Natural Disasters Disproportionately Affect Populations and Regions: A Disaster Analysis of the 2004 Indian Ocean Tsunami

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This paper is a comprehensive review of the 2004 Indian Ocean Tsunami that took place in Sumatra, Indonesia. The causes, as well as the direct and indirect impacts of this natural disaster are explored to understand the tsunami's true damage and magnitude. A disaster risk analysis was conducted to provide an overview of the relationship between various interacting factors: the hazard, peoples' exposure to the hazard, and their vulnerability to the hazard. This analysis is key in interpreting the risk of the hazard and determining its deadliness. Solutions and efforts to improve safety and resilience after the disaster are analyzed through several hazard paradigm lenses. The paradigms provide a well-rounded overview of the multifaceted nature of a hazard to better understand, plan, and mitigate associated risks. An overview of geographic areas and populations most at risk, as well as prospective solutions are described. Finally, this paper briefly discusses the growing impact of climate change on the frequency, risk, and magnitude of future extreme weather events.

Introduction

Environmental hazards have been part of humanity for millennia. It was once believed that such disasters were 'acts of god', punishing people for their indiscretions.[1] However, humans have only recently been able to understand the full scope of environmental hazards, including causation factors, hazard monitoring, and risk mitigation.[1] The World Health Organization reports that environmental hazards kill approximately 90,000 people and affect almost 160 million people worldwide annually.[2] To assess the multifaceted topic of environmental hazards, it is important to define this phenomenon. A hazard is a natural or human-induced physical event that may have adverse impacts on life or property.[1] Environmental hazards originate from extreme geophysical or biological events, including epidemic disease, volcanos, avalanches, floods, hurricanes, and more.[1] There is an increasing number of impacts, doubling from 2005 to 2010, along with adaptation and vulnerability associated with hazards.[1] Arguably, the most captivating large-scale hazard was the 9.[1] magnitude earthquake that triggered the Indian Ocean tsunami of December 26 2004, occurring off the West Coast of Sumatra, Indonesia. This natural disaster affected many communities in Southeast Asia, including Indonesia, India, Sri Lanka, and Thailand (Figure 1).[1] This event is one of the deadliest recorded in history, gravely affecting millions of people in several coastal communities and resulted in huge economic losses.[3] While the economic losses of this disaster are less than other events of similar magnitude, this event remains far more deadly.[1] Therefore, it is important to explore what factors contributed to the increased vulnerability of these coastal regions and populations to better mitigate disaster risk in the future and to ensure the livelihood of such communities. As well, it is key to employ systemic awareness to assess the projected frequency, risk, and impact of future natural hazards to translate this knowledge to populations, policy makers and relevant stakeholders to further increase hazard predictability and preparedness. This paper will discuss the hazard's causation factors (disaster risk, including vulnerability and exposure to the hazard) and how these factors exacerbated the disaster and its impacts. Furthermore, this paper will outline key contributing factors to disaster risk, including climate change and other demographic characteristics such as socioeconomic status (SES), age, and gender.

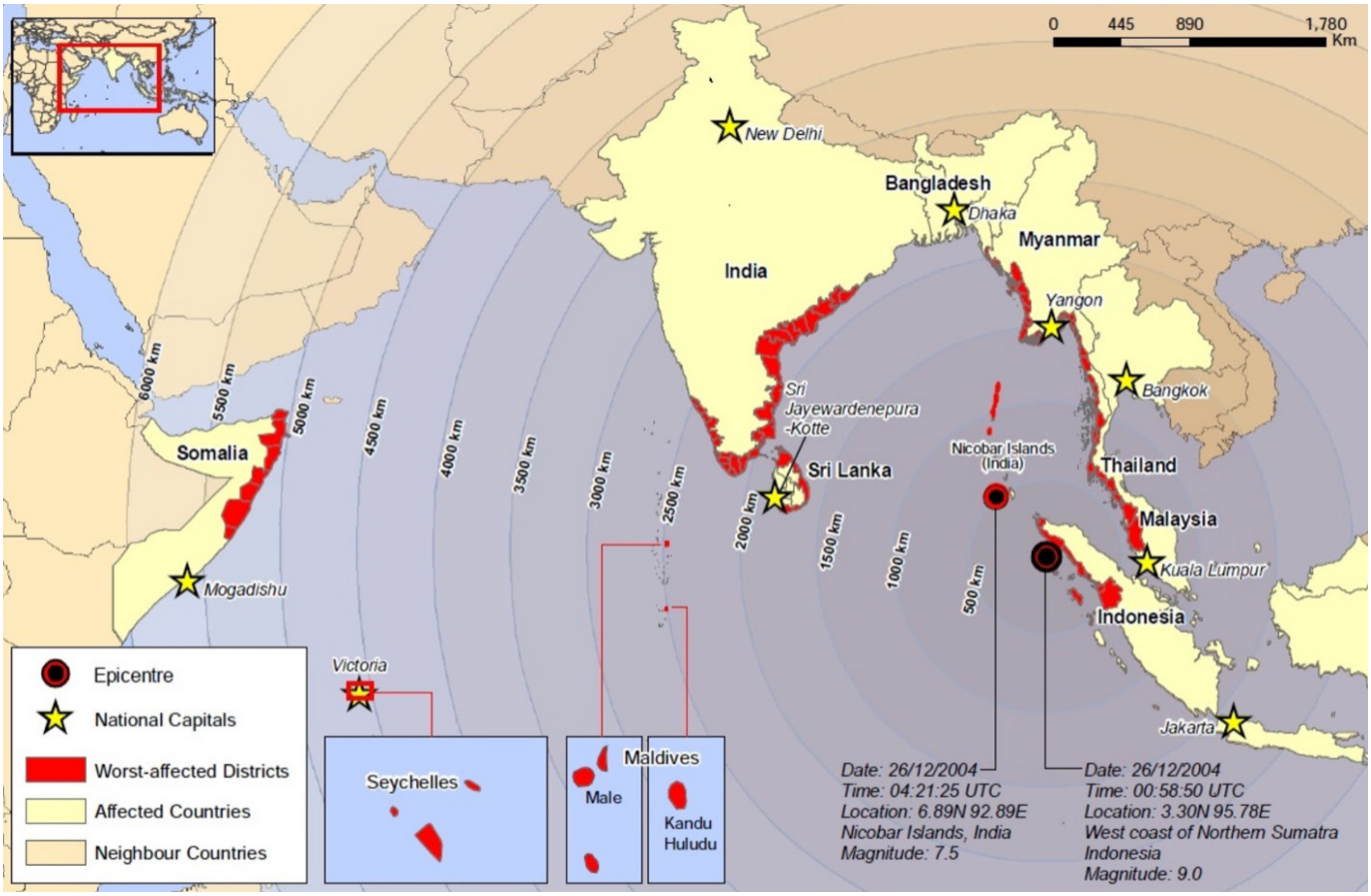

Figure 1 | Geographic Regions Affected by the 2004 Indian Ocean Tsunami.[20]
This figure illustrates the geographic regions that were affected by the 2004 Indian Ocean Tsunami by varying degrees of severity. Figure adapted from the UNOCHA website.[20]

Overview and Causes

A tsunami evokes giant sea waves that are produced by a submarine earthquake or slope collapse into the seabed.[4] Tsunamis can travel at very high speeds of about 300 to 600 miles per hour with minimal energy loss.[4] A tsunami may be less than a foot tall on the open ocean surface, which is typically the reason they go unnoticed in the beginning.[5] Sea waves generated from a tsunami can arrive at ten to forty-five-minute intervals and continue for several hours.[4] The Indian Ocean tsunami was triggered by an earthquake, a geological natural disaster, due to the sliding portion of the Earth's crust, called the India plate, which slid under a section called the Burma plate.[5] The Sumatra earthquake was centered in the Indian Ocean and caused the sea floor to uplift by several meters.[6] The earthquake's 9.1 magnitude was one of the highest recorded in history, with the energy of about 23,000 Hiroshima-type atomic bombs.[6] Over the next seven hours, a series of catastrophic waves devastated the coastal areas of numerous regions.[6]

Impacts

The 2004 Indian Ocean tsunami resulted in both direct and indirect impacts, causing devastating damage to coastal communities (Figure 1). Direct impacts include over 275,000 fatalities, mostly in Sumatra, and the displacement of over 1.1 million people.7 Furthermore, millions of people were left destitute.8 India reported a total of 19,592 injuries, with most injuries (84.1%) occurring in the Andaman and Nicobar Islands and in Tamil Nadu.9 Indirect impacts include short-term and long-term mental health issues (i.e., post-traumatic stress disorder and depression), interruption of basic healthcare services, public transit, and education in addition to shortages of food and clean water.[10] The total economic losses accumulated to $9.9 Billion.[7] This estimate includes direct impacts due to infrastructural damage and damage to assets (i.e., personal belongings, cars, etc.), as well as indirect impacts due to lack of economic activity (i.e., fisheries, markets, tourism) in these regions.[10]

Disaster Risk Analysis

As part of the direct impact, a huge loss of life was recorded, mainly resulting from drowning, which far outweighed the economic damages.[6] Other natural hazards, including the 2011 Great East Japan tsunami, yielded significantly higher economic damages; however, had less than half the amount of fatalities.[1] Similar trends are observed with Hurricane Katrina in 2005 and Hurricane Harvey in 2017 that also illustrate trends of higher economic losses and fewer fatalities.[1] This begs the question: what made the 2004 Indian Ocean tsunami so deadly? Was there a warning system in place, and if so, why was the number of fatalities still so high? This dilemma can be critically analyzed using disaster risk, which describes the interaction of three factors: the hazard, peoples' exposure to the hazard, and their vulnerability to the hazard.[1]

Vulnerability refers to the characteristics of people and their living situation that influences their capacity to deal with the impact of a natural hazard.[1] Factors that influence vulnerability are the ability to cope, access to resources, and household arrangements.[1] Populations living in coastal areas along the Indian Ocean are mostly of low SES, which can limit their access to insurance services and private transportation.[11] Furthermore, this disaster demonstrated the 'harvesting effect' as a disproportionately large number of vulnerable people were killed.[9] In general, those with lower levels of education, children, older adults and women experienced a much higher mortality rate.[11] The elderly had the highest mortality rate of any demographic, recorded at 28.1% among those ≥ 70 years of age.[9] Conversely, the mortality rate in individuals aged 20 to 29 years old was just 10.5%.[9] Finally, the United Nations International Children's Emergency Fund (UNICEF) estimated that ~50% of fatalities were in children.[9] These groups are more vulnerable and therefore more susceptible to the hazard due to discrepancies in physical attributes and athleticism, among other factors.[11]

Exposure refers to the presence of people, infrastructure or other assets in places that could be adversely affected by a hazard.[1] Higher mortality rates were observed among individuals from households relying on fishing, as such individuals typically reside in dwellings in low-lying coastal areas, that are susceptible to flooding or heavy rainfall.[11] The infrastructural integrity of buildings and homes in these regions are not tsunami-resistant as these coastal communities are in developing countries.[12] Most of the damage was to coastal infrastructure such as fisheries, harbours, bridges, buildings and homes, creating not only a loss of economic livelihood, but also extensive debris which contributed to injuries and deaths.[12] Vulnerable groups of people who do not have the means to protect themselves and deal with disaster, combined with increased exposure, leads to increased disaster risk.

High exposure and vulnerability are the result of poor infrastructure development leading to environmental degradation, rapid and poorly planned urbanization in hazardous areas, a lack of government policy, and the scarcity of sustainable livelihood options.[13] Inequities such as SES, demographic characteristics, and health-related disparities influence local coping and adaptive capacity, which can lead to disaster risk management and adaptation challenges.[13] Developed countries are far better equipped financially and institutionally to respond and adapt to projected changes due to disaster risk and climate extremes than are developing countries.[13] Furthermore, humanitarian relief - which is required when disaster risk reduction measures are inadequate – is particularly challenging for economically less-diversified countries.[13] These countries face challenges in providing public goods, absorbing losses, and utilizing disaster relief and reconstruction resources.[13]

Studies suggest that increasing climate variability directly impacts the frequency, duration, intensity, spatial context, and timing of weather extremes, which can result in unprecedented extremes.[13] This includes highly variable atmospheric conditions such as temperatures, motions, and precipitation.[13] Model projections indicate that precipitation, rising mean sea levels and extreme hot and cold days will increase in many regions globally.[14] In fact, the frequency of heat waves is projected to increase from once every 20 years to once every other year by the end of the 21st Century.[14] As well, climate variability can lead to extreme conditions by crossing a critical threshold, or by occurring simultaneously with other non-extreme climate events.[13] For instance, climate extremes such as floods and landslides can result from an accumulation of weather events such as increases in precipitation that are, individually, not extreme.[13]

Hazard Paradigm Analysis

The ideologies behind hazard paradigms are geared towards making sense of disasters, their contributing factors and disaster risk.[15] These paradigms represent human perceptions about how anthropogenic influences exacerbate disaster risk and disaster-related consequences. However, disasters are primarily a naturally occurring process.[15] Hazard paradigms offer relevant stakeholders such as engineers, land-use planners, and the general population information about vulnerable groups and regions, preventative measures, and strategies to mitigate disaster risk and damage.[15]

The Engineering Paradigm was established prior to the 1950s. It was the first paradigm to focus on the built environment to ensure that infrastructure was hazard resistant.[1] A reconstruction effort after the Indian Ocean tsunami aimed to reduce the vulnerability of these populations to future disasters.[16] The intention was to build stronger, more resilient settlements by constructing structural countermeasures, elevating land surfaces, and installing evacuation roads.[17]

The Behavioural Paradigm was founded and used between 1950 to 1970. This paradigm focused on how people perceive risk.[1] By understanding individual choices and motivations for settling in hazard-prone land, scientists can use this information to educate these individuals, and ultimately prevent them from living there.[1] In this paradigm, modifying peoples' exposure to hazards is accomplished by ensuring proper warning systems are in place and adequate land use planning.[1] After the 2004 disaster, an extensive warning system, known as the tsunami detection system, was established in the Indian Ocean.[18] In the future, if an earthquake begins, the seafloor sensors and surface buoys relay satellite signals to government warning centers globally, alerting them that a tsunami is imminent.[18] This system increases the evacuation time for coastal communities. Land use planning, in the case of disaster risk management, involves transforming exposed areas into regions that do not support residential areas and businesses.[1] In 2005, the Indonesian government enforced a land use regulation: areas within 2 km of the shoreline could not be used for housing or economic activity.[17] This reduces risk as mainly coastal infrastructure and individuals living and working in coastal areas were most affected by the 2004 tsunami.[12]

The Development Paradigm, used between 1970 and 1990, believes that people should expect that certain regions are more disaster-prone and therefore, should choose to live accordingly.[1] Marginalization is a theory that emerged from this paradigm, which describes a phenomenon where vulnerable people are forced to interact with the environment in ways that increase their risk due to reasons outside of their control.1 Prior to the disaster, vulnerable people were forced to live in dwellings that were highly exposed because they did not have the financial means to relocate to safer grounds, and relied on fishing for their livelihood.[12]

The Complexity Paradigm is the current paradigm recognized by scientists today. It encompasses all three paradigms and states that people are not simply victims of disasters because they choose to pursue environmental amenities despite risk.[1] The focus of this paradigm is the facilitation theory. This theory states people are allowed to pursue environmental amenities despite the associated risk and are encouraged to do so by institutional and/or economic structures such as governments and insurance companies.[1] In this case, during the reconstruction and land use planning process, some residents requested to return to where they resided initially.[17] This occurred because many were seeking a rapid revival of their livelihoods, which was available to them within these coastal regions.[17] As a result, the Japan International Cooperation Agency (JICA), an agency that undertook the urban planning in tsunami-affected zones in 2005, put in place several countermeasures.[17] For instance, the placement of evacuation roads and facilities to foster proper safety and disaster risk mitigation measures.[17] Eventually, many houses were rebuilt in tsunami-affected zones, originally designated as restricted areas as part of the land use planning project.[17] Institutional structures facilitated the return of these residents to their coastal villages, recreating a residential area that is vulnerable to future tsunamis.[17]

Future Recommendations

Unfortunately for such coastal regions, the tectonic plates centered in the Indian Ocean have been pushing against each other and building pressure for millennia.[5] This will continue, likely leading to future earthquakes and tsunamis.[5] More importantly, climate variability remains a major contributing factor to the frequency, risk, and impact of extreme climate events.[13] As a result, the occurrence of disasters is projected to increase due to climate change.[14] As natural disasters increase in frequency and magnitude, vulnerable regions and groups will become even more marginalized as such areas will no longer offer sustainable livelihoods.[17] As a result, relocation and displacement would be inevitable. Large scale migration will foster new pressures in areas of relocation, creating an even more difficult living situation for those who immigrated as well as for current residents.[13] Relocation may also hinder existing community ties if not done in a well-planned manner.[17] Taken together, this confirms that the risk remains high for coastal communities. Understanding the impact and the risks that climate change poses with respect to natural hazards is key to mitigate disaster risk in the future. Countries may find themselves better equipped to manage disaster risk if national development and sector plans, including climate change adaptation strategies, while employing a tailored approach for vulnerable areas and groups.

The four paradigms play a role in understanding, planning, and preventing risk. In today's day and age, scientists know more than ever about predicting, preventing, and mitigating risk, yet there is an increasing number of disasters and disaster damage in the world.[1] This is largely because of people, as the Complexity Paradigm explains: people pursue environmental amenities despite risk and are supported in doing so by institutional structures.[1] In this case, the land use planning outline and its associated restrictions were not followed as many homes and businesses were re-built in disaster-prone areas, leaving locals exposed and at risk. Furthermore, vulnerable people have jobs that degrade the environment, which are often located in exposed areas. This also increases their risk.

The most effective strategies for reducing risk are concentrated in the Behavioural and Engineering Paradigms, in addition to increasing the awareness and education of relevant stakeholders. Frequently observed dilemmas in disaster recovery are speed of reconstruction and restoration of livelihoods while ensuring dwellings and communities are safer against future disasters.[17] As a result, strong government leadership is required to enforce reconstruction policy and land use planning regulations to keep such communities safe long-term.[17] Also, as prolonged reconstruction processes negatively impact the recovery of economic and social activities, it is important that for areas where future disasters are anticipated, pre-disaster recovery planning should be prioritized as a preparedness measure.[17] Additionally, ensuring advanced notice is provided by local warning systems and increasing awareness of such systems and other indicators is key for the prosperity of coastal communities.[19] For instance, a rapidly receding ocean, where the seafloor, fish and even boats are left exposed on the sand, is a sign that a tsunami is approaching.[19] Therefore, including this information in the national curriculum of all schools would be beneficial by tailoring disaster planning to protect this highly vulnerable group.[19]

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