Aftershock decay analysis of the 5th August 2020 Sumba earthquake

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Abstract. On 5th August 2020, an earthquake occurred at Sumba and was felt by people who lived in Tambolaka, Waingapu, Waitabula, Bima with III MMI. Based on BMKG (Indonesian Agency for Meteorology, Climatology and Geophysics) analysis, the earthquake occurred at 15.27.12 WIB with magnitude (M) 5.2, depth 11km, epicenter at 9.82° S and 119.11°E. This earthquake was preceded by several foreshocks and produced hundreds of aftershocks. In this study, we estimated the earthquake decay using early aftershock data with 4 empirical scaling relations: 1) Omori's law; 2) Mogi 1's law; 3) Mogi 2's law, and 4) Utsu's law. The data were obtained from BMKG data repository. The results of this study are aftershocks estimated to end: on day 72 by the Omori's law (r = 0.29), on day 522 by the Mogi I (r = 0.29), on day 29 by the Mogi 2 (r = 0.29) and on day 516 by the Utsu law (r = 0.29). The appropriate method for determining earthquake decay in the Sumba region is the Mogi 2 method with r = -0.63, i.e. the aftershocks will end on September 3th, 2020. This was in good agreement with the data from BMKG, where the aftershock ended on September 2nd, 2020.

1. Introduction

Indonesia is one of the countries with a very high productivity of earthquakes. Almost every day there is an earthquake in Indonesia. At least 40,000 earthquakes with magnitude 1.4 - 8.5 were recorded during 2009-2016. This is due to the large number of triggers for earthquakes that are very active in Indonesia, including Indonesia's tectonic conditions which are located at the junction of the world's major plates and several small plates or micro-blocks [1]. As we know, Indonesia is surrounded by four main plates, i.e. the Eurasian Plate, the Indo-Australian Plate, the Philippine Sea Plate and the Pacific Plate. Further research using geodetic, geological, and seismological information shows that tectonics in Indonesia could be divided into several small plates, namely Burma, Sunda, Banda Sea, Maluku Sea, Timor, Bird's Head, Maoke, and Woodlark. In Sumba region, apart from the result of plate encounters, there are several active faults that often trigger earthquakes, namely Sumba Strike Slip and Sumba Ridge [2]. In the past, a high level of seismicity occurred in the south of Sumba Island in 1997 The earthquake was a tsunami earthquake with a normal fault mechanism. Earthquakes with a magnitude ≥ 6 and a thrust mechanism also occurred in the north of this region. The earthquakes were related to Flores and Wetar thrust. These two thrusts occurred due to the style accommodation of the subduction in the southern islands of Nusa Tenggara.

Recently, in August - September 2020, there have been many earthquakes that have occurred and some of them were quite significant earthquakes that were also felt by the people around Sumba Island. Before the main earthquake, from the results of monitoring by BMKG [2] there were 9 preliminary earthquakes on 30 July 2020 to 5 August 2020 with $3.1 \leq M \leq 4.4$. Furthermore, on August 5, 2020 an earthquake was quite strong and felt by people live in Tambolaka, Waingapu, Waitabula, Bima with an intensity of III MMI. Based on BMKG analysis, the mainshock occurred at 15.27.12 WIB with magnitude (M) 5.2, depth 11km, epicenter at 9.82° S and 119.11°E, at a location 30 km southwest of Wanokaka, West Sumba Regency. At least 515 aftershocks occurred and some of them were felt by the surrounding community as shown in the Figure 1. The aftershocks are defined as events of following the larger mainshock that are distributed over the fault area of the mainshock [3]. In general, the number of aftershocks has relatively decreased at time.

There are several methods used in calculating earthquake decay that have been used by several researchers i.e.: 1) Omori's law; 2) Mogi 1's law; 3) Mogi 2's law, and 4) Utsu's law [4, 5, 6]. Determination of earthquake decay using these 4 statistical methods has been carried out for earthquakes in Indonesia since the 2000s, such as the Manokwari and Talaud earthquakes in 2009 [7], the Biak earthquake in 2010 [8], the Soroako earthquake in 2011 [9], the earthquake in the Aceh Segment in 2013 and the Sianok Segment in 2014 [10], the Lombok earthquake in 2018 [11], the Banten earthquake in 2018 [12], and the Ambon earthquake in 2019. Another study using earthquake data from 2009-2017 concluded that the Omori's law was the right method for determining earthquake decay in the Sumatra region, for the Java region using the Omori's law, the Papua region using the Mogi 2 method, the Sulawesi region using the Omori method, the Maluku region using the the Utsu's law, while the appropriate method for the Kalimantan region is the Mogi 2's law [13]. The results from these studies have found different methods to determine earthquake decay in each region. This is probably related to the type of rock material in the study area [5]. In this study, we also use these 4 methods to determine earthquake decay. This result of the aftershock decay analysis is expected to be used as a basis for disaster mitigation and can provide information regarding the estimated aftershocks will end. Morover, it could be a reference in determining when the aftershocks in the Sumba region will end in the future.

2. Method

The earthquake data used in this analysis were obtained from the BMKG earthquake repository for the period 5th to 19th August 2020 in the Sumba region, West Nusa Tenggara with coordinates 9.0° S - 10.50° S and 118.0° E - 121.0° E [3]. The research area on Sumba Island can be seen in the Figure 1.

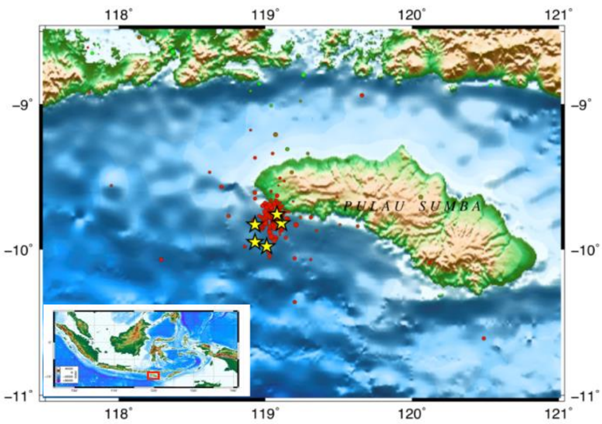


Figure 1. Map of the study area in Sumba. The star symbol indicates the significant earthquakes ($M \geq 4.9$) and the red circles indicates the aftershocks

Figure 1 shows the study area where the yellow star symbol is a significant aftershock with a magnitude of M 4.9 - 5.6, and the red circles represents aftershocks with a magnitude of $M < 4.9$. In this paper, we used 4 earthquake decay methods, namely Omori's law, Mogi 1's law, Mogi 2's law, and Utsu's law. The four equations from this method is simplified into simple linear regression as follows:

$$Y = A + Bx \tag{1}$$

2.1. Omori's Law

Omori's law is a method used to analyze aftershocks in a region. Omori studied the reduction in the half-day frequency and monthly frequency of aftershocks against time after the 1891 Nobi (Mino-Owari) earthquake, central Japan and two other earthquakes in Japan [4]. He shows that the frequency of aftershocks per unit time interval n (t) at time t is shown by the following equation:

$$n(t) = k(c+t)^{-1} \tag{2}$$

Where :

n (t) = frequency of aftershocks at a certain time (*t*).
t = time after the mainshock.
k and *c* = constants that depend on local geology

2.2. Mogi 1's Law

Mogi stated that the frequency of earthquakes occurring more than 100 days in an elastic medium under constant load can be formulated in an exponential relationship [5], with the equation:

$$n(t) = a\,.\,t^{-b} \tag{3}$$

Where :

n (t) = frequency of aftershocks at a certain time (*t*).
t = time after the mainshock.
a and *b* = constants that depend on local geology

2.3. Mogi 2's Law

Mogi (1962) also formulated the relationship between frequency and time in exponentials for aftershocks occurring less than 100 days [6], with the equation:

$$n(t) = a\,.\,e^{-bt} \tag{4}$$

Where :

n (t) = frequency of aftershocks at a certain time (*t*).
t = time after the mainshock.
a and *b* = constants that depend on local geology

2.4. Utsu's Law

Utsu's law is a modification of the Omori equation by Tokuji Utsu which is used to analyze the decay of aftershocks in an area. The frequency of aftershocks per unit time interval (one day, one month, etc.) is well represented by the modified Omori formula [6] as follows:

$$n(t) = k\,(t + c)^{-p} \tag{5}$$

Where :

n(t) = frequency of aftershocks at a certain time (*t*).
t = time after the mainshock.
k, *c*, and *p* = constants that depend on local geology

3. Results and Discussion

The data used in this discussion are 515 aftershocks from the Sumba 2020 Mw 5.5 earthquake, as for the distribution of aftershocks can be seen in Figure 2. The number of aftershocks quite fluctuated on day 1 to day 5. Day 5 after the main earthquake a series of aftershocks occurred up to 136 events a day, this is the number of aftershocks at most. After that, the frequency of aftershocks decreased relative to time.

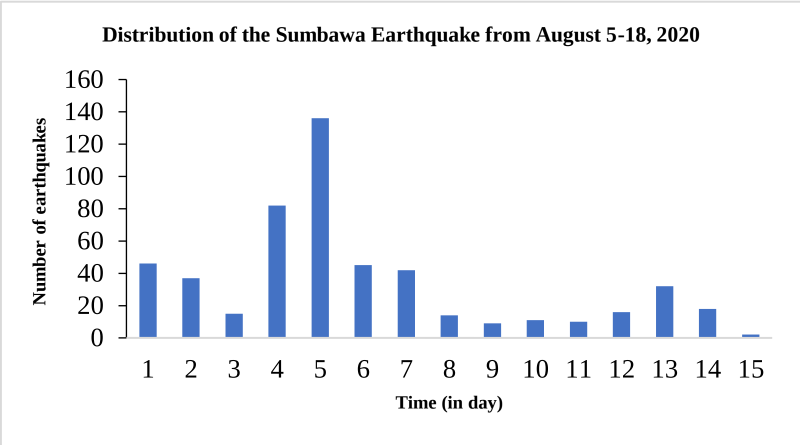


Figure 2. Distribution of aftershocks from the Sumba Mw 5.5 earthquake on 5th August 2020 for 15 days after the mainshock.

The results of statistical calculations using four methods in equations 2, 3, 4, and Equation 5 show different results as shown in Figure 3.

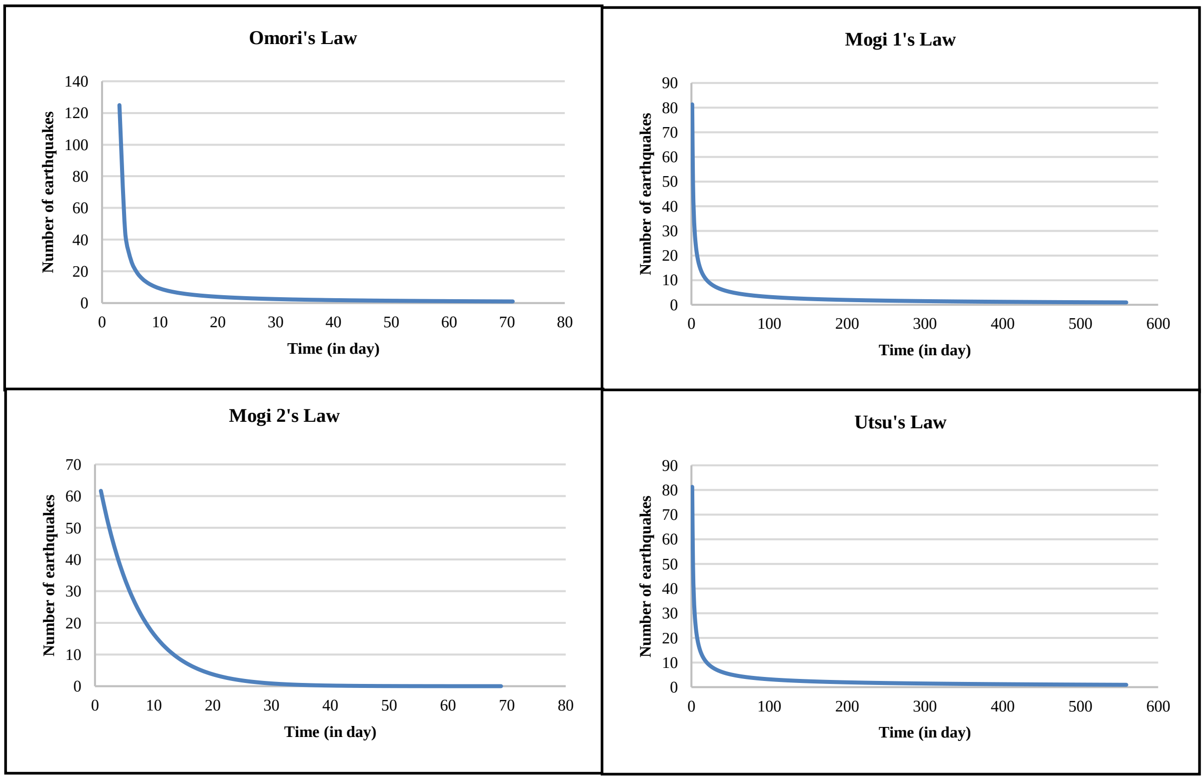


Figure 3. The Decay of the Sumba Earthquake, August 5th, 2020 using the laws of Omori, Mogi 1, Mogi 2, and Utsu.

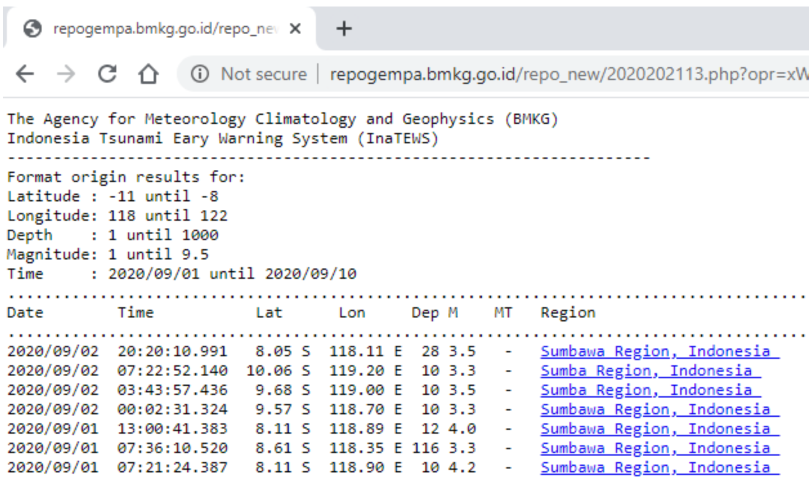
Figure 3 shows the statistical calculation results of the four methods. Omori's law indicates that the aftershock activity ends on the 71th day (15 October 2020), the Mogi 1's law on the 522th day (9 January 2022), the Mogi 2's law on the 29th day (3 September 2020), and Utsu's law on day 516 (January 3, 2022). Based on the results of the four equations, it can be seen that each equation has a decay time which results in a different reduction speed of aftershocks. Omori's law records that the rate of aftershocks decays with a time of t^{-1} after the mainshock occurs [4]. Mogi's law states that the rate of aftershocks occurring more than 100 days in an elastic medium decays with a time of log t, while the rate of aftershocks occurring less than 100 days decays with a time of t [5]. Utsu'Law stated that the rate of aftershocks decays with a time of log (t + 0.01) after the main earthquake occurs [6]. In general, in some cases of earthquakes in Indonesia, aftershocks will decrease in frequency and will end if the movement of the broken plates or rocks has found a new equilibrium point however, each region may have a different time of decay depending on the magnitude of the mainshock and differences in rock types in each region [12, 13]. From the characteristics of the earthquake on Sumba Island where there were several preliminary earthquakes, the main earthquake and followed by aftershocks, it is possible due to the structure of material on Sumba Island is non uniform [5].

To determine the strength of the relationship between the variable x (time of the earthquake) and the variable y (the number of earthquake) of the 4 methods, the correlation coefficient was calculated. The statistical calculation including the correlation coefficient results of 4 method can be seen at Table 1. The correlation coefficient (r) shows how strong the relationship between variables X and Y where the positive and negative signs are the direction of the relationship between the two. The positive sign shows a relationship that is directly proportional, while the negative sign shows the relationship between the two variables X and Y is inversely proportional [14].

Table 1. The statistical calculation results of the Law of Omori, Mogi 1, Mogi 2, and Utsu.

Method	Correlation Coefficient	Days to (*t*)	The Time of the End of the Aftershocks
Omori	0.54	71	October 15, 2020
Mogi 1	-0.53	522	January 9, 2022
Mogi 2	-0.63	29	September 3, 2020
Utsu	-0.53	516	January 3, 2022

For the analysis of the accuracy of earthquake decay times using 4 methods, we compared the time of aftershock decay with real data from BMKG monitoring. Figure 4 shows the last aftershock recorded in Sumba on September 10, 2020, occurred on September 2, 2020. Of all these methods, the most suitable method for determining earthquake decay in the Sumba region is Mogi 2's law. According to this law, it is estimated that the earthquake will end on day 29, on September 3th, 2020, according to real data from BMKG monitoring results.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The Agency for Meteorology Climatology and Geophysics (BMKG)
Indonesia Tsunami Eary Warning System (InaTEWS)

Format origin results for:
Latitude : -11 until -8
Longitude: 118 until 122
Depth : 1 until 1000
Magnitude: 1 until 9.5
Time : 2020/09/01 until 2020/09/10

Date	Time	Lat	Lon	Dep	M	MT	Region
2020/09/02	20:20:10.991	8.05 S	118.11 E	28	3.5	-	Sumbawa Region, Indonesia
2020/09/02	07:22:52.140	10.06 S	119.20 E	10	3.3	-	Sumba Region, Indonesia
2020/09/02	03:43:57.436	9.68 S	119.00 E	10	3.5	-	Sumba Region, Indonesia
2020/09/02	00:02:31.324	9.57 S	118.70 E	10	3.3	-	Sumbawa Region, Indonesia
2020/09/01	13:00:41.383	8.11 S	118.89 E	12	4.0	-	Sumbawa Region, Indonesia
2020/09/01	07:36:10.520	8.61 S	118.35 E	116	3.3	-	Sumbawa Region, Indonesia
2020/09/01	07:21:24.387	8.11 S	118.90 E	10	4.2	-	Sumbawa Region, Indonesia

Figure 4. BMKG monitoring results for the aftershocks of the August 5 Sumba earthquake on September 10, 2020.

4. Conclusion

The first paragraph after a heading is not indented (Bodytext style). The results of research using 4 different statistical methods can be concluded that the appropriate method for determining earthquake decay in the Sumba region is Mogi 2's law with a correlation coefficient of -0.63. The aftershocks from the main earthquake on August 5, 2020 are estimated to end on day 23, on September 3th, 2020, according to BMKG monitoring results.

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