International Journal of Disaster Risk Reduction 7 (2014) 122–141

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

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

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ARTICLE INFO

Article history:
Received 16 May 2013
Received in revised form
8 October 2013
Accepted 8 October 2013
Available online 2 November 2013

Keywords:
Natural disaster
Earthquake
Tsunami
Stochastic
Probabilistic model
Disaster mitigation policy

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.

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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http://dx.doi.org/10.1016/j.ijdrr.2013.10.003

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

[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.

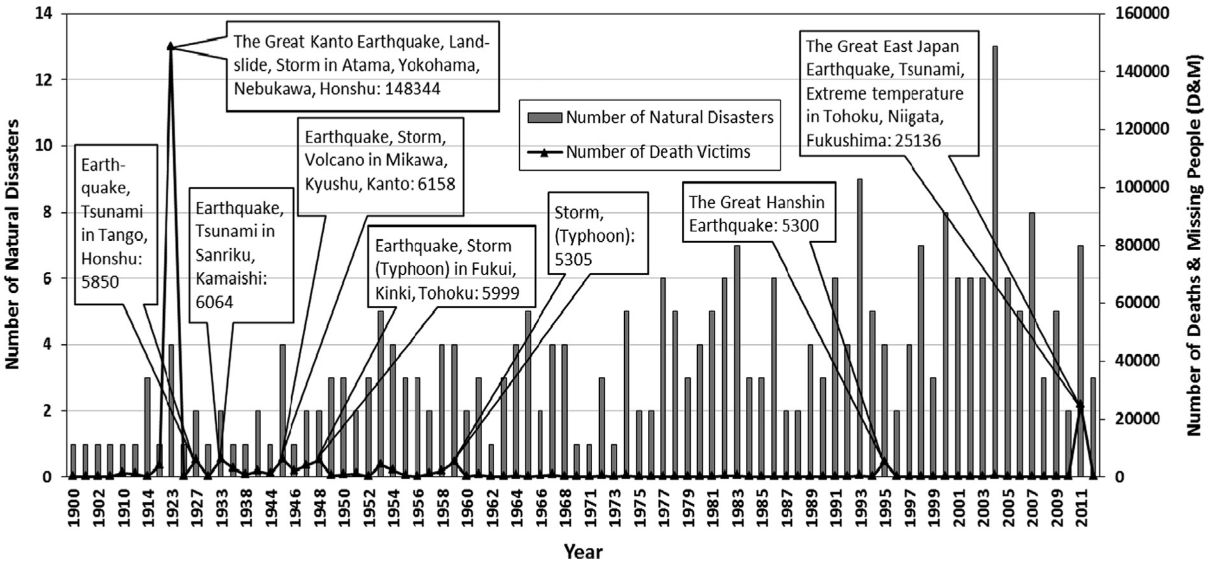

Fig. 1. Number of natural disasters and number of depths and missing people in Japan from 1900 to 2012.

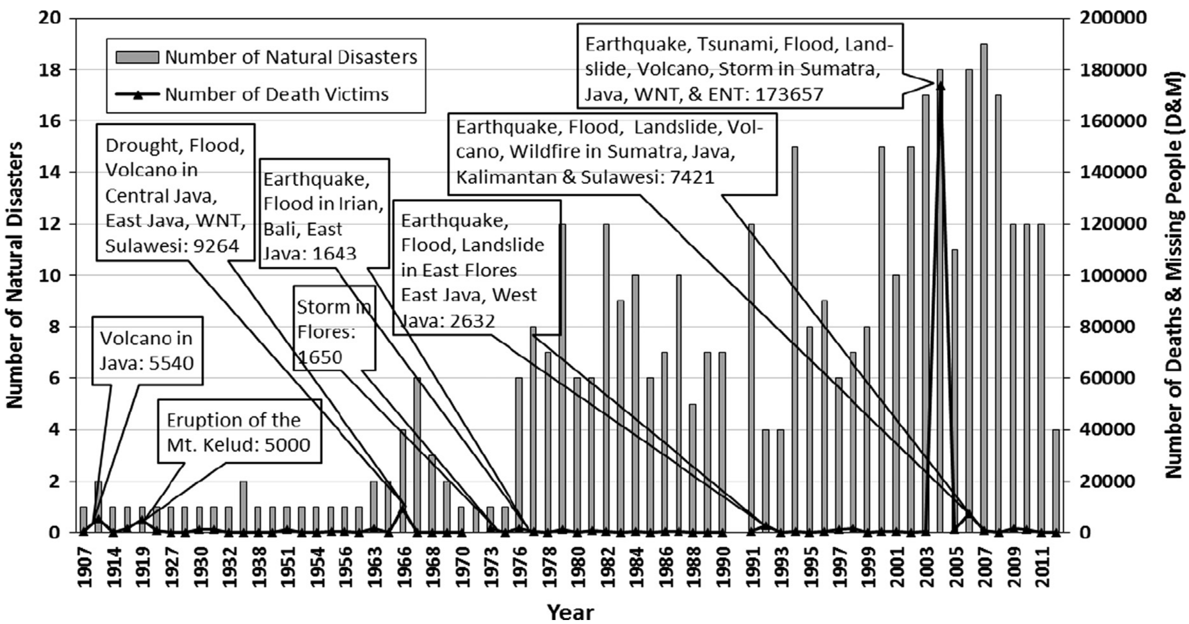

Fig. 2. Number of natural disasters and number of deaths and missing people in Indonesia from 1900 to 2012.

highest number of D&M is 173,657 people, which happened in 2004, a year that had 18 recorded natural disasters. One of these 18 natural disasters was one of the greatest recorded tsunamis in history, that is the 2004 Indian Ocean earthquake and tsunami, which occurred on December 26th 2004 at 07:58 am. This disaster itself claimed as many as 172,761 lives in Indonesia alone. The second highest number of D&M caused by natural disasters occurred in 1966, during which about 9264 people lost their lives. The natural disaster events and estimated fatalities in 1966 are as follows: a drought in Lombok (8000 deaths), a flood in Java (176 deaths), a volcanic eruption in Mount Kelud (1000 deaths) and a volcanic eruption in Mount Awu (88 deaths). In third place are natural disasters that happened in 2006, which claimed about 7421 lives. In 2006, there were 18 recorded natural disasters, of which two of them are the 6.3 Mw earthquake in Yogyakarta which occurred on May 27th 2006 at 05:55 am and caused about 5757 deaths and the Tasikmalaya tsunami, triggered by a 7.7 Mw earthquake, that happened on July 17th, 2006 and killed about 802 people.

Fig. 3 presents the share of the number of natural disasters in Japan and Indonesia from 1900 to 2012. According to EM-DAT [10], the total number of natural disasters during the period in Japan is 294, while that in Indonesia is 416. In Japan, storms or typhoons, with 144 occurrences, have the highest share at 49%, followed by earthquakes with 57 occurrences (19%). In Indonesia, floods have the highest share at 35%

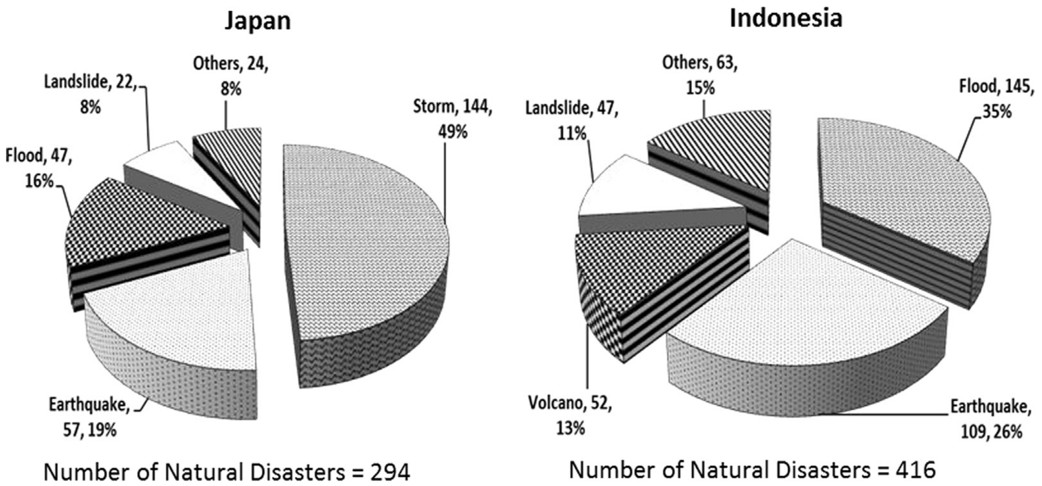

Fig. 3. Share of the natural disasters in Japan and Indonesia, 1900–2012.

with 145 occurrences, followed by earthquakes with 109 occurrences (26%). Hence, earthquakes (including subsequent tsunamis) are the second most frequent natural disaster in both countries.

3. Data analyses on earthquakes and tsunamis

As Fig. 3 indicates, earthquakes commonly occur in Japan and Indonesia. The earthquakes that occur sometimes are followed by other natural disasters such as landslides, eruptions, and tsunamis. Among these, as has been recorded by the NGDC [9],[2] tsunamis are one of the most deadly natural disasters causing not only substantial damage and loss, but also a significant number of D&M.

As our objective, this study uses the database of all the major earthquakes and tsunamis from NGDC for Japan and Indonesia from 1900 to 2012.[3] Regarding earthquake measurement, E. Wiechert of Göttingen, a German seismologist, introduced a seismograph with a viscously-damped pendulum as a sensor. He then modified his first seismograph into a mechanically-recording seismograph using an inverted pendulum. Thus, the seismograph was completed in 1900. Furthermore, in the early 1900s, B.B. Galitzin, a Russian seismologist, developed the first electromagnetic seismograph, which has proven to be much more accurate and reliable than previous mechanical instruments. Incidentally, all modern seismographs are electromagnetic. Thus, we consider the year 1900 as the beginning of the modern era of earthquake monitoring. In addition, the data available at EM-DAT also started from 1900. Thus, we decided to collect the data of earthquakes and tsunamis during the period from 1900 to 2012. The source of earthquake data is the Significant Earthquake Database (SED), issued by NGDC [13], which contains information on destructive earthquakes from 2150 B.C. to the present that meet at least one of the following criteria: Moderate damage (approximately $1 million or more), 10 or more deaths, Magnitude 7.5 Mw or greater, Modified Mercalli Intensity X or greater, or tsunami generated. SED contains information about the date and location of earthquake, earthquake parameters: moment magnitude scale (Mw) and focal depth (km), and earthquake effects: D&M and damage.

The source of the tsunami data is the Global Historical Tsunami Database (GHTD), also issued by NGDC [14]. This database consists of two related files containing information on tsunami events from 2000 B.C. to the present in the Atlantic, Indian, and Pacific Oceans; and the Mediterranean and Caribbean Seas. Although both databases are issued by NGDC, they have separated the consequences or effects of both disasters, such as fatalities, injuries, financial losses, houses destroyed and damaged houses. Therefore, in this study we are able to study the effects of earthquakes and tsunamis separately.

GHTD lists the date, cause, primary magnitude (Mw), location, maximum height of water (m), and number of D&M. All of these disasters fall within the disaster risk framework. Having at least one casualty is enough to satisfy the exposure criteria, but this does not mean that

[2] The National Geophysical Data Center (NGDC), located in Boulder, Colorado, is a part of the US Department of Commerce (USDOC), National Oceanic & Atmospheric Administration (NOAA). The NOAA/WDC tsunami database is a listing of historical tsunami source events and run-up locations throughout the world that range in date from 2000 B.C. to the present. The definition used in this database is the arrival or travel time of the first wave that arrives at a run-up location. The first wave may not have been the largest wave; therefore the travel time reported in the original source may have been the second or third wave. The events were gathered from scientific and scholarly sources, regional and worldwide catalogs, tide gauge reports, individual event reports, and unpublished works. There are currently over 2000 source events in the database with event validities >0 (0=erroneous entry). In this database, the validity of the actual tsunami occurrence is indicated by a numerical rating of the reports of that event: -1=erroneous entry, 0=event that only caused a seiche or disturbance in an inland/a mainland river, 1=very doubtful tsunami (certainty of tsunami occurrence is 25%), 2=questionable tsunami (certainty of tsunami occurrence is 50%), 3=probable tsunami (certainty of tsunami occurrence is 75%), and 4=definite tsunami (certainty of tsunami occurrence is 100%). In this study, we only include tsunami events in which have the certainty of a tsunami occurrence is above 50% (validity ≥ 2).

[3] The difference in the number of earthquakes and tsunamis of the EM-DAT and NGDC is due to differences in concepts and definitions and methodologies used in the collection of data by these two institutions.

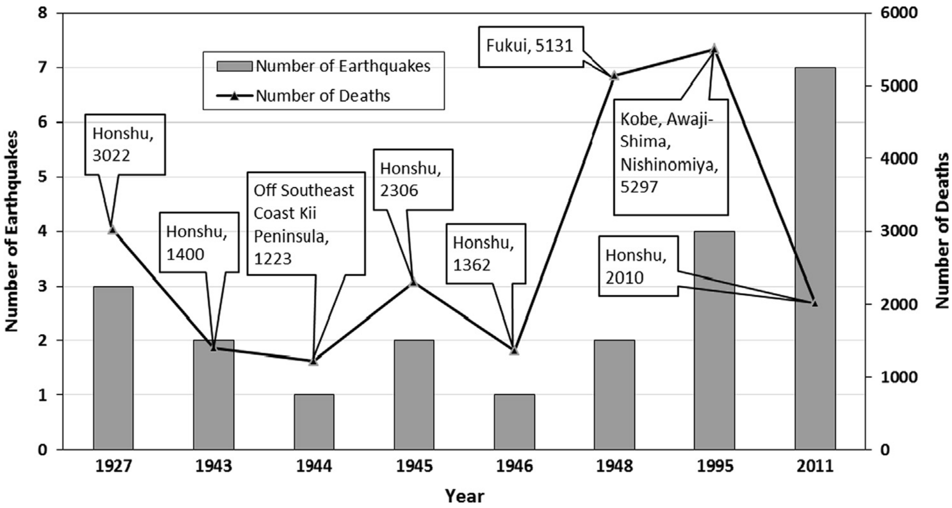

Fig. 4. Earthquakes that caused more than 1000 deaths by year in Japan.

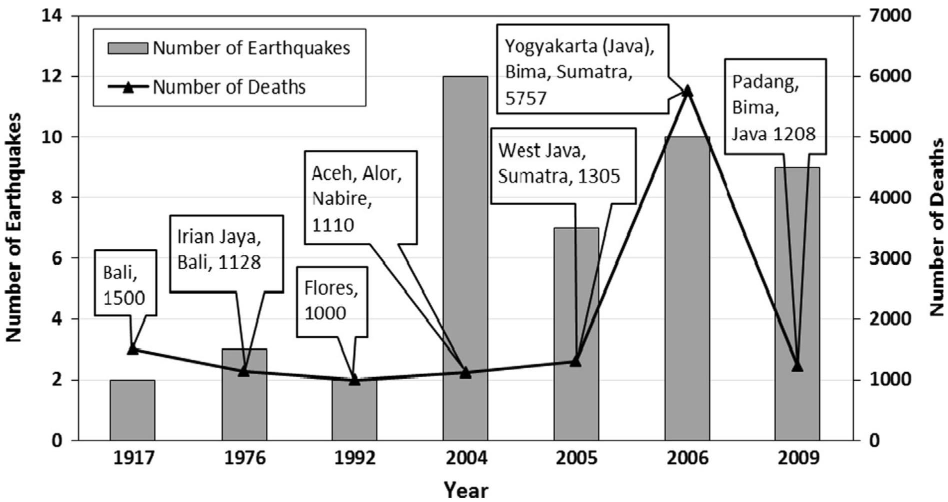

Fig. 5. Earthquakes that caused more than 1000 deaths by year in Indonesia.

a natural hazard without casualty cannot be considered as a disaster. There are a number of earthquakes and tsunamis in these data sources without any casualties, but the exposure may be in terms of the number of injured people, the number of internally displaced people and/or the actual amount of damage.

According to the NGDC database, there were 221 significant[4] earthquakes from 1900 to 2012 in Japan [13]. During this period, the earthquake that claimed the greatest number of D&M was the 1923 Great Kanto earthquake, followed by earthquakes that occurred in 1995, 1948 and 1927. The SED also reveals that almost all the major earthquakes, namely more than two-thirds, and a huge loss of life occurred on Honshu Island. For providing an overall picture only, Fig. 4 presents the earthquakes that caused D&M of more than 1000 people by year (exclude the 1923 Great Kanto earthquake).

In Indonesia, there were 246 significant earthquakes from 1900 to 2012 [13]. The earthquake that caused the most deaths occurred in 2006 with 5757 people, followed by earthquakes that occurred in 1917, 2005 and 2009. For an overall picture, Fig. 5 depicts the earthquakes that caused D&M of more than 1000 lives by year. The majority of large earthquakes struck on the islands of Sumatra, Java and Bali, Sulawesi and Irian Jaya, the four largest islands in Indonesia, leaving Kalimantan Island as the largest island not threatened, since it does not lie on the path of the Ring of Fire.

From 1900 to 2012, 149 tsunamis occurred in Japan [14]. Of these tsunamis, 20 tsunamis claimed a substantial number of victims, namely tsunamis that occurred in Sagami bay, Sanriku, off the southeast coast of the Kii Peninsula, off the south coast of Honshu, and off the Pacific coast of Tohoku where the 2011 Great East Japan tsunami took place. Fig. 6 shows the tsunamis that caused more

[4] The definition of significant earthquake follows the criteria established by the NGDC.

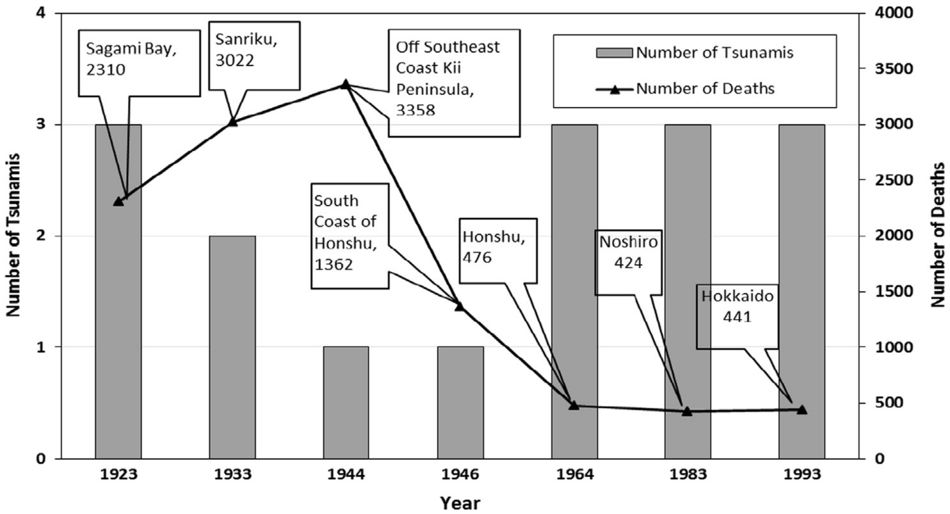

Fig. 6. Tsunamis that caused more than 100 deaths by year in Japan.

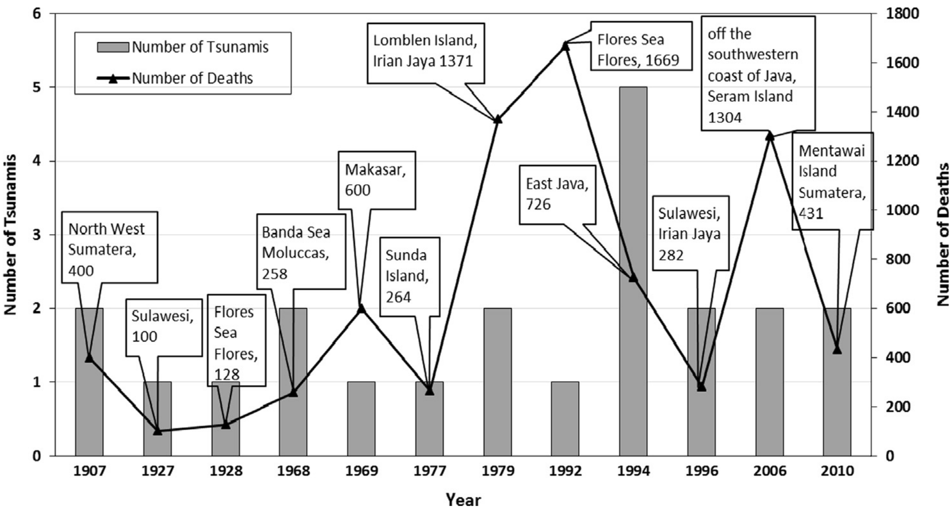

Fig. 7. Tsunamis that caused more than 100 deaths by year in Indonesia.

than 100 deaths by year (exclude the 2011 Great East Japan tsunami).

In Indonesia beside the 2004 Indian Ocean tsunami, which had its epicenter off the west coast of Aceh, there were 84 tsunamis during 1900–2012 [14]. They include tsunamis in Lomblen Island, Flores and off the coast of West Java. Fig. 7 shows the tsunamis that caused more than 100 deaths by year (exclude the 2004 Indian Ocean tsunami).

If we investigate further, the 2011 Great East Japan earthquake and the 2004 Indian Ocean earthquake themselves did not caused a large number of D&M. In fact, it was the subsequent natural disasters, namely tsunamis, which caused thousands of D&M and great damage. In addition, the location of the epicenter of an earthquake is also a significant factor in causing D&M, which is an issue we will return to in Section 4.

Fig. 8 shows the share of the causes of tsunami events in Japan and Indonesia during the period 1900–2012. We find that most of the tsunamis are caused by earthquakes alone, 95% and 88%, respectively, in Japan and in Indonesia. As an earthquake with a certain level of magnitude can trigger a tsunami, it is necessary for the existence of an early warning system (EWS) against the possibility of a tsunami. Moreover, as pointed out by Oki and Nakayachi [15], conveying basic knowledge of a hazard is also very important; in other words, to enhance the effectiveness of the EWS, a good under-standing and improved public appraisal of tsunamis are important. From Figs. 3 and 8, we see that earthquakes are common in Japan and Indonesia, and earthquakes are the main trigger of most tsunamis. The question is whether there are similar patterns between these two natural disasters in Japan and Indonesia from 1900 to 2012.

To better analyze the trend of earthquakes and tsunamis in Japan and Indonesia, we divide the whole period into three periods, period I: 1900–1937, period II: 1938–1975 and period III: 1976–2012. By dividing the whole

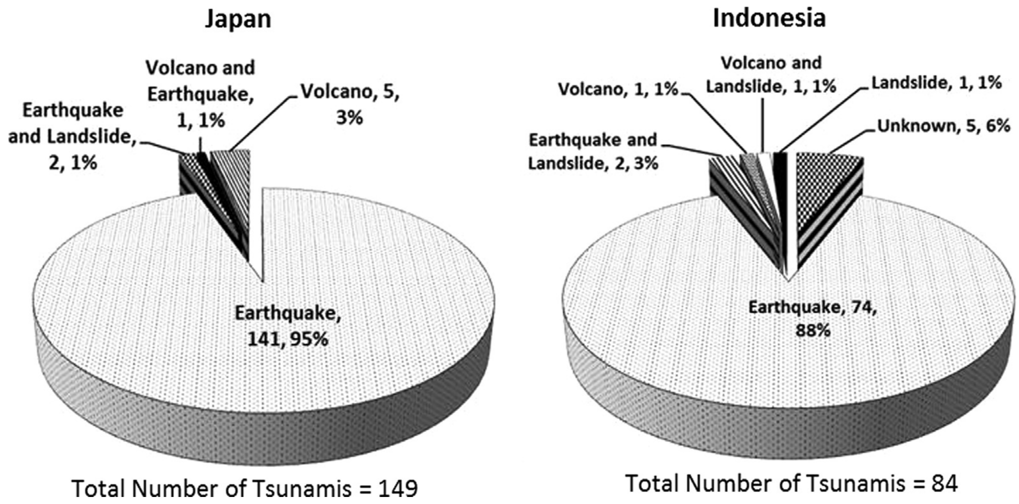

Fig. 8. Share of causes of tsunamis in Japan and Indonesia.

Table 2
Basic statistics on the frequency of earthquakes and tsunamis.

Period	Earthquake				Tsunami			
	Total	Mean	Std. dev	Max	Total	Mean	Std. dev	Max
Japan								
I	53	1.39	1.37	5	29	0.76	1.22	5
II	71	1.87	2.32	11	61	1.61	2.13	10
III	97	2.62	2.20	8	59	1.59	1.28	4
All	221	1.96	2.05	11	149	1.32	1.63	10
Indonesia								
I	61	1.61	1.20	4	28	0.74	0.79	3
II	46	1.21	1.26	4	20	0.53	0.86	3
III	139	3.76	2.92	12	36	0.97	1.30	5
All	246	2.18	2.23	12	84	0.74	1.02	5

period into three sub-periods with almost equal length of 36 or 37 years, we try to investigate the historical trend of these natural disasters. However, as we described in the beginning of Section 3, we need to take e.g. technology progress related to earthquake measurement such as earthquake monitoring devices [16].

Table 2 presents the basic statistics on the frequency of earthquakes and tsunamis in Japan and Indonesia from 1900 to 2012. In this period there are years without any disasters caused by earthquakes or tsunamis. Different patterns can be observed. In Japan, the frequency of tsunamis increased 110.34% from periods I to II and declined around 3.28% in period III. In Indonesia, the frequency of tsunamis declined 28.57% from periods I to II and increased about 80% in period III.

Fig. 9 displays the histogram of the frequency of earthquakes and tsunamis, which occurred in Japan and Indonesia from 1900 to 2012 by year. In Fig. 9, the horizontal coordinate indicates the number of earthquakes and tsunamis in each year, while the vertical coordinate shows the number of years corresponding to each frequency. We can see that earthquakes and tsunamis are rather rare events as in almost 80% of the years they occur less than twice a year.

The trend of earthquakes with magnitude 5 Mw and above and their epicenter location in Japan is shown in Fig. 10. In Japan, this has an almost linear trend of increases in total occurrences, where from period I to period II the total number increased 33.96%, and increased again to 36.62% in period III. However, in terms of the epicenter location, which is divided into offshore/sea and mainland, the trends are not totally linear. The data reveal that the percentage of sea epicenters increased 11.37% between periods I and II but decreased about 12.44% between periods II and III.

In Indonesia, as depicted in Fig. 11, the trend of total earthquake occurrences is not linear, where from periods I to II the total number decreased 23.33%, but then increased more than threefold to 202.17% in period III. In terms of the epicenter location, the trend is also not linear. The data show that the percentage of sea epicenters increased 3.9% between periods I and II but decreased 14.9% between periods II and III.

Table 3 lists the inter-occurrence times (in days) between two consecutive occurrences of earthquakes and tsunamis in Japan and Indonesia from 1900 to 2012. The higher the number is, the longer the duration between two consecutive earthquakes and tsunamis becomes. From Table 3 we find that the average number of days between two consecutive tsunamis in Japan was about half of that in Indonesia. This finding conforms to the results of a study by Suppasri et al. [7].

Unlike the case of tsunamis, the average inter-occurrence time between two consecutive earthquakes in Indonesia is smaller than that in Japan, which implies that earthquakes are relatively more frequent in Indonesia than in Japan. However, in general, both earthquakes and tsunamis show the same pattern in Japan and Indonesia; namely, they show a declining trend in the average of inter-occurrence times. Once again, it is a warning that the frequency of occurrences of these two natural disasters will be more frequent in the future.

Table 4 shows the basic statistics of D&M caused by earthquakes and tsunamis that occurred in Japan and

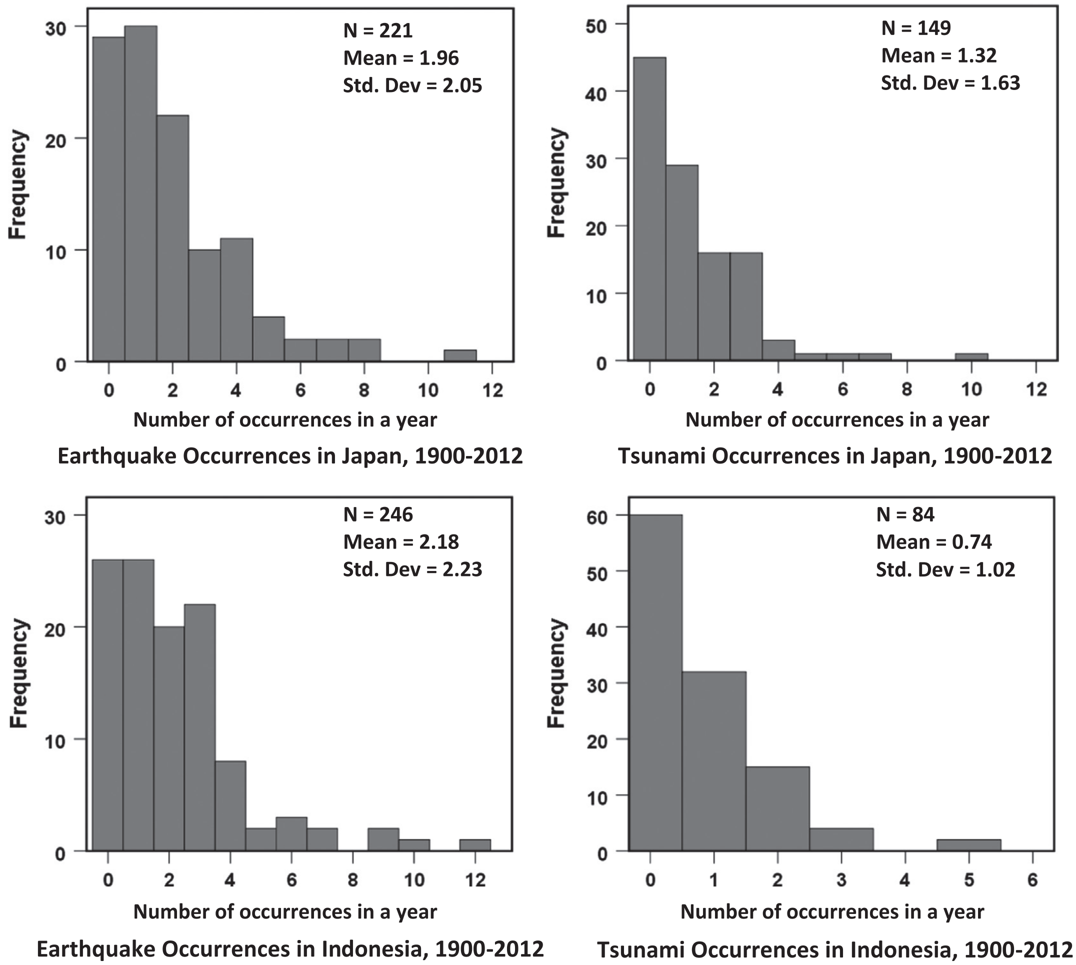

Fig. 9. Histogram of the annual frequency of earthquakes and tsunamis occurred in Japan and Indonesia.

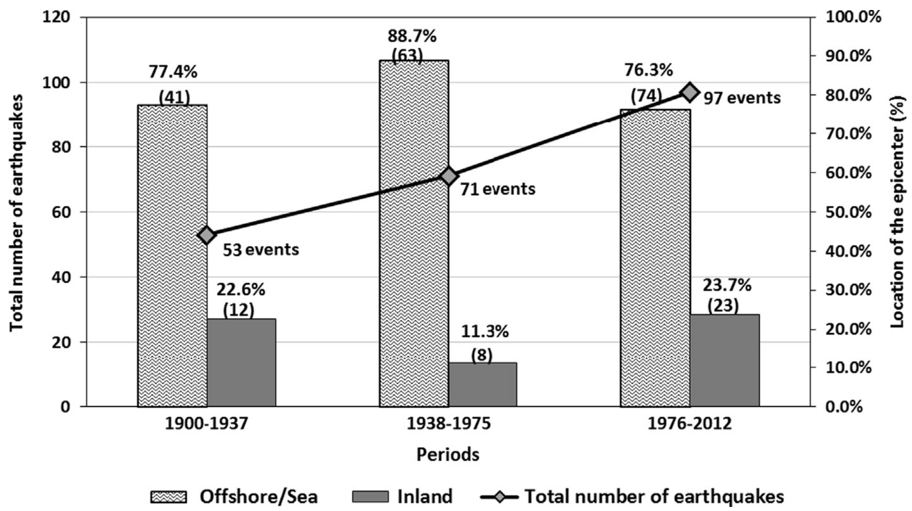

Fig. 10. Trend of earthquakes (magnitude ≥ 5 Mw) occurrences during 1900–2012 in Japan.

Indonesia from 1900 to 2012. As we mentioned in Section 2, there are a number of earthquakes and tsunamis without any casualties. Due to the extremely large D&M for the 2011 Great East Japan tsunami, the 2004 Indian Ocean tsunami, and the 1923 Great Kanto earthquake, we exclude these cases in the D&M data in Table 4. For the whole

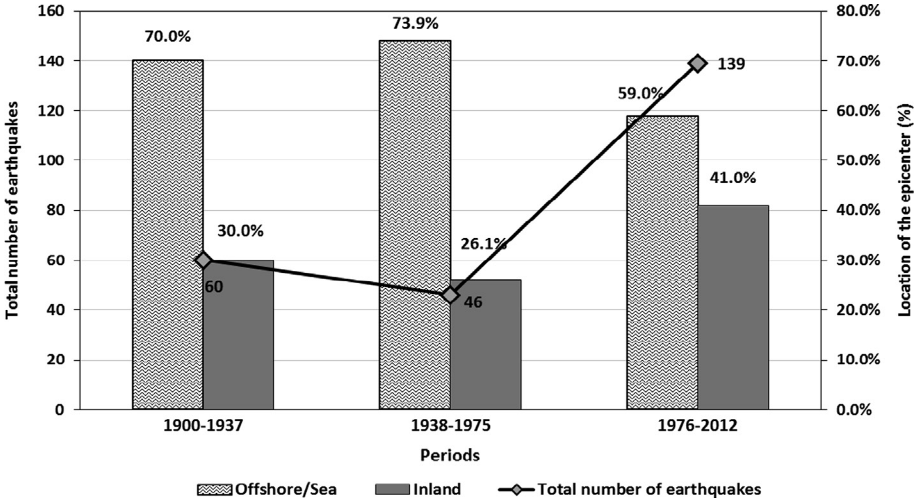

Fig. 11. Trend of earthquakes (magnitude ≥5 Mw) occurrences during 1900–2012 in Indonesia.

Table 3
Basic statistics on the inter-occurrence between two consecutive occurrences of earthquakes and tsunamis (days).

Period	Earthquake						Tsunami					
	Total	Mean	Std. dev.	CV	Max	Min	Total	Mean	Std. dev.	CV	Max	Min
Japan												
I	13,500	259.62	312.04	1.202	1314	0	12,924	461.57	616.91	1.337	2769	0
II	13,993	197.08	257.82	1.308	1345	0	13,701	224.61	293.36	1.306	1417	0
III	13,478	138.95	190.27	1.369	1000	0	13,825	234.32	278.75	1.190	1347	0
All	40,971	186.23	249.19	1.338	1345	0	40,450	273.31	379.51	1.389	2769	0
Indonesia												
I	13,815	230.25	244.61	1.062	931	0	13,544	501.63	482.61	0.962	2272	30
II	13,609	295.85	352.34	1.191	1461	1	11,432	571.60	861.68	1.507	3085	1
III	13,679	98.41	124.35	1.264	640	0	15,753	437.58	695.67	1.590	3099	0
All	41,526	167.77	230.00	1.371	1461	0	40,729	490.71	674.78	1.375	3099	0

Note: *CV*, coefficient of variation.

Table 4
Basic statistics of the number of deaths and missing people caused by earthquakes and tsunamis.

Period	Earthquake				Tsunami			
	Total	Mean	Std. dev.	Max	Total	Mean	Std. dev.	Max
Japan								
I	3950	0.28	25.98	3022	5389	0.39	32.29	3022
II	11,579	0.83	51.60	5131	5242	0.38	31.02	3358
III	7832	0.59	50.92	5502	865	0.07	5.32	441
All	23,361	0.57	44.35	5502	11,496	0.28	26.23	3358
Indonesia								
I	2489	0.18	14.21	1500	639	0.05	3.67	400
II	510	0.04	2.10	213	959	0.07	5.58	600
III	13,009	0.97	58.85	5749	6087	0.46	22.78	1669
All	16,008	0.39	31.81	5749	7685	0.19	13.51	1669

period, the average D&M of earthquakes in Japan is 0.57 people per day, while in Indonesia it is 0.39 people per day. And the average D&M of tsunamis in Japan is 0.28 people per day, while in Indonesia it is 0.19 people per day. Incidentally, in case we include the three extreme earthquakes and tsunamis mentioned above, we find the following: (i) If we include the 1923 earthquake data for Japan, the corresponding mean increases from the current 0.28 to 7.44, while the corresponding standard deviation rises from 25.98 to 843.52. (ii) If we include the 2004 tsunami data for Indonesia, the corresponding mean increases from the current 0.46 to 13.53, while the corresponding standard deviation rises from 22.78 to 1502.65. (iii) If we include the 2011 tsunami data for Japan, the corresponding mean increases from the current 0.07 to 1.51, while the corresponding standard deviation rises from 5.32 to 165.81. Thus, we can conclude that the basic statistic data would be misleading with a certain amount of confusion if we include these extremely unusual disaster data. As a conclusion, Table 4 reveals that, even though the average D&M of tsunamis in Japan is relatively higher than in Indonesia for the whole period, the trend of the average D&M from period I to III in Japan exhibits a declining trend, whereas in Indonesia it shows an increasing trend. For the case of earthquakes, although at earlier period, Japan had a relatively higher average of D&M compared to that in Indonesia, in the last period the opposite result is observed.

These conditions reflect the process of some preparedness against natural disasters, which have been conducted in a sustainable manner in Japan, namely the construction of earthquake-resistant buildings, the implementation of disaster preparedness drills, the building of sea walls, the provision of reliable EWS, the dissemination of disaster information, and the incorporation of disaster education in official curriculum guidelines. Efforts to improve the safety of buildings have taken a relatively long time; namely since 1919 when the urban building law was enacted to provide minimum requirement for structural safety for the first time. The processes to make people safer still continue as a reflection of learning from disasters.

4. Mathematical model analyses for earthquakes and tsunamis

4.1. Modeling inter-occurrence times and fatalities of earthquakes and tsunamis

The timing and magnitude of natural disasters are both unpredictable and contain great uncertainty; thus, we know that the phenomena of natural disasters are “stochastic” in principle. Uncertainty is a critical element in the model analysis related with natural disasters [17]. Although they are very hard to predict, natural disasters such as earthquakes and tsunamis can be analyzed using probability models to guide decision makers on how to quantitatively describe the nature of earthquakes and tsunamis. In this section, historical data of earthquakes and tsunamis will be used as the source for building probability models. As for the timing of these two types of natural disasters, data on inter-occurrence times will be used, and as for the magnitude of earthquakes and tsunamis, data on the number of D&M will be used. Figs. 12 and 13 depict the inter-occurrence times between two consecutive earthquakes in Japan and Indonesia, respectively, in descending order from 1900 to 2012. In Japan, the average number of days between earthquakes is 186.23 days, whilst, in Indonesia, it is 167.77 days.

To align with the previous discussion, Figs. 14 and 15 present an overview of the inter-occurrence times between two consecutive tsunamis in Japan and Indonesia, in descending order from 1900 to 2012, respectively. In Japan, the average number of days between tsunamis is 273.31 days; whilst in Indonesia it is 490.71 days.

Figs. 12–15 show that the numbers of days between consecutive earthquakes and tsunamis are generally long meaning that earthquakes and tsunamis are rare events. A common distribution to model waiting times between occurrences of rare events is exponential distribution; and we will prove this in the following analysis. In order to develop parameters to describe the data from earthquakes and tsunamis, the data will be analyzed by comparing them to various probability distributions and then a standard distribution will be chosen that provides a close “fit” to the set of theoretical probability distributions [18]. To assess which probability distribution is best, the Chi-square test will be used, a lower Chi-square value indicates the best fitting probability distribution [19].

Our estimation procedure is as follows: first, we try to find the best fitting probability distribution for modeling the inter-occurrence times between two consecutive earthquakes or tsunamis and D&M data from among various probability distributions including exponential, normal, and log-normal. Then applying the Chi-square test, probability distributions with lower Chi-square values are shown in Tables 5 and 8, respectively. We apply the application software “Best Fit” [20,21] to find the appropriate probability distribution that best fits the actual data depicted in Figs. 12–15. The result in Table 5 reveals that the exponential distribution fits best to the actual data of the inter-occurrence times of earthquakes and tsunamis in Japan and Indonesia.

The probability density function (pdf) of an exponential distribution is:

$$y = \lambda e^{-\lambda x}, \quad (1)$$

where x is the inter-occurrence times between two consecutive occurrences (days), y is the occurrence probability and λ is the parameter.

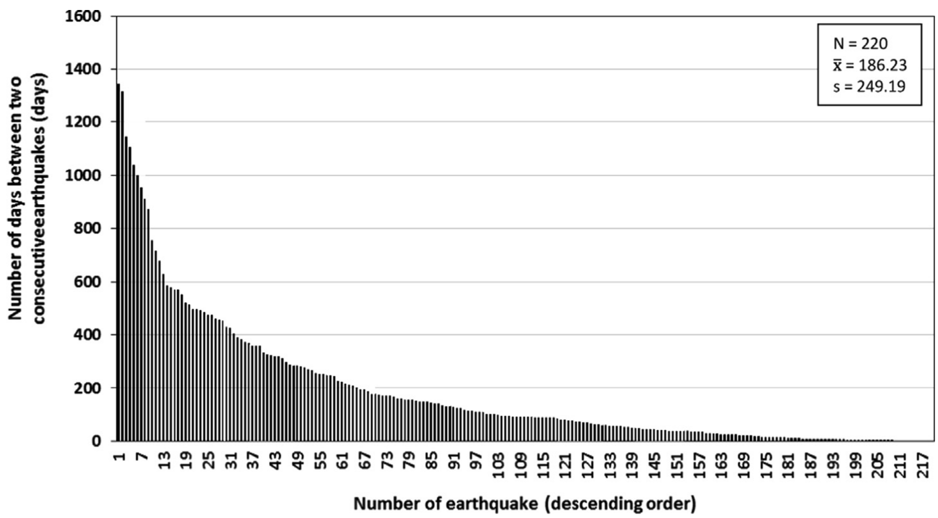

Fig. 12. The inter-occurrence times of earthquakes in Japan, 1900–2012.

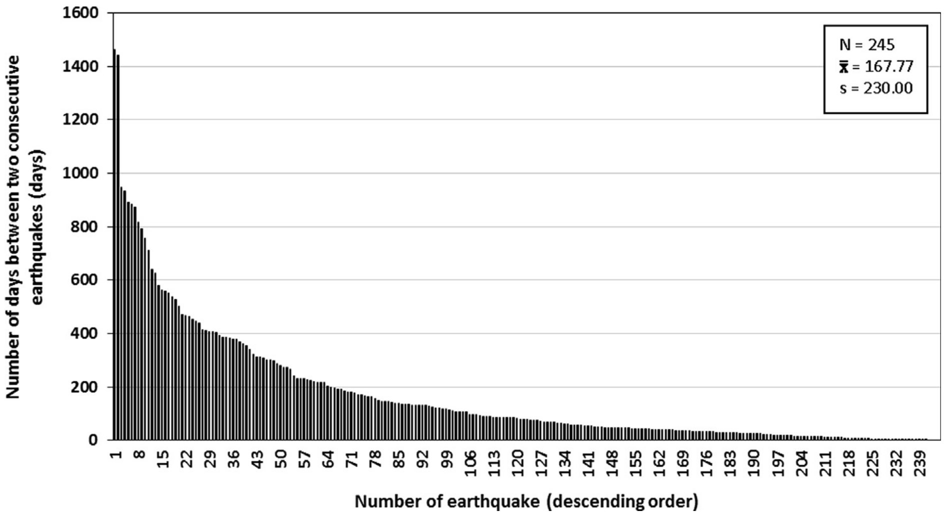

Fig. 13. The inter-occurrence times of earthquakes in Indonesia, 1900–2012.

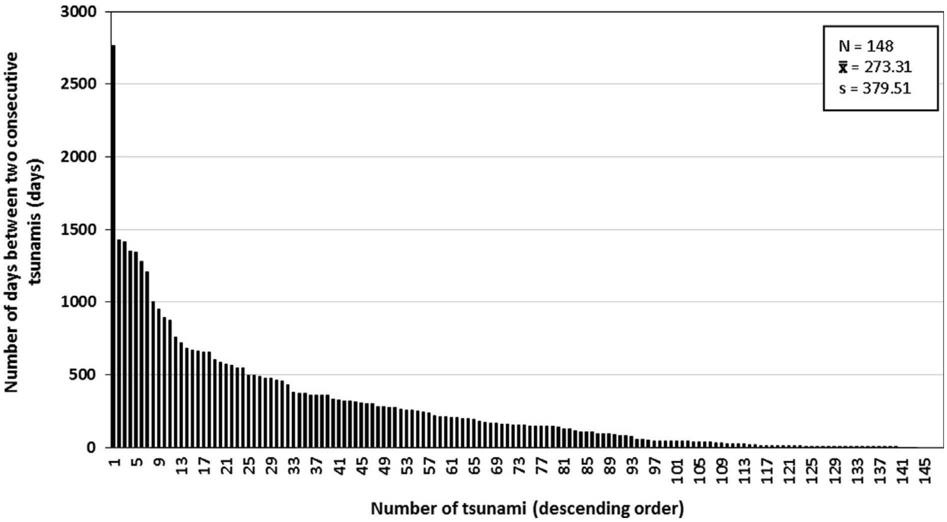

Fig. 14. The inter-occurrence times of tsunamis in Japan, 1900–2012.

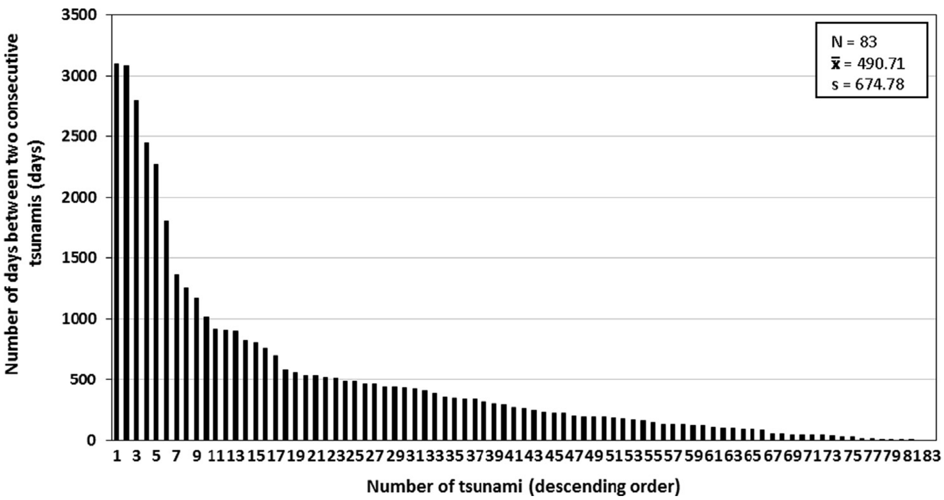

Fig. 15. The inter-occurrence times of tsunamis in Indonesia, 1900–2012.

Table 5
Fitness of probabilistic model for the inter-occurrence times of earthquake and tsunami in Japan and Indonesia.

Period	Test	Earthquake			Tsunami		
		1 Rank	2 Rank	3 Rank	1 Rank	2 Rank	3Rank
Japan							
All	Chi-sq	*Exp* *68.44*	Log 190.2	Norm 233.4	*Exp* *59.65*	Log 97.42	Norm 235.1
I	Chi-sq	*Exp* *8.23*	Log 29.69	Norm 35.92	*Exp* *4.14*	Log 21.29	Norm 22.57
II	Chi-sq	*Exp* *31.39*	Log 89.99	Norm 94.77	*Exp* *28.26*	Norm 49.51	Log 77.25
III	Chi-sq	*Exp* *14.02*	Log 68.23	Norm 88.87	*Exp* *9.49*	Log 20.47	Norm 28.41
Indonesia							
All	Chi-sq	*Exp* *49.47*	Log 229.6	Norm 334.9	*Exp* *7.25*	Log 49.66	Norm 79.88
I	Chi-sq	*Exp* *12.60*	Log 30.00	Norm 36.00	*Exp* *1.70*	Log 5.78	Norm 8.74
II	Chi-sq	*Exp* *5.83*	Log 23.91	Norm 33.65	*Exp* *2.80*	Log 2.80	Norm 27.60
III	Chi-sq	*Exp* *19.53*	Log 96.96	Norm 132.5	*Exp* *7.56*	Log 19.22	Norm 37.50

Table 6
Estimate of parameters for estimating the inter-occurrence times of earthquakes and tsunamis in Japan.

Parameter	Earthquake				Tsunami			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
λ	0.00537	0.00385	0.00507	0.00720	0.00366	0.00217	0.00445	0.00427
$\mathbf{1}/\lambda$	186.22	259.74	197.24	138.89	273.22	460.83	224.72	234.19

Table 7
Estimate of parameters for estimating the inter-occurrence times of earthquakes and tsunamis in Indonesia.

Parameter	Earthquake				Tsunami			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
λ	0.00596	0.00434	0.00338	0.01016	0.00204	0.00199	0.00175	0.00229
$\mathbf{1}/\lambda$	167.79	230.41	295.86	98.43	490.20	502.51	571.43	436.68

The properties of an exponential distribution are Mean $(\mu)=1/\lambda$ and variance $(\sigma^2)=1/\lambda^2$.

Table 6 gives the estimate of the parameter λ for the inter-occurrence times of earthquakes and tsunamis in Japan from 1900 to 2012. For earthquakes, we obtain 0.00537, 0.00385, 0.00507, and 0.0072 for the whole period, periods I, II and III, respectively. Hence, the expected interval period between two earthquake occurrences for the whole period is $1/\lambda=186.22$ days, while for period III it is $1/\lambda_{III}=138.89$ days, which is shorter than in period I: $1/\lambda_I=259.74$ days. For tsunamis, we obtain 0.00366, 0.00217, 0.00445, and 0.00427 for the whole period, periods I, II, and III, respectively. Then, the expected interval period between two tsunami occurrences for the whole period is $1/\lambda=273.22$ days, while for period III it is $1/\lambda_{III}=234.19$ days, which is about half that in period I: $1/\lambda_I=460.83$ days.

Table 7 shows the estimate of the parameter λ for the inter-occurrence times of earthquakes and tsunamis in Indonesia during 1900–2012. For earthquakes, we obtain 0.00596, 0.00434, 0.00338, and 0.01016 for the whole period, periods I, II and III, respectively. Therefore, the expected interval period between two earthquake occurrences for the whole period is $1/\lambda=167.79$ days, while for period III it is $1/\lambda_{III}=98.43$ days, which is less than half of the inter-occurrence time in period I: $1/\lambda_I=230.41$ days. For tsunamis, we obtain 0.00204, 0.00199, 0.00175, and 0.00229 for the whole period, periods I, II, and III, respectively. Then, the expected interval period between two tsunami occurrences for the whole period is $1/\lambda=490.20$ days, while for period III it is $1/\lambda_{III}=436.68$ days, which is relatively shorter than in period I: $1/\lambda_I=502.51$ days.

The results in Tables 6 and 7 are in accordance with Table 3, in which from the expected inter-occurrence times, we should be aware that in the future, these two natural disasters are expected to become more frequent in Japan and Indonesia. Furthermore, we will add on the above mathematical modeling analysis that our “about 120 years” and “about 40 years” period data analyses are mainly focused on investigating the “recent” trend of the natural disasters such as earthquake and tsunami with respect to their occurrences and damages based on the data measured under the almost same conditions. Thus, considering that these natural disasters' analysis needs much longer range such as several hundred years or more, we believe we have to be cautious about reliability and accuracy of our parameter estimates, model results, and so on.

Next, we also model the number of D&M as fatalities caused by earthquakes and tsunamis in Japan and Indonesia using the probabilistic model. The D&M caused by these two natural disasters measures the magnitude of disasters. To model the D&M, we include all days from 1900 to 2012, which total more than 40,000 days. Our objective is to estimate the number of D&M per day. However, since earthquakes and tsunamis are rare events and did not always cause D&M, we will analyze the number of D&M per month. The parameters for both distributions are estimated using the method of maximum likelihood. The Chi-square goodness of fit test will be used to determine the appropriate distribution to the data.

Table 8 shows the results of the fitness of the probabilistic model for the D&M per month caused by earthquakes and tsunamis. The results show that the Poisson and negative binomial distribution fit the actual data of D&M per month in Japan and Indonesia. It appears that the negative binomial has Chi-square values smaller than the Poisson. However, since earthquakes and tsunamis are rare events, unpredictable and stochastic natural phenomena as described in Section 3, in terms of $p \to 0$ and $n \to \infty$, taking the limit so that $\lambda = np$, we know we can approximate the probability of the Negative Binomial by the Poisson distribution [22]. Therefore, we conclude that the number of D&M follow the Poisson distribution. However, regarding our estimates given in Table 8, we believe that the estimate values should have certain ranges surrounding them due to the uncertainty rather than insisting on these exact estimates.

The Poisson distribution specifies a stochastic counting process that represents the total number of events that have occurred up to time t [23]. The probability density function of the Poisson distribution is as follows:

$$y = \frac{e^{-\lambda}\lambda^x}{x!} \tag{2}$$

where x is the number of deaths and missing people (D&M), y is the probability of deaths and missing people and λ is the parameter.

The properties of the Poisson distribution are Mean $(\mu) = \lambda$ and Variance $(\sigma^2) = \lambda$. Table 9 presents the parameter estimates (λ) for D&M caused by earthquakes and tsunamis. In interpreting the estimated parameter, one should always remember that as we have mentioned in the early part of Section 4, uncertainty is always unavoidable in the model analysis of natural disasters. Thus, the estimated parameter should be interpreted cautiously and judiciously. The estimated parameter (λ) interpretations are as follows; for the earthquakes case, the average of D&M in Japan for the whole period is 17.330 people per month or 0.578 people per day, and for periods I, II, and III they are 8.623, 25.393, and 18.005 people per month, respectively. In addition, for Indonesia the average of D&M from 1900 to 2012 is 11.849 people per month or 0.395 people per day, while for periods I, II and III they are 5.458, 1.118, and 29.633 people per month, respectively. Although, in period I the average of D&M in Japan is larger than in Indonesia, in period III the opposite occurred.

For the tsunamis case, in Japan, the average number of D&M of tsunami from 1900 to 2012 is 8.535 people per month or 0.284 people per day, and for periods I, II and III they are 11.818, 11.496, and 1.989 people per month, respectively. In Indonesia, the average number of D&M of tsunami for the whole period is 5.705 people per month or 0.19 people per day, and for periods I, II and III they are 1.401, 2.103, and 13.993 people per month, respectively. Here, there is an opposite pattern of D&M between Japan and Indonesia; namely, while in Japan the average number of D&M of tsunamis shows a decreasing trend, in Indonesia

Table 8
Fitness of probabilistic model for number of deaths and missing people of earthquakes and tsunamis.

Period	Test	Earthquake		Tsunami	
		1 Rank	2 Rank	1 Rank	2 Rank
Japan					
All	Chi-sq	NegBin *849.2*	*Poisson* 1302	NegBin *944.2*	*Poisson* 1390
I	Chi-sq	NegBin *225.7*	*Poisson* 311.3	NegBin *54.77*	*Poisson* *58.49*
II	Chi-sq	NegBin *123.9*	*Poisson* 152.8	NegBin 500.8	*Poisson* *948.3*
III	Chi-sq	NegBin *256*	*Poisson* 402.9	*Poisson* *383.2*	NegBin 387
Indonesia					
All	Chi-sq	*Poisson* *2118*	NegBin *2520*	NegBin *257.3*	*Poisson* 288.6
I	Chi-sq	NegBin *106.8*	*Poisson* 124.8	NegBin *103.7*	*Poisson* 118.2
II	Chi-sq	NegBin *74*	*Poisson* 83.23	*Poisson* *93.8*	NegBin 105.7
III	Chi-sq	*Poisson* *1163*	NegBin 1273	NegBin *249.8*	*Poisson* 352.7

Table 9
Estimate of parameters (λ) for estimating the number of D&M caused by earthquakes and tsunamis.

Parameter	Earthquake				Tsunami			
	All	Period I	Period II	Period III	All	Period I	Period II	Period III
Japan	17.330	8.623	25.393	18.005	8.535	11.818	11.496	1.989
Indonesia	11.849	5.458	1.118	29.633	5.705	1.401	2.103	13.993

it exhibits an increasing trend. This could be a warning that the number of people threatened by tsunamis in Indonesia has increased. Referring to Table 4, the estimated number of D&M caused by earthquakes and tsunamis in Table 9 is almost the same.

By the using estimated average number of deaths as in Table 9 and the return period of a great event and if we also do not consider any change in the countermeasures, we can estimate future loss for a specific location and event. We define a great event as an earthquake with moment magnitude 8 Mw and above. For the return period of the event we will use the return period of an earthquake with moment magnitude of 8.1–8.8 Mw calculated by Yegulalp for Japan [24]. In Japan from 1900 until 2012, there have been 12 earthquakes with magnitude 8.0 Mw and above, of which 7 earthquakes generated tsunami. According to Yegulalp [24] the return period of an 8.8 Mw earthquake in Japan is 220 years. The last great earthquake in Japan that also generated tsunami is the 2011 Great East earthquake and tsunami, with its epicenter off the Pacific coast of Tohoku. Given that the estimated average number of D&M per day of tsunamis in Japan is 0.284 and the return period of an 8.8 Mw or 9.0 Mw earthquake is 220 years, which most probably will also generate a tsunami, there will be about 22,000 deaths in Tohoku.

We know from the trend of D&M of earthquakes and tsunamis that Japan and Indonesia are both topographically located on the Ring of Fire, which also makes Indonesia face a high threat of earthquakes and/or tsunamis, as well as volcanic eruptions. Nevertheless, it seems the community in Indonesia less anticipates these threats. As a result, each disaster have always caused casualties in large numbers. Indonesia can learn from Japan about the handling of earthquakes and tsunamis.

Of the countries in the world that have the highest frequency of earthquakes and tsunamis, Japan has the most advanced hazard warning system [25–27]. The awareness and education of natural disasters should also be given and included as one of the subjects in schools starting from elementary school. Disaster preparedness exercises should be carried out regularly and continuously. Reliable EWS should also be provided, especially in disaster prone areas. Despite their short warning times, EWS, such as for earthquakes, can become very useful means in risk mitigation [27]. Hence, when a disaster occurs, people instantly know what to do and what not to do. The cause of a high number of D&M is unpreparedness when disaster strikes, resulting in panic.

4.2. Major causes and fatalities of earthquakes and tsunamis

We will continue our modeling analysis of earthquakes and tsunamis. First, as earthquakes are the major causes of tsunamis, we will propose a probability model that can describe the relationship between earthquakes and tsunamis. Second, we will analyze some factors that affect the number of D&M due to earthquakes and tsunamis using statistical methods. Regarding the relationship between earthquakes and tsunamis, some studies have been conducted, for instance by Gusiakov [28] and Suppasri et al. [29], in which both of them also used the GHTD. Gusiakov [28] divided the Pacific regions into 10 regions and calculated the Tsunami Efficiency (TE) for each region. TE is the ratio between the number of tsunami and the number of earthquakes with magnitude higher than 7 Mw and focus depth shallower than 100 km. He found that the region of Japan and Indonesia have larger TE values compared to other regions. Almost similar with Gusiakov [28], Suppasri et al. [29] also calculated the Tsunamigenic Ratio (TR) of the Pacific Ocean earthquakes, they also proposed a Tsunami Index. They also divided the Pacific regions into nine regions. They suggested that a great earthquake magnitude and a shallow focal depth have a high potential to generate tsunamis with a large tsunami height. The TR calculated for each region shows the relationship among three influential parameters: magnitude, focal depth and sea depth. Nonetheless, none of them have included epicenter location into the model.

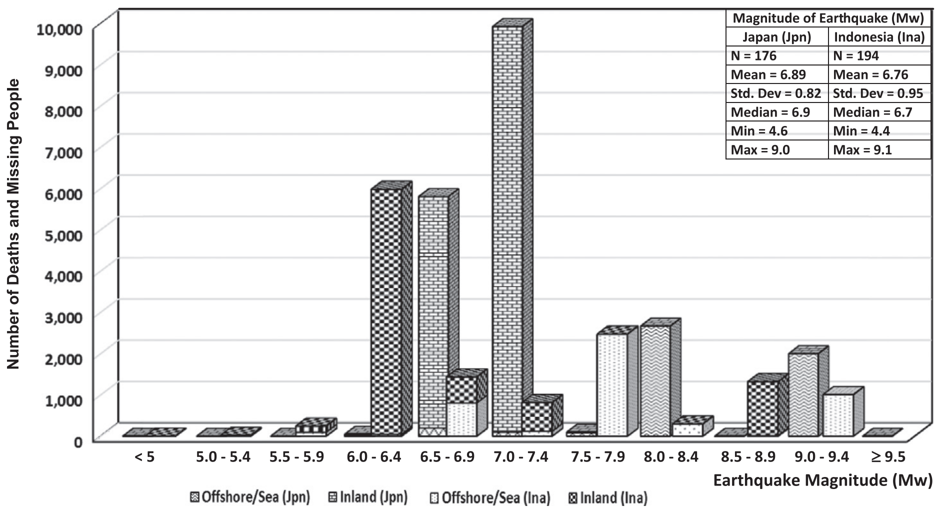

Fig. 16. Magnitude of earthquakes and number of deaths and missing people caused by earthquakes by location of epicenter in Japan (Jpn) and Indonesia (Ina).

Before we conduct analyses on major causes of tsunamis and fatalities of earthquakes and tsunamis, first we will look at the condition of earthquakes which have occurred in the past related with the number of D&M and the location of their epicenters. Fig. 16 shows the magnitude of earthquakes and D&M divided by the epicenter location in Japan and Indonesia, with the exception of the 1923 Great Kanto earthquake. In Fig. 16, most of the earthquakes in Japan and Indonesia have epicenter locations offshore/at sea, namely 78.4% and 63.9% for Japan and Indonesia, respectively. Yet, not all these earthquakes caused human casualties, in Japan only 58 recorded earthquakes caused D&M, while in Indonesia only 90 earthquakes did so.

In general, Fig. 16 shows that the earthquakes which caused considerable loss of human life in Japan and Indonesia, are those with magnitude above 6.0 Mw. Furthermore, earthquakes with magnitude ranging from 6.0 Mw to 7.4 Mw and having epicenters in the mainland cause more casualties, while those with magnitude 7.5 Mw and above and having epicenters offshore/at sea cause relatively fewer casualties. This implies that mainland earthquake has higher probability to bring more casualties than the sea earthquake. Subsequently, the question is how far the epicenter of an earthquake at sea has to be in order to result in considerably large casualties. By the information of the epicenter location from SED on Google maps we can approximately measure the distance between the epicenter and the closest mainland. In Japan, the 2011 Great East Japan earthquake (9.0 Mw) had its epicenter approximately 72.45 km from the Oshika Peninsula of Tohoku. The 1944 Tonankai earthquake (8.1 Mw) was 35.84 km away, and the 1946 Nankaido earthquake (8.1 Mw) was 50.78 km away. In addition, the 1923 Great Kanto earthquake (7.9 Mw) had its epicenter approximately 10.62 km from Jogashima Island, Kanagawa Prefecture. In Indonesia, the approximate distances from the nearest mainland to the epicenter of the following earthquakes are for the 1992 Flores earthquake (7.8 Mw): 1.57 km, the 2009 West Sumatra earthquake (7.9 Mw): 29.24 km, and the 2004 Indian Ocean earthquake (9.1 Mw): 84.52 km. Therefore, earthquakes with magnitude above 7.5 Mw and having the distance of the epicenter at sea closer than 80 km can cause great loss of life.

In addition, it is noted that a large earthquake with its epicenter on land may also generate a tsunami if the rupture extend to the sea, such as the Kita-Tango earthquake (7.3 Mw) which occurred on March 7th 1927 in Kyoto Prefecture, Japan and the Nias earthquake (8.7 Mw) which occurred on March 28th 2005 on Nias Island, Indonesia.

Earthquakes are the major cause of tsunamis (see Fig. 8). A model to examine the effect of an earthquake's parameter on the probability of a tsunami will be generated. The dependent variable is the occurrence of tsunami from an earthquake, and the independent variables are the earthquake's parameter, namely, magnitude (Mw), focal depth (km) and epicenter location. The model is a binary response model having the dependent variable has a binary outcome. Here we consider the outcome of tsunami occurrences - whether a tsunami occurred or not. We estimate the association between tsunami occurrences and various other outcomes using a linear probability model (LPM), probit and logit models.

Table 10
LPM, probit and logit specification models.

Model	$P(y=1\|\boldsymbol{x})=F(x\boldsymbol{\beta})$
Linear probability model	$x\boldsymbol{\beta}$
Probit	$F(x\boldsymbol{\beta})=\Phi(x\boldsymbol{\beta})=\int_{-\infty}^{x\beta}\phi(z)\ dz$ where $\phi(z)=\frac{1}{\sqrt{2}}e^{-z^2/2}$
Logit	$F(x\boldsymbol{\beta})=\frac{e^{x\beta}}{1+e^{x\beta}}$

Table 11
Marginal effect for LPM, probit and logit.

Model	$P(y=1\|\boldsymbol{x})=F(x\boldsymbol{\beta})$	Marginal effect $f(x\boldsymbol{\beta})\beta_j$
Linear probability model	$\boldsymbol{x\beta}$	β_k
Probit	$\Phi(\boldsymbol{x\beta})$	$\phi(\boldsymbol{x\beta})\beta_j$
Logit	$F(\boldsymbol{x\beta})$	$F(\boldsymbol{x\beta})\ (1-\ F(\boldsymbol{x\beta}))\ \beta_j$

Consider a standard multiple regression model:

$$y=\beta_0+\beta_1\times_1+\cdots+\beta_k x_k+\varepsilon=x\boldsymbol{\beta}+\varepsilon, \tag{3}$$

where $\boldsymbol{x}=(1, x_1, \ldots, x_k)$ and $\boldsymbol{\beta}=(\beta_1, \ldots, \beta_k)$.

In this case, y takes a value 1 if a tsunami occurred and 0 otherwise. And under the assumptions $E(\varepsilon|\boldsymbol{x})=0$ then $E(y|\boldsymbol{x})=\boldsymbol{x\beta}$. Thus, when y is binary we have:

$$E(y/\mathbf{x})=1\times P(y=1/\mathbf{x})+0\times P(y=1/\mathbf{x})=P(y=1/\mathbf{x}),$$

and then

$$P(y=1/\mathbf{x})=\mathbf{x}\beta.$$

The specification models of LPM, probit, and logit are summarized in Table 10.

The marginal (partial) effects for the binary response models are different from those for linear regression models. The marginal effect is given by:

$$\frac{\partial P(y=1/\boldsymbol{x})}{\partial x_j}=\frac{\partial E(y/\boldsymbol{x})}{\partial x_j}=f(x\boldsymbol{\beta})\beta_j, \tag{4}$$

where $f(\boldsymbol{x\beta})=dF(x)/dx$. Table 11 describes the marginal effects for each model.

Using "Stata ver. 12" we estimated the parameters of the models and the marginal effects. The results are summarized in Tables 12 and 13, respectively.

Whilst in Japan, all the independent variables or covariates are statistically significant, in Indonesia only the earthquake magnitude and epicenter location are statistically significant. We should note that the results of the probit and the logit in Table 12 are reporting the coefficient estimates, which are not equivalent to the marginal effects such as the coefficient estimation in the LPM. We cannot expect the coefficients from the different models to be equal [30].

In Table 12, the signs and significance of the coefficients are similar among the three models. However, it is better to compare the marginal effects between models, as shown in Table 13. The marginal effects of the variables can be found using the mfx command after the estimation [30]. The default

Table 12
LPM, logit and probit estimates of tsunami occurrences in Japan and Indonesia. Dependent variable: associate with tsunami.

Independent variable	Japan			Indonesia		
	LPM (OLS)	Probit (MLE)	Logit (MLE)	LPM (OLS)	Probit (MLE)	Logit (MLE)
Magnitude	0.090*	0.374*	0.646*	0.161***	0.549***	0.918***
	(0.044)	(0.159)	(0.293)	(0.031)	(0.118)	(0.204)
Focal_depth	−0.003***	−0.016***	−0.028***	−0.001	−0.003	−0.005
	(0.000)	(0.004)	(0.007)	(0.001)	(0.002)	(0.004)
Location	−0.561***	−1.730***	−2.904***	−0.205**	−0.711**	−1.225**
	(0.077)	(0.310)	(0.567)	(0.066)	(0.238)	(0.415)
Constant	0.819*	0.530	0.796	−0.432	−3.148***	−5.191**
	(0.355)	(1.234)	(2.269)	(0.263)	(0.927)	(1.587)
N	178	178	178	194	194	194
Log-likehood value		−77.040	−77.095		−101.699	−101.676
R-squared	0.393			0.195		
Pseudo-*R*-squared		0.346	0.346		0.173	0.173

Standard errors in parentheses.
$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

Table 13
Marginal effects (dy/dx)[a] of probit and logit model of tsunami occurrences in Japan and Indonesia.

Variable	Japan		Indonesia	
	Probit	Logit	Probit	Logit
Magnitude	0.144*	0.154*	0.187***	0.185***
	(0.060)	(0.067)	(0.039)	(0.040)
Focal_depth	−0.006***	−0.006***	−0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Location	−0.666***	−0.692***	−0.244*	−0.247*
	(0.125)	(0.146)	(0.079)	(0.081)
Marginal effects after the model y=Pr (tsunami) (predict)	0.60398	0.60749	0.29032	0.28135

Standard errors in parentheses. $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.
[a] dy/dx if for discrete change of location from sea to mainland.

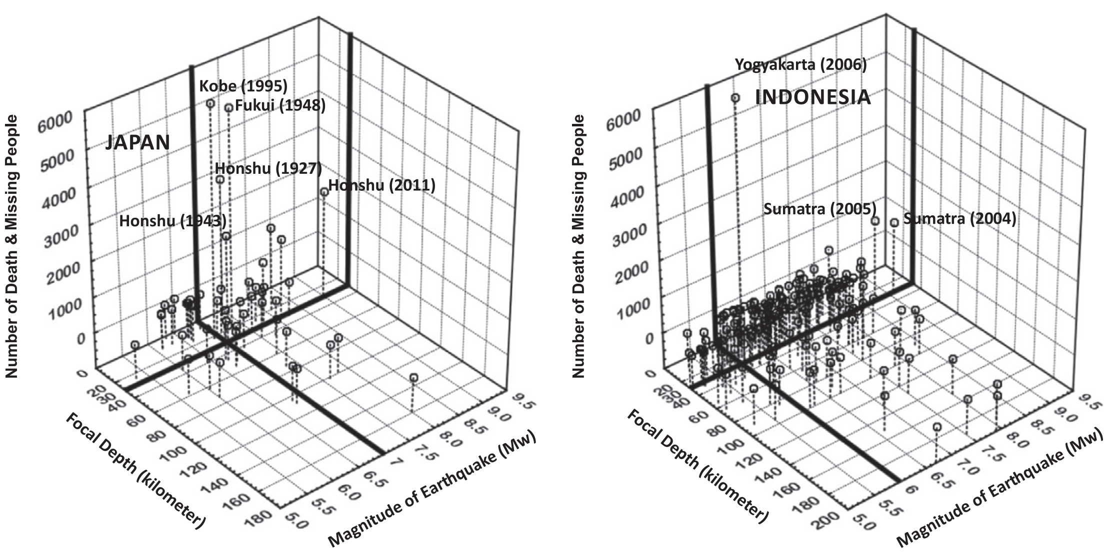

Fig. 17. 3D Scatterplot of number of deaths and missing people against magnitude of earthquake and focal depth of earthquakes in Japan and Indonesia.

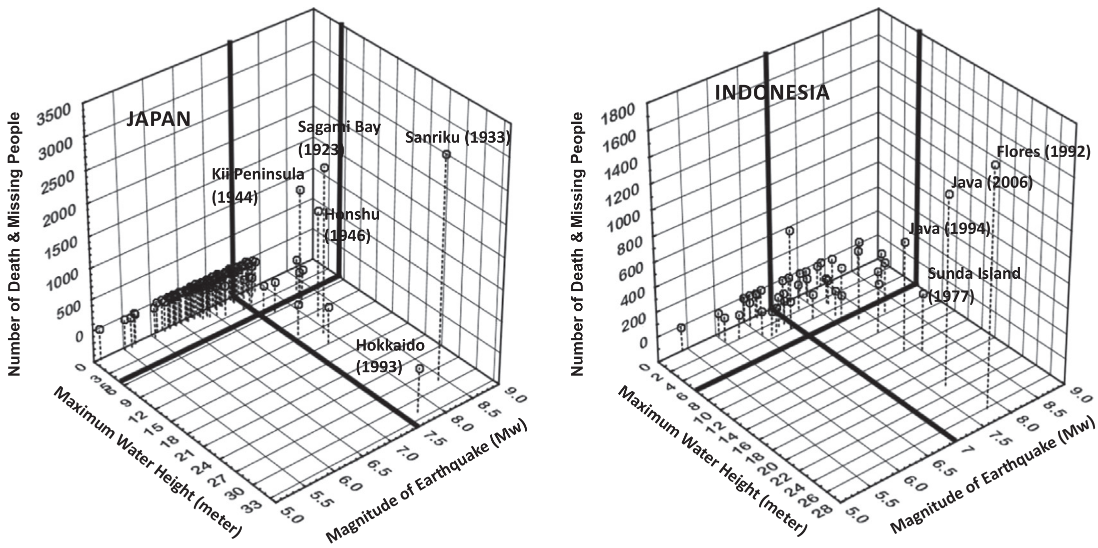

Fig. 18. 3D Scatterplot of number of deaths and missing people against magnitude of earthquake and maximum water height of tsunamis in Japan and Indonesia.

output of mfx after the probit and logit is the marginal effects desired. In Japan, an increase of earthquake magnitude by 1 Mw is associated with a 14.4% or 15.4% increase in the probability of a tsunami occurrence for the probit or the logit, respectively. A decrease in the depth of hypocenter/focus by 1 km is associated with a 0.6% increase, and if the epicenter location is offshore/sea then it is associated with an increase of 66.6% or 69.2%. In Indonesia, an increase of earthquake magnitude by 1 Mw is associated with a 18.7% or 18.5% increase in the probability of a tsunami occurrence for the probit or the logit, respectively; and an epicenter location which is offshore/sea is associated with an increase of 24.4% or 24.7% (compared to 9%, 0.3% and 56.1% for Japan; and 16.1% and 20.5% for Indonesia from the LPM). These results imply that the magnitude of an earthquake and the location of the epicenter are important factors in the possibility of tsunami occurrence, as well as D&M.

Many factors affect the D&M of earthquakes and tsunamis. Figs. 17 and 18 visually portray some of these factors on D&M. Fig. 17 portrays the relation between earthquake magnitude, focal depth, and number of D&M of earthquakes in Japan and Indonesia, except for the Great Kanto earthquake (1923). Looking at Fig. 17, we can see some sort of threshold of earthquake magnitude and depth in causing D&M. The estimated threshold for magnitude in Japan is 7.0 Mw, and in Indonesia, it is 6.0 Mw. The difference in the scale of magnitude is likely because of the quality of buildings/houses, where in general the quality of earthquake-resistant buildings in Japan is better than in Indonesia. This should be a concern of both the government and the public, particularly in Indonesia, and should lead to further improvement in the quality of buildings/houses from the increasing threat of earthquakes. For the threshold depth, generally, Japan and Indonesia are the same, namely less than 30 km.

Fig. 18, with the exception the 2004 Indian Ocean tsunami and the 2011 Great East Japan tsunami, has clearly described the relationship between earthquake magnitudes, maximum water height and number of D&M inflicted. For tsunamis inflicting D&M, the thresholds for earthquake magnitude in Japan and Indonesia are estimated to be 7.5 Mw and 7.0 Mw, respectively. In addition, the thresholds for tsunami height are estimated to be about 5 m and 6 m for Japan and Indonesia, respectively. In general, the higher the tsunami wave, the greater the number of casualties.

Then to analyze this association, we apply the statistical method, namely the Analysis of Covariance (ANCOVA). ANCOVA is a multivariate statistical method in which the dependent variable is a quantitative variable and the independent variables are a mixture of nominal variables and quantitative variables [31]. Thus, an analysis of variance comparing the means of D&M for the two epicenter locations while controlling for the variables of Mag, Depth and Height will be conducted using the following model:

For earthquakes:

$$E(\mathrm{DM})_t = \beta_0 + \beta_1\ \mathrm{Mag}_t + \beta_2\ \mathrm{Depth}_t + \beta_3\ \mathrm{Loc}_t + \varepsilon_t, \quad (5)$$

and for tsunamis:

$$E(\mathrm{DM})_t = \beta_0 + \beta_1\ \mathrm{Mag}_t + \beta_2\ \mathrm{Depth}_t + \beta_3\ \mathrm{Height}_t + \beta_4\ \mathrm{Loc}_t + \varepsilon_t, \quad (6)$$

where DM is the number of death and missing people (D&M), Mag is the magnitude of earthquake (Mw), Depth is the focal depth (kilometer), Height is the maximum water height (meter), Loc the a dummy variable of epicenter location: offshore/sea (o) and mainland (m). and ε_t the error term.

The summary results of the regression model using ANCOVA for earthquakes and tsunamis are presented in Tables 14 and 15, respectively. Note that all the models as a whole both for earthquakes and for tsunamis in Japan and Indonesia are statistically significant. However, not every explanatory variable is statistically significant. This evidence, in fact, reveals some characteristics of each natural disaster in each country.

Table 14
Summary results of the regression model for earthquakes in Japan and Indonesia. Dependent variable: DM.

Source	Japan					Indonesia				
	Type III sum of squares	DF	Mean square	*F* value	Pr > *F*	Type III sum of squares	DF	Mean square	*F* value	Pr > *F*
Model	4,570,821.531	3	1,523,607.177	3.823	0.011	373,058.734	3	124,352.911	4.645	0.004
Error	68,158,507.326	171	398,587.762			5,059,856.303	189	26,771.726		
Total	75,142,486.000	175				5,745,406.000	193			
	R-squared = 0.063 (adjusted *R*-sq = 0.046)					*R*-squared = 0.069 (adjusted *R*-sq = 0.054)				

Parameter	Japan				Indonesia			
	Estimate	*T* for *H*0: parameter = 0	Pr > |*T*|	Std error of estimate	Estimate	*T* for *H*0: parameter = 0	Pr > |*T*|	Std error of estimate
Intercept	−818.605	−1.969	0.051	415.694	−257.180	−3.017	0.003	85.231
Mag	178.785**	2.779	0.006	64.342	48.518***	3.673	0.000	13.208
Depth	−1.218	−1.626	0.106	0.749	−0.180	−1.096	0.275	0.164
Loc								
o	−302.458*	−2.465	0.015	122.684	−32.873	−1.246	0.214	26.377
m	0	–	–	–	0	–	–	–

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 15
Summary results of the regression model for tsunamis in Japan and Indonesia. Dependent variable: DM.

Source	Japan					Indonesia				
	Type III sum of squares	DF	Mean square	*F* value	Pr > *F*	Type III sum of squares	DF	Mean square	*F* value	Pr > *F*
Model	4,858,089.682	4	1,214,522.421	12.504	0.000	4,021,051.096	4	1,005,262.77	43.830	0.000
Error	11,752,457.747	121	97,127.750			940,364.557	41	22,935.721		
Total	17,135,126.000	126				5,647,056.000	46			
	R-squared = 0.292 (adjusted *R*-sq = 0.269)					*R*-squared = 0.810 (adjusted *R*-sq = 0.792)				

Parameter	Japan				Indonesia			
	Estimate	*T* for *H*0: parameter = 0	Pr > |*T*|	Std error of estimate	Estimate	*T* for *H*0: parameter = 0	Pr > |*T*|	Std error of estimate
Intercept	−850.165	−2.290	0.024	371.224	305.324	1.245	0.220	245.175
Mag	116.971*	2.267	0.025	51.592	−49.382	−1.463	0.151	33.746
Depth	−0.978	−0.622	0.535	1.573	−0.290	−0.904	0.371	0.321
Height	27.114***	5.178	0.000	5.236	56.553***	12.697	0.000	4.454
Loc								
o	82.764	0.579	0.563	142.829	−31.691	−0.518	0.607	61.131
m	0	–	–	–	0	–	–	–

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

In Table 14, the earthquake magnitude has a significant effect on the number of D&M in Japan and Indonesia. However, only in Japan does the location of the epicenter have a significant effect on D&M. Furthermore, Table 15 shows that the maximum water height is the most important factor in a tsunami event, affecting the number of D&M. This variable is highly statistically significant. As tsunamis are more "common events" of natural disasters in Japan than in Indonesia, the government of Japan should take more precautionary efforts in order to mitigate the number of victims and damage/losses due to tsunami events.

Moreover, the magnitude of earthquakes also plays a significant role in causing D&M. This evidence could be a warning for those people who live near the shore or coastal areas, since they would be the first victims to be stricken if there is a tsunami. There should be some rules related with the safe distance to build residences from the shoreline, or if there are some people who live in areas with a supposedly dangerous tsunami threat, the government should relocate them to some other safe places.

5. Summary and policy recommendation

Using about 100 years' data from 1900 to 2012, this study aims to investigate the past trend of natural disasters, focusing upon earthquakes and tsunamis with respect to their occurrences and human casualties. We know that 100 years' data may not be enough to investigate the past trend of earthquakes and tsunamis. However, we believe these data measured under the almost same conditions would be sufficiently useful for our investigation. We apply mathematical policy analyses techniques in our natural disaster risk analysis and assessment in order to develop policies to mitigate the casualties caused by these natural disasters. Our study confirms that the exponential distribution fits the data of the inter-occurrence times between two consecutive occurrences of earthquakes and tsunamis, while the Poisson distribution fits the data of D&M. We will add again that uncertainty is a critical element in the model analysis related with natural disasters, as we mentioned in Section 4.

For Japan and Indonesia, the average numbers of inter-occurrence times of earthquakes are 186.23 days and 167.77 days, respectively, whilst the inter-occurrence times of tsunamis are 273.31 days and 490.71 days, respectively. In addition, on average, the number of D&M per day caused by earthquakes in Japan and Indonesia are 0.578 and 0.395, respectively, whilst the numbers of D&M per day caused by tsunamis are 0.284 and 0.19, respectively. This finding implies that earthquakes are more frequent in Indonesia than in Japan, in the contrary, tsunamis are more frequent in Japan than in Indonesia. However, in terms of fatalities, earthquakes and tsunamis have caused more deaths in Japan than in Indonesia.

Based on the results obtained from the probit, logit and linear probability model analyses, we conclude that the magnitude of earthquakes and the location of the epicenter are considered to be important factors in the possibility of tsunami occurrence, as well as D&M. Even though these factors are influential and important for tsunami occurrences, as we know tsunami and earthquakes are very closely connected with each other, the magnitude and location need to be investigated further in order to determine a more detailed relation among those factors with respect to occurrences and D&M.

One of the findings of this study is that the occurrences of earthquakes and tsunamis tend to increase over time, both in Japan and Indonesia. This finding should be addressed judiciously and carefully, both by the government and by the people. To anticipate the impact of earthquakes, the government is expected to provide guidelines for earthquake-resistant house/building. Furthermore, the government should ensure its implementation, either through government regulation or careful supervision. In addition, the government is also expected to provide detailed information on areas prone to earthquakes, so that people do not build houses/buildings in such regions. In anticipation of the increasing tsunami threat, the government is expected to issue regulations on the construction of houses/buildings in coastal zones.

A reliable early warning system for earthquakes and tsunamis should also be provided by the government. We know that almost all tsunamis are caused by earthquakes, thus, early tsunami warnings are indispensable to avoid large D&M so that residents including school children and senior people can evacuate safely to higher places. The system should be run reliably and be able to provide accurate information so that people can act properly and appropriately. Regarding the early warning system, since the 1995 Kobe earthquake, the Japanese government has invested about $1 billion in research and development of an Earthquake Early Warning (EEW) system. The Japan Meteorological Agency (JMA) implemented the system in December 2007. The flow of the EEW is as follows: when an earthquake strikes, seismographs near its source detect the first seismic waves (P-waves). P-waves are followed by more powerful secondary S-waves. JMA analyses the P-waves and estimates the intensity of the S-waves. If the S-waves are deemed to be sufficiently powerful to warrant alerting the public, the system automatically issues a warning. The warning is broadcast to the public through media, such as TV, radio, speaker, and mobile phones. Subsequently, after seeing or hearing an EEW, people have only *a matter of seconds* before strong tremors arrive, meaning that people need to act quickly to protect themselves. Furthermore, when an earthquake occurs, JMA also estimates the possibility of tsunami generation from the seismic observation data. If disastrous waves are expected in coastal regions, JMA issues a Tsunami Warning/Advisory for each region expected to be affected based on estimated tsunami heights. JMA also issues information on tsunami details such as estimated arrival times and heights.

In short, Japan has one of the best earthquake early warning systems in the world. There are more than four thousand Seismic Intensity Meters in place throughout Japan to measure the earthquakes activities. These meters provide information within two minutes of an earthquake happening. Information about the strength and the center of the earthquake can be learned within three minutes. In the case of the 2011 Great East Japan earthquake and tsunami, the Japan Meteorological Agency released its first tsunami warnings just three minutes later.

Finally yet importantly, the government is also expected to carry out regular disaster training/drill programs both at schools and in society, people can learn correctly about natural disaster hazards and procedures to anticipate them. From the experience of the Great East Japan earthquake, we learned that education and training for the disaster are essential for reducing D&M and related damages. Ultimately, all of these measures are useful for mitigating the impact and losses due to natural disasters.

Acknowledgments

The authors are very grateful to two anonymous reviewers whose have given thorough and insightful reviews of an initial version of the manuscript, in which led to a significant improvement of the paper.

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