A statistical analysis and comparison of historical earthquake and tsunami disasters in Japan and Indonesia

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ABSTRACT

This study aims at quantitatively investigating the past trend of natural disasters, focusing upon earthquakes and tsunamis, which occurred in Japan and Indonesia with respect to their occurrences and human casualties; including both deaths and missing people (D&M). We apply mathematical policy analysis techniques in our natural disaster risk analysis and assessment in order to develop policies to mitigate the casualties caused by these natural disasters. First, we review the historical trend of earthquakes and tsunamis related to their occurrences and D&M from 1900 to 2012 to explain their occurrence frequency and forecast the D&M using probabilistic models. We divide the entire period into three time-periods and compare their tendency in both countries. Using about 100 years of data, our study confirms that the Exponential distribution fits the data of inter-occurrence times between two consecutive earthquakes and tsunamis, while the Poisson distribution fits the data of D&M. The average numbers of inter-occurrence times of earthquakes for Japan and Indonesia are 186.23 days and 167.77 days, respectively, whilst those of tsunamis are 273.31 days and 490.71 days, respectively. We find that earthquakes with magnitudes ranging from 6.0 Mw to 7.4 Mw and having epicenters in the mainland cause more casualties, while those with magnitudes 7.5 Mw and above and having epicenters offshore/at sea cause relatively fewer casualties. This implies that mainland earthquakes have higher probability to bring more casualties than the sea earthquakes. In terms of fatalities, earthquakes and tsunamis have caused more deaths in Japan than in Indonesia.

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1. Introduction

Japan and Indonesia are two archipelago countries with populations of over 100 million people. Both of them are also located along the Pacific Ring of Fire, which makes them particularly prone to natural disasters. Throughout their history, Japan and Indonesia have encountered extensive devastation as a consequence of a variety of natural disasters including both geophysical disasters such as earthquakes, tsunamis, landslides, volcanic eruptions, and hydro meteorological disasters such as typhoons, rainstorms, floods, heavy snow, droughts, strong winds and heat waves [1]. Among these natural disasters, some commonly occur in both Japan and Indonesia, namely earthquakes, volcanic eruptions, and tsunamis.

Natural disasters in relation to exposure and vulnerability all have corresponding economic costs [2] and social costs [3]; indeed, "if there were no costs they would not be classified as disasters in the first place" [4]. The economic impact of a disaster usually consists of direct (e.g. damage to infrastructure, crops, housing) and indirect (e.g. loss of revenue, unemployment, market destabilization) costs to the local economy. Given the damage and

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Table 1

Comparison between the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami.

Item	2004 tsunami	2011 tsunami
Earthquake magnitude	9.3	9
Size of rupture (km^2)	1000×150	500×200
Max. tsunami height (m)	50.9	40.5
No. of deaths	230,000	20,000
No. of affected countries	15	Mostly in Japan

costs that natural disasters can bring, it is important to understand the "nature" of disasters in order to assist policy makers and planners who are involved in disaster preparedness and mitigation.

Since Japan and Indonesia have a long history of experiencing natural disasters and the lessons learned from each disaster are usually documented by various agencies, non-government organizations and academic reports, analyzing historical data can assist in identifying the main vulnerabilities and priority areas in relation to natural disasters such as earthquakes and tsunamis. Gusiakov estimate that about 700,000 fatalities are resulted from tsunamis during the last 250 years from 1755 to 2005 [5]. Hence, we believe that investigating the frequency and intensity of recent tsunamis is important [6]. Moreover, according to Suppasri et al. [7], Japan faces the highest tsunami risk, followed by Indonesia. The most recent tsunami events, which claimed many lives and caused severe damages are the 2011 Great East Japan tsunami and the 2004 Indian Ocean tsunami. A comparison of these tsunamis is presented in Table 1 [8]. Powerful earthquakes with magnitudes of class 9.0 Mw [1] triggered both of these tsunamis. Significant differences between these two tsunamis include the number of fatalities, in which the 2004 Indian Ocean tsunami caused fatalities about ten times greater than that of the 2011 Great East Japan tsunami, and the number of countries affected.

Earthquakes are the most destructive natural hazard, and one of the most destructive earthquakes in Japan was the Great Kanto earthquake that occurred in 1923. Earthquakes take place because of the sudden transient motion of the ground as a result of elastic energy. Earthquakes not only destroy villages and cities and result in many deaths, but subsequently may also cause destabilization of the economic and social structure of the nation [2,3,10]. Earthquakes can also trigger other natural disasters such as tsunamis, landslides, and volcanic eruptions.

In this study, a mathematical modeling approach is used to analyze the natural disasters, namely earthquakes and tsunamis, in Japan and Indonesia from 1900 to 2012 (note: for 2012, the data cover only up to mid-2012, due to the availability of the existing database when this study was conducted). First, we will describe the historical data of natural disasters in Japan and Indonesia from 1900 to 2012. Then the past data of earthquakes and tsunamis in Japan and Indonesia from the same periods will be presented in Section 3. Descriptive statistical analyses will be used to present the changes in the frequency and the number of D&M. In Section 4, probability models will be used to estimate the parameters to represent the number of D&M resulting from earthquakes and tsunamis and the inter-occurrence times or number of days between these natural disasters. From the results of the quantitative analyses, the properties of earthquakes and tsunamis will be presented using parameter estimates, which can be used to estimate the expected social costs (in the form of D&M) and to plan for disaster preparedness and mitigation by using the inter-occurrence times of earthquake and tsunami events. Finally, we will conclude this study with the summary and policy recommendations.

2. Natural disasters in Japan and Indonesia

This section will briefly describe the natural disasters that occurred in Japan and Indonesia during the period 1900–2012. Historical data from the International Disaster Database (EM-DAT) [11] will be used to present the number of D&M and natural disasters from 1900 to 2012. For a disaster to be entered into the EM-DAT database at least one of the following criteria must be fulfilled: ten or more people are reported killed, one hundred or more are reported affected. A state emergency is declared, and a call is made for international assistance.

Fig. 1 presents the number of natural disasters and D&M from 1900 to 2012 in Japan. Here, the highest number of D&M is 148,344, which occurred in 1923, a year that had "only" four recorded natural disasters (two earthquakes, a landslide and a storm). One of these disasters is known as the 1923 Great Kanto earthquake, which caused about 99,331 deaths. Because the earthquake struck at lunch time (11:58 am) when many people were cooking with fire, many people died as a result of the many large fires that broke out. Some fires developed into firestorms that swept across cities. The second largest number of D&M is 25,136, which occurred in 2011, the year in which the most destructive tsunami in Japan occurred, namely, the 2011 Great East Japan tsunami, which occurred at 14:46 pm on March 11th 2011 and caused about 19,057 deaths. In addition, regarding the tsunamis in Japan, besides the 2011 Great East Japan tsunami, Japan has experienced other large tsunamis, namely the 1933 Showa-Sanriku, which occurred on March 2nd 1933 at 02:31 am and the 1896 Meiji tsunami, which occurred on June 15th 1896 at 19:32 pm. The 1933 Showa and 1896 Meiji tsunamis had epicenters located off the coast of Sanriku of the Tohoku region of Honshu and were generated by 8.4 Mw and 8.5 Mw earthquakes and attained a height of approximately 28 and 25 m resulting in nearly 3000 and 22,000 deaths, respectively [12]. The third largest number of D&M is 6158, which occurred in 1945. The natural disasters and estimated fatalities in 1945 are an earthquake in Mikawa (1961 deaths), the Akune storm (451 deaths) and the Makurazaki storm (3746 deaths).

Fig. 2 shows the number of natural disasters and D&M in Indonesia during the period of 1900–2012. In Fig. 2, the

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[1] The primary magnitudes of earthquakes used in this paper, as taken from the Significant Earthquake Database (SED) and the Global Historical Tsunami Database (GHTD) issued by the National Geophysical Data Center (NGDC), are measured in Moment Magnitude Scale, abbreviated as MMS and denoted as Mw or M.