crescent Societies ProVention Consortium.

[21] Tracy, A., Javernick-Will, A., & Torres-Machi, C. (2021). Human-induced or natural hazard? Factors influencing perceptions of actions to be taken in response to induced seismicity. International journal of disaster risk reduction, 57, 102186.

[22] Walder, J. S., & O'Connor, J. E. (1997). Methods for predicting peak discharge of floods caused by failure of natural and constructed earthen dams. Water Resources Research, 33 (10), 2337–2348.