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# Earthquake Decay Analysis to Determine the Afters Thock end Time in West Sumatra in 2021-2023 Using The Omori-Utsu Method

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***Abstract***. *West Sumatra, situated at the convergence of the Indo-Australian and Eurasian tectonic plates, experiences frequent earthquakes and aftershocks due to the complex geological setting. This study utilizes the Omori-Utsu method, a modified version of Omori's law by seismologist Tokiji Utsu, to estimate aftershock duration. Data on aftershocks from significant earthquakes (magnitude ≥5.5M) between 2021 and 2023 were accessed through the BMKG earthquake catalog. The study finds that aftershock durations vary significantly depending on the earthquake's tectonic origin. The longest recorded aftershock duration occurred after the West Pasaman earthquake on February 22, 2022, lasting 21 days, while the shortest was one day following the Mentawai earthquake on September 11, 2022. These variations highlight the influence of tectonic structures on aftershock activity, with subduction zones exhibiting shorter decay times. This research provides critical insights into earthquake behavior, aiding in disaster preparedness and mitigation strategies for the West Sumatra region*.

***Keywords***: *Aftershock duration, Earthquake decay, Omori-Utsu law, West Sumatra*

## 1. INTRODUCTION

Indonesia is situated at the convergence of three major tectonic plates: the Indo-Australian Plate in the south, the Eurasian Plate in the north, and the Pacific Plate in the east. The Indo-Australian Plate moves relatively northward and subducts beneath the Eurasian Plate, while the Pacific Plate moves westward (Simanjuntak & Olymphia, 2017). Sumatra Island is a region that has two geological conditions that could influence seismic activity and tectonic condition. Due to its unique tectonic arrangement, it drew significant attention from geologists and earth scientists, especially in West Sumatra (Asnita et al., 2016).

In West Sumatra, one of the regions on the Sumatra island, the geological setting is complex due to its location in an area where two active tectonic plates collide such as the Indo-Australian Plate in the south and the Eurasian Plate in the north. The movement of these plates is highly active, resulting in frequent earthquakes in West Sumatra (Salamah, 2018). In the western part of West Sumatra, there is a subduction zone along the Sunda Trench west Mentawai Islands, which extends to southern Java (Madrinovella et al., 2011). In addition, the west Sumatra mainland is also crossed by the Sumatra fault system, which consists of active fault segments, namely Sumpur, Sianok, Sumani, Suliti, and Talamau (Dewanto et al., 2022). Talamau is part of the active Sumatran fault system, which influences the seismicity in the

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region (Natawidjaja & Triyoso, 2007). The geological conditions like that, cause a very high-level seismic activity in West Sumatra (Dahlia et al., 2022).

Notably, a significant earthquake occurred in West Sumatra on September 30, 2009, with a magnitude of 7.5 Mw. This earthquake was preceded by 102 foreshocks and followed by 49 aftershocks within a 12-month period, varying in magnitude. Additionally, another earthquake centered in Padang Panjang occurred on March 6, 2007, with a magnitude of 6.4 Mw. It had 2 foreshocks and 15 aftershocks within a 12-month timeframe (Putra, 2021). West Sumatra also has the potential for a significant earthquake, especially on Siberut Island and the southern part of Nias Island, due to the low b-value in these areas (Syafriani, 2018).

An earthquake is the sudden release of energy within the Earth’s crust, often caused by the rupture of rock layers (Syamsi, 2018). An earthquake can also be defined as an event of energy release in the Earth's crust. One form of this energy is wave energy, known as seismic waves. These waves are emitted from a source and propagate in all directions, thus they can be detected by sensors (Hilmi et al., 2019). The magnitude of the effects felt due to an earthquake is positively correlated with the distance of a region from the hypocenter of an earthquake. The hypocenter is the actual location where the earthquake occurs, while the epicenter is the projection of the hypocenter on the Earth's surface (Gutenberg, 1955).

Large-magnitude earthquakes are typically followed by aftershocks (Ali, 2021). Aftershocks occur in areas adjacent to the main earthquake, and their magnitude distinguishes them from the main event (Ariyanto & Januarti, 2020). Aftershocks generally occur along local faults on the Earth's surface. When a major fault ruptures at a certain depth, most of the stress energy is released during the main earthquake. However, the remaining high stress in the vicinity of the fault area leads to fractures and local faulting. Then, average stress decreases after the main earthquake, if the stress concentrations remain high and fluctuate in the area, it could trigger extended aftershocks (Pahlevi, 2020). Aftershock are earthquakestrigger that occur in the same area as the main earthquake but have a smaller magnitude and appear in pattern that follows Omori’s law. Since 1894, Japanese seismologist Fusakichi Omori has observed a regular pattern in the distribution of aftershocks globally. The mathematical calculation of this seismic distribution is called Omori’s Law (Sari et al., 2012).

The Omori-Utsu method is used to analyze the timing of aftershocks. This method, based on observations by Japanese seismologist Tokuji Utsu, modifies Omori's law by adding estimated values for parameters p and c (Utsu & Ogata, 1995). Utsu demonstrated that the aftershock occurrence rate based on Omori’s law follows the equation:

$$n(t) = Kt^{-p} \tag{1}$$

with an index p approximately around 1.4. Since this function diverges at (t = 0), Utsu recommended using:

$$n(t) = K(t + c)^{-p} \tag{2}$$

where the additional small positive constant c is included

Utsu referred to equation (2) as the modified Omori formula. The value of p was in the range about 0.9 to 1.5 and the value of c was scattered from less than 0.01 days to more than 1 day, with a median of about 0.3 days (Utsu, 1957). The value of p typically refers to the parameter that determines the frequency of aftershock. This value is calculated based on previous earthquake data and is used to predict how often aftershocks can occur after a main earthquake. The decreasing number of earthquakes in successive aftershock indicates that the value of p can show the rate of decrease inn the number of aftershocks. This is due to the fact that residual stress un the aftershock area decreases rapidly in high-temperature areas due to rock-flow (Islamiati et al., 2020). Therefore, the Omori-Utsu method allows for flexible analysis of earthquake data, enabling model adjustments based on local geology and rock properties, which allows for more specific and relevant prediction for a particular location.

Previous studies have been conducted in several areas comparing the four methods for calculating aftershocks decay. In the case of Banten earthquake Januari 14, 2022 by Wahyu Fitrianto and the May 23, 2021 Sunda Strait earthquake by Ariyanto, P. and Januarti, Y., it was found that the appropriate method for determining the decay of these two earthquakes are the Mogi I and Utsu or Omori-Utsu methods. Based on previous research that compared several earthquake decay methods, this study specifically discusses the Omori-Utsu method, which can estimate the time of the end of aftershock and show how the earthquake decay pattern occurs, especially in West Sumatra. The data used is also the latest data since 2021 which can compare several major earthquake events in recent years and identify the factors that affect the duration and intensity of aftershock in each earthquake event.

Based on the explanation above, the purpose of this research is to analyze the timing of aftershocks in order to provide information to the public that aftershocks can occur following a major earthquake. Additionally, it serves as an effort for earthquake disaster mitigation, aiming to prevent further loss of life in West Sumatra and surrounding areas. The Omori-Utsu method used can also provide valuable insights, indicating its suitability for estimating the duration of aftershocks in the West Sumatra region.

## 2. METHODS

This study focuses on three key variables: the frequency of aftershocks (as the independent variable), the estimated end time of aftershocks (as the dependent variable), and control variables including the Omori-Utsu method, study area, and time period (2021–2023). The selected timeframe ensures the use of recent and comparable earthquake data from West Sumatra.

Aftershock data from earthquakes with magnitude ≥5.5M were obtained from the BMKG catalog, including event time, coordinates, depth, magnitude, and aftershock counts within 10 days. Data processing was conducted in Microsoft Excel by organizing aftershocks into time intervals. These intervals were used to calculate the Omori-Utsu parameters K and p using the linearized logarithmic equation using the Least Squares method. This interval data is then used to calculate coefficients y and x according to Equation (2), which can be expanded into the following equation:

$$\log n(t) = \log K - p \log(t + 0{,}01) \tag{3}$$

Based on Equation (3), coefficient y and x can be obtained using the Least Squares method, thus the value of y and x are:

$$y = \log n(t) \tag{4}$$

$$x = \log(t + 0{,}01) \tag{5}$$

Then, the Least Squares method can be used to calculate the value of coefficient A and B based on value of x and y. The value of A and B obtained from:

$$B = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} \tag{6}$$

$$A = \frac{1}{n}\left(\sum y - B\sum x\right) \tag{7}$$

then the values of A and B can each represent the constant values of K and p based on equation (3):

$$K = 10^A \tag{8}$$

$$p = -B \tag{9}$$

Finally, the correlation coefficient (r) is computed using:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{(n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2)}} \tag{10}$$

After obtaining the values of K, p, and the correlation coefficient r, the next step is to input the values of K and p into equation (2) to estimate the end time of the aftershock with the value of n(t)=1.

The outcome of this research is an estimated end time for aftershocks following several significant earthquakes in West Sumatra. Using these estimated values and calculating the Pearson correlation coefficient, the study analyzes the relationship between the chosen method and the Pearson correlation coefficient. Furthermore, the interrelationships between each variable are examined to assess the suitability of the method for determining the end of aftershocks.

## 3. RESULTS AND DISCUSSION

This study provides an estimate of when aftershocks might occur following a significant earthquake in the West Sumatra region. The data analyzed comes from the BMKG earthquake catalog, covering the period from 2021 to 2023. Data on significant earthquakes in the West Sumatra region during the period 2021-2023 is presented in the Table 1.

**Table 1: Significant Earthquake in West Sumatra in 2021-2023 (Magnitude ≥5.5M).**

| Date | Mag | Latitude | Longitude | Depth |
|---|---|---|---|---|
| 25/02/2022 | 6,1 | 0,174542293 | 99,95087433 | 10 |
| 29/08/2022 | 6,1 | -1,04390192 | 98,6208725 | 33 |
| 11/09/2022 | 6,2 | -1,137766957 | 98,67895508 | 27 |
| 24/04/2023 | 7 | -0,975783169 | 98,33918762 | 11 |

(Source: BMKG)

The data processing utilized the Omori-Utsu method, based on aftershock data from four significant earthquake events in the West Sumatra region. Aftershock data for each mainshock event were grouped by time intervals (t) and the number of earthquake occurrences, n(t). These time intervals (t) and event counts, n(t), were then analyzed using the Least Squares method to determine the coefficients (p) and (K), which were incorporated into Equation (2).

The research recorded aftershocks from four significant earthquakes in West Sumatra. The West Pasaman earthquake on February 22, 2022, had 75 aftershocks within a 7-day period, with an estimated aftershock end time of 21 days. The Mentawai earthquake on August 29, 2022, recorded 13 aftershocks within a 36-hour period, with an estimated end time of 2 days. The Mentawai earthquake on September 11, 2022, had 5 aftershocks within a 36-hour period, with an estimated end time of 1 day. Lastly, the Mentawai earthquake on April 25, 2023, recorded 14 aftershocks within a 3-day period, with an estimated end time of 8 days. The results of the Omori-Utsu method, including the calculated p and K constants, correlation coefficient (r), and estimated aftershock duration, are summarized in Table 2

**Table 2: Results of the Omori-Utsu Method for a significant Earthquake in West Sumatra.**

| Date | P | K | r | t (day) |
|---|---|---|---|---|
| 22/02/2022 (Pasaman) | 1,07466 | 26,21114 | -0,84 | 21 |
| 29/08/2022 (Mentawai) | 1,96765 | 9,83331 | -0,99 | 2 |
| 11/09/2022 (Mentawai) | 1,06923 | 2,74921 | -0,93 | 1 |
| 25/04/2023 (Mentawai) | 0,954559 | 7,40016 | -0,93 | 8 |

The Utsu method, an extension of the Omori law introduced by Fusakichi Omori in 1894, posits that the frequency of aftershocks decreases exponentially over time following a main earthquake. Tokuji Utsu refined this model to improve accuracy based on empirical data. Analysis of data from four significant earthquakes in West Sumatra revealed variations in the parameters p and K. The p value represents the decay rate of aftershock frequency, with higher values indicating a faster decay. The K value relates to the intensity of the main earthquake and the initial number of aftershocks, with higher K values indicating more immediate aftershocks following the main event, typically correlated with the magnitude of the main earthquake (Utsu & Ogata, 1995).

For the Pasaman earthquake on February 22, 2022, the p value is 1.07466 and the K value is 26.21114, indicating a higher frequency of aftershocks and a slower decay rate. For the Mentawai earthquake on August 29, 2022, the p value is 1.96765 and the K value is 9.83331, suggesting fewer aftershocks with a faster decay rate. Conversely, the Mentawai earthquake on September 11, 2022, had a p value of 1.06923 and a K value of 2.74921, indicating fewer aftershocks and a slower decay rate. The Mentawai earthquake on April 25, 2023, showed a slower decay rate and even fewer aftershocks, reflected in the p value of 0.954559 and the K value of 7.40016. A correlation coefficient value of -1 in each calculation indicates that there is a good relationship between the decreasing frequency variable and the increasing or longer time variable.

Based on the calculated values of p and K, as well as the estimated end time of the aftershocks, it is observed that in the Mentawai Islands region, the frequency of aftershocks is lower following the main earthquake, with an estimated end time ranging from 1 to 8 days. In contrast, the Pasaman earthquake has a higher frequency of aftershocks and a longer estimated end time. These differences are likely due to varying tectonic conditions at each earthquake epicenter. The Mentawai Islands located in a subduction zone, which contributes to the formation of volcanic belts and active fault activity, heightening the earthquake risk. The Mentawai Islands also feature the Mentawai Fault. The Mentawai Fault is a significant tectonic feature associated with strike-slip movement, which plays a role in regional seismicity which runs parallel to the Sumatra Fault System and extends north to Nias Island and the Sunda Strait. The Pasaman earthquake resulted from the activity of the large Sumatra fault. This fault is formed by the bending of the Indo-Australian oceanic plate beneath the Eurasian and Sunda plates, generating significant pressure and causing active tectonic movements, including earthquakes and volcanic activity. Pasaman Barat itself is traversed by a fault segment running from Mount Malintang to Mount Talamau (Natawidjaja & Triyoso, 2007) (Dewanto et al., 2022b)

Moreover, the decay graph of aftershock for each earthquake event, can be seen in Figure 1.

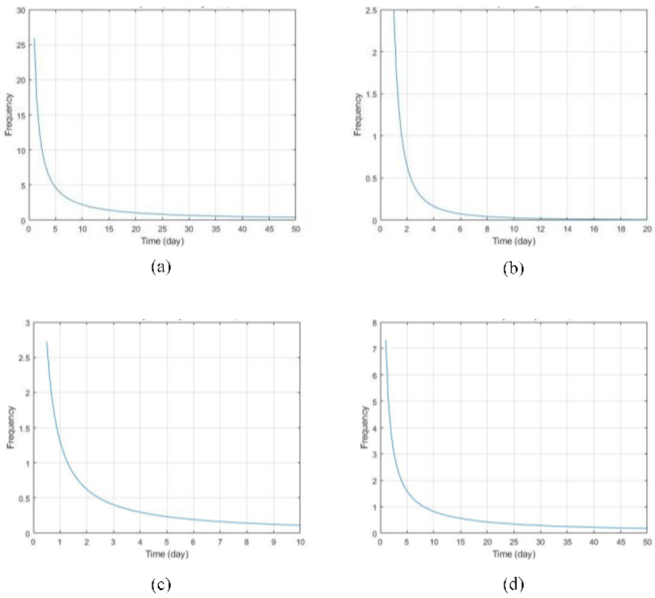


**Figure 1. Time-Frequency plot of aftershock decay in West Sumatra, (a) Pasaman earthquake February 22, 2022 (b) Mentawai earthquake August 29, 2022 (c) Mentawai earthquake September 11, 2022 and (d) Mentawai earthquake April 25, 2023**

Based on the aftershock decay graph in Figure 1 it is observed that for the three Mentawai earthquakes (Figures 1b, 1c, and 1d), aftershock activity decreased rapidly, indicating that the energy stored from the main earthquake was quickly released. In contrast, the Pasaman earthquake (Figure 1a) showed a slower decrease in aftershock activity, suggesting a slower energy release. However, the aftershock decay curves for all four events display an exponential pattern consistent with the Omori-Utsu law.

The aftershock sequence in Pasaman on February 25 2022, was expected to end within a time span of 49 to 473 days after the mainshock, according to a study by Rizki Wulandari in 2023, based on data collected over an 18-day period following the mainshock, with a total of 217 aftershocks recorded (Wulandari et al., 2023). Meanwhile, in this study, an estimated time of 20 days since the mainshock was obtained, with K value and p value 26,2 and 1,2. In Mentawai Islands, located in the subduction zone of Sumatran Island, aftershock in this subduction zone tend to had a long duration with varying intensities. For instance, the 2004 Sumatra-Andaman earthquake produced a series of aftershocks that lasted for several years after the mainshock (Shcherbakov et al., 2013). Meanwhile, in this study, the estimated value ranges from 1 to 8 days, with varying p value of 0,9-1,9 and K value of 2,7-9,8, which the estimated time value was quite short. These findings suggest that more accurate estimations of aftershock end times can be achieved with longer time intervals and more data. The decay pattern of aftershocks in the West Sumatra region generally follows the Omori-Utsu law, exhibiting an exponential decrease.

## 4. CONCLUSION

The estimated end time of aftershocks is obtained based on data from four significant earthquakes in the West Sumatra region. These earthquakes occurred in West Pasaman on February 22, 2022, lasting for 21 days after the main earthquake. The estimated values for the decay exponent (p) are 1.07466, and the constant (K) is 26.21114, with a correlation coefficient of -0.89. For the Mentawai earthquake on August 29, 2022, which lasted for two day after the main earthquake, the estimated p value is 1.96765, K value is 9.83331, and the correlation coefficient is -0.99. Similarly, for the Mentawai earthquake on September 11, 2022, lasting one day after the main earthquake, the p value is 1.06923, K value is 2.74921, and the correlation coefficient is -0.93. Finally, for the Mentawai earthquake on April 25, 2023, lasting eight days after the main earthquake, the estimated p value is 0.954559, K value is 7.40016, and the correlation coefficient is -0.93. The p value represents the decay rate of aftershocks, while the K value is related to the intensity of the main earthquake and the number of immediate aftershocks following the main event.

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