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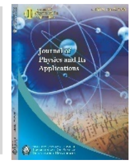

Pangandaran Earthquake and b-value Analysis for Better Understanding of Seismic Vulnerability in Java using Statistical Earthquake Data of 2002-2010

Siti Fauzatun Wachidah[1]*, Agung Wibawa[2], Kurniawan[1], and Muhammad Syauqi[1]

[1]*Industrial Engineering, Universitas Nahdlatul Ulama Al Ghazali Cilacap, Central Java, Indonesia*
[2]*Information System, Universitas Nahdlatul Ulama Al Ghazali Cilacap, Central Java, Indonesia*

**Corresponding author:*
sitifaw.fti@unugha.ac.id
agungwibawa@unugha.ac.id
uzumakireiha01@gmail.com
muhammadsyauqi43820@gmail.com

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ABSTRACT

The application of statistical methods in seismicity analysis can provide a robust description of the relationship between earthquake magnitude and frequency in each region. This statistical relationship is formulated using the Gutenberg-Richter law, which continues to be developed through empirical and analytical studies of earthquakes in many regions. This study aims to analyze two significant earthquakes that affected the island of Java in 2006: the destructive Yogyakarta earthquake on 27 May 2006 and the Pangandaran earthquake on 17 July 2006. Both events were generated by active subduction mechanisms on the southern side of the island, where earthquakes of various magnitudes occur periodically. Through a temporal and spatial analysis of the b-value, this study compares different earthquake catalogs and analyzes the seismic vulnerability of Java by calculating the deformation caused by the 2006 earthquakes. The calculated b-values from the USGS and IRISDMC earthquake catalogs are 1.38 ± 0.04 and 0.92 ± 0.01, respectively. The magnitude of completeness (Mc) values are 4.9 for the USGS catalog and 4.3 for the IRISDMC catalog. The earthquake data span from 2002 to 2010. Deformation calculations using the IRISDMC data for 2006 show that the Pangandaran earthquake resulted in a surface rupture length of 140.60 km, a rupture area of 3,235.94 km^2, and a displacement of 7.96 m.

1. Introduction

As the world's most populated island, Java lies within the seismically active Pacific Ring of Fire and is situated on a plate boundary characterized by active tectonic and volcanic activity. Currently home to over 156 million people, Java's dense population underscores the critical need to understand its tectonic behavior [1]. In 2006, two major earthquakes struck Java with destructive force. The first, on 27 May 2006, shook the city of Yogyakarta, resulting in 6,652 fatalities. The second, on 17 July 2006, occurred off the coast of Pangandaran, generated a tsunami, and claimed 668 lives, with 65 others reported missing [2]. Both seismic events were caused by Java's complex tectonic system, which lies at the convergent boundary of the Indo-Australian and Eurasian plates. The interaction of these major plates is the primary driver of earthquakes and volcanic formation in the region. Earthquakes in this subduction zone also carry a high potential for triggering tsunamis. The southern coast of Java is particularly vulnerable to tsunami-related destruction due to the presence of a plunging subduction zone approximately 150 km offshore.

Damage analysis from tectonic earthquakes in Java can be approached from multiple perspectives. One method, employed in this research, utilizes earthquake statistics based on the Gutenberg-Richter law established in 1944 [3]. This analysis reveals a relationship between the frequency and magnitude of earthquakes in a given region, indicating that a higher frequency of small-scale earthquakes correlates with a lower probability of a major event. Although deriving a precise linear relationship is often challenging due to incomplete catalogs and varying tectonic conditions, the Gutenberg-Richter approach provides valuable insights, particularly through changes in the b-value, spatial and temporal analysis of earthquake distribution, and epicenter depth.

Nuannin and Kulhanek [4] analyzed the b-value in the Andaman-Sumatra region using catalogs from ISC, NEIC, IDC, and HRVD, comprising between 1,107 and 13,672 events. Temporal variation, b(t), was analyzed using a sliding window of 50 events with a 5-event shift. The results showed that major earthquakes typically occur when the b-value decreases to approximately 0.3–0.1, providing a medium-term (months to years) precursor estimate. Spatial analysis, performed on a 0.5° × 0.5° grid with a minimum of 50 earthquakes, produced b-value maps that reflect stress distribution; low b-values indicate areas that are potential epicenters for major quakes. Regions with b-values of ~0.5–1.1 were identified as past epicenters of large earthquakes, while areas with b-values of ~1.2–2.2 had not experienced significant seismic events.

Research by Christopher H. Scholz [5] demonstrated the relationship between b-value and rock stress at a laboratory level. By comparing laboratory measurements with global earthquake data, the study found that a decrease in b-value correlates with an increase in applied stress, a pattern consistent in continental crust and subduction zones. This led to the conclusion that b-value can be a useful parameter in earthquake forecasting models.

A study by Lawerissa, R. et al. [6] on b-value and Mc in Papua showed dominant seismicity at plate boundaries, with a b-value of 0.92 ± 0.02, an a-value of 7.02, and an Mc of 4.3. Investigation of the b-value along the Ransiki-Yapen faults revealed a decreasing trend to 0.84 ± 0.02, indicating increasing stress within the rock layer. Temporal analysis for the period 2002–2009 showed multiple decreases in b-value prior to major mainshocks, followed by increases afterward. These fluctuations are likely due to the accumulation and subsequent release of stress during rupture and aftershock sequences, providing corroborating evidence for Probabilistic Seismic Hazard Analysis (PSHA) in West Papua.

However, research by Marzocchi [7] highlighted potential ambiguities in interpreting b-values, which can arise from insufficient catalog data, magnitude binning, and catalog incompleteness. The paper recommends using more robust statistical models, such as maximum likelihood estimation, to avoid misinterpretation of b-value as a direct stress indicator.

Based on this foundational research, this study aims to determine the b-value in Java for the period 2001–2010 by analyzing earthquake catalogs from the USGS and IRISDMC. A further analysis of deformation will be conducted for 2006, the year which witnessed two destructive earthquakes in Yogyakarta and Pangandaran. This is particularly noteworthy as the 27 May 2006 Yogyakarta earthquake was a crustal fault event with a hypocenter at 15 km depth, while the tsunami-generating Pangandaran earthquake was a megathrust subduction event at 25 km depth [2].

The research questions addressed are as follows:

1. How does the b-value change temporally and spatially in the study area?
2. What differences exist in the b-value and its variations between the two different catalogs used?
3. What are the estimated values for surface rupture length, rupture area, and displacement from the Pangandaran earthquake using the Wells and Coppersmith empirical relationship?

2. Methods

The b-value and Magnitude Completeness was determined as follows: the relationship between earthquake frequency and b value set by Gutenberg-Richter can be written as the following linear equation:

$$\log N = a - bM \quad (1)$$

with N being the number of earthquake events within M±ΔM interval, while a and b are Real constants. Constant a relates to seismicity level and shows variations from one area to the next, depending on observation period and width of the area being observed. Constant b relates to tectonic structure, depending on stress level of the area being observed [3].

B-value may be obtained using either the least square method or the maximum likelihood method. Using the formula put forward by Aki [8], calculation for maximum likelihood is as follows:

$$b = \frac{\log_{10} e}{\bar{M} - M_{min}} \quad (2)$$

where ¯M is the average magnitude above M_{min}. Calculation for standard deviation of b-value was introduced by Shi and Bolt [9] as follows:

$$\delta_b = 2.3b^2 \sqrt{\sum_{i=1}^{n} \frac{(M_i - \bar{M})^2}{n(n-1)}} \quad (3)$$

where n is the number of earthquake events taken as samples.

The earthquake magnitudes provided by the USGS and IRISDMC for the period from 1 January 2002 to 31 December 2010 are reported in various scales, including mb (body-wave magnitude), Mw (moment magnitude), M_L (local magnitude), M_s (surface-wave magnitude), M_d (duration magnitude), M_{jma} (Japan Meteorological Agency magnitude), and M_{Lv} (local magnitude with vertical displacement). These diverse magnitude scales were converted to a uniform Mw (moment magnitude) scale using the equations detailed in Table 1. This homogenization process is essential to facilitate b-value calculation on a consistent scale and to minimize potential errors in the interpretation of empirical data [15].

Table 1: Conversion of various earthquake scales to the Mw

Magnitude Scale	**Conversion to Mw**
m_D (Body magnitude)	$M_w = 0.67 \times m_D + 1.5$
M_{jma} (Japan Meteorology Agency Magnitude)	$M_{jma} - 0.90 \times M_{jma} - 0.03$
m_b (Body Magnitude) **[10]**	$M_w = 0.85 \times m_b + 1.03$
M_L (Local Magnitude)	$M_w = 0.67 \times M_L + 0{,}1$
m_S (Surface Wave Magnitude) **[11]**	$M_w = 0.64 \pm 0.005\ M_s + 2.07\ (\pm 0{,}05)$, $3{,}0 \leq M_s \leq 6.1$
M_{LV} (Local Velocity Magnitude) **[10]**	$M_W = 0.67 M_{Lv} + 1.46$

The Reasenberg declustering algorithm was applied as follows: Declustering is necessary to identify mainshocks within an earthquake catalog. In this research, declustering was performed using the Reasenberg method, which isolates mainshocks from foreshocks and aftershocks based on spatiotemporal windows in the time and distance domains [16]. The parameters involved in this method include the confidence level, magnitude range, return period, and lower and upper bounds.

The stages involved in this research are illustrated in Fig. 1.

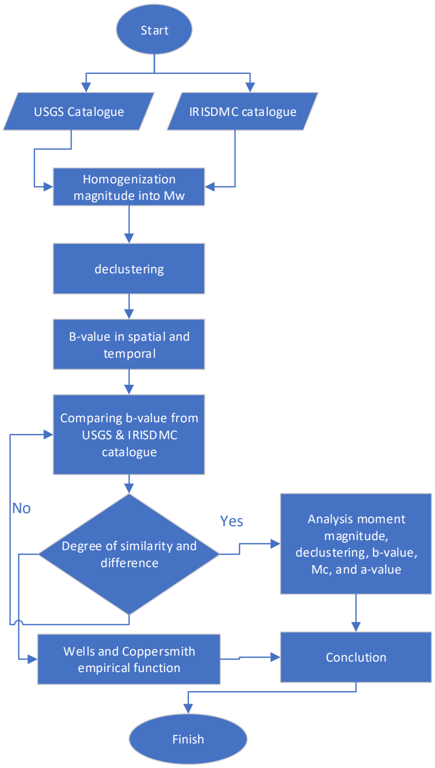

Fig. 1: Flowchart of b-value research in Java by analyzing two different earthquake catalogs.

Research area of this study is depicted in Fig. 1, and it covers the mainland of Java and its sea which makes up a subduction convergence zone. This area is within 104° BT-114° BT and 6°LS - 10° LS coordinate. Figure 1 depicts the research area chosen.

The earthquake data used are taken from the catalogs provided by the USGS (United States Geological Survey) and IRISDMC (Incorporated Research Institutions for Seismology Data Management Center) from 1 January 2002 through 31 December 2010. The data chosen for this research are those of magnitude ≥ 3. The number of earthquake events and categorization of magnitude types available are given in Table 2.

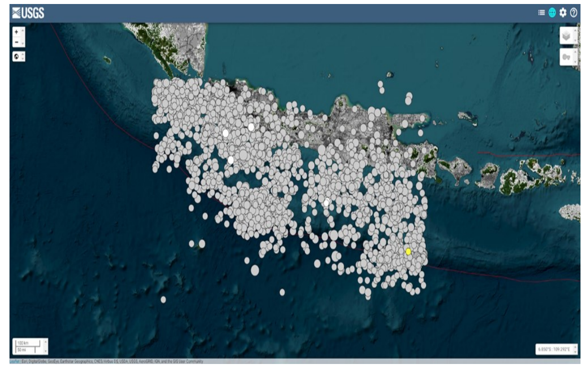

Fig. 2: The research area covers all areas of Java with greater emphasis on analyzing the earthquake in Pangandaran on 17 July 2006 which recorded a magnitude of 7.7 and resulted in a Tsunami.

The catalog filtering process involved homogenizing earthquake magnitudes to the Mw scale using the formulas provided in Table 1, applied according to the available data. The distribution of the number of earthquake events from both the IRISDMC and USGS catalogs is shown in Fig. 3. Only earthquake events with a magnitude greater than or equal to 3 (M ≥ 3) were converted and included.

Figure 3 shows an increase in the number of events in 2006 compared to previous years, followed by a decrease in 2007, despite a significant M7.5 earthquake occurring in West Java on 9 August 2007. This surge in seismic activity during 2006 indicates a substantial release of energy in the southern part of Java. Based on the analysis of earthquake events and hypocenter positions, a b-value analysis was conducted using both temporal analysis, f(t), and spatial analysis, f(x,y), as illustrated in Fig. 4.

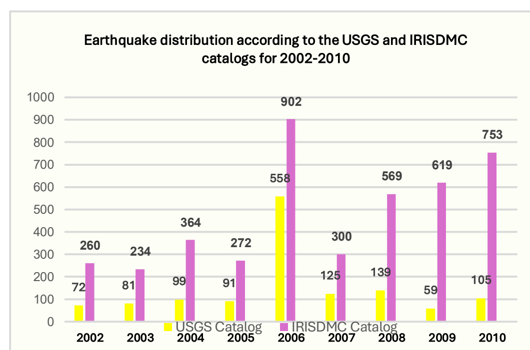

Fig. 3: Number of annual earthquake events used in this research.

Table 2: Number of earthquake events and their categorization based on magnitude of at least 3 for the process of catalog data filtering

Name of Data Supervisor	No. of Events	Depth	Mag.	*b*-value	Mc
USGS (15.01.2002 to 22.12.2010)	1329	0.80 ≤ Z ≤ 609.30 km	2.7 ≤ Mw ≤ 7.7	1.38 ± 0.04	4.9
IRISDMC (03.01.2002 to 30.12.2010)	4274	0.00 ≤ Z ≤ 627.60 km	2.11 ≤ Mw ≤ 7.7	0.92 ± 0.01	4.3

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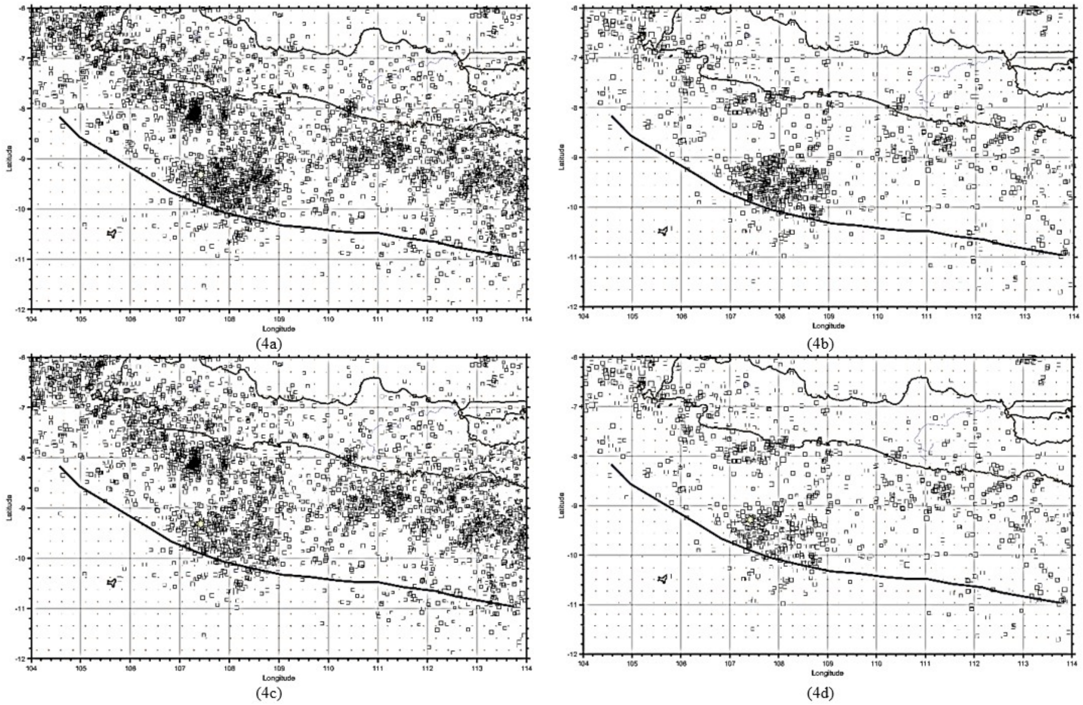


Fig. 4: Data distribution in the IRISDMC catalog is given in Figure 4(a) (4274 events), data distribution in the USGS catalog is given in Figure 4(b) (1329 events), Figure 4(c). shows declustered IRISDMC data using the Reasenberg method with confidence level of 90%, and Figure 4(d). Shows declustered USGS data using the same method at confidence level of 80%.

3. Results and Discussion

Declustering process was performed for both USGS and IRISDMC data using the Reasenberg method at confidence level of 90% (IRISDMC) and 80% (USGS) respectively [14]. Results show that 34 earthquake clusters and 287 events for the USGS catalog and 72 earthquake clusters and 496 events for the IRISDMC catalog. IRISDMS data has more information, but for the coordinate cluster of Pangandaran area, USGS data is more rigid.

Parameters were chosen in line with the available earthquake events. Calculation for b-value analysis and δ_b is made using the Mc-DuoB-Cao approach to obtain a graph of b-value versus time, the result of which is depicted in Fig. 5. For the USGS catalog, calculation of b-value varies from 0.2 -1.8, while for the IRISDMC catalog, calculation of b-value varies from 0.2-1.6.

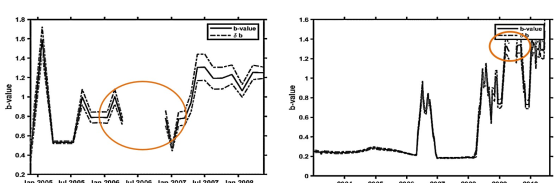


Fig. 5: Results of analysis for USGS data (left) and IRISDMC data (right) after declustering using the Reasenberg and grid selection 5 km ×5 km

Figure 5 also shows that the relationship between b-value and time for the USGS data (left) starts from 2005, and that between July 2006 - January 2007, no b-value is observed (not calculated), and this is due to the limitation of the USGS catalog. Meanwhile, for the IRISDMC data (right), calculation for b-value comes up empty for 2009-2010. For the IRISDMC data, during mid-2006-2007, b-value experiences an increase and later a decrease at the end of 2007-2008.

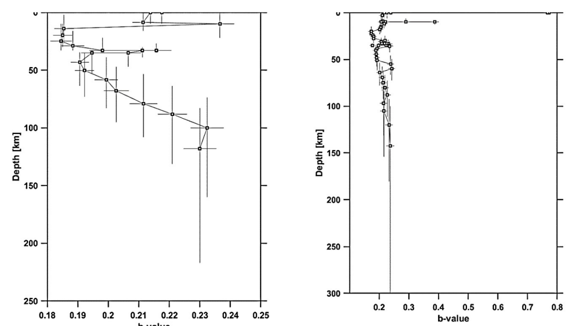
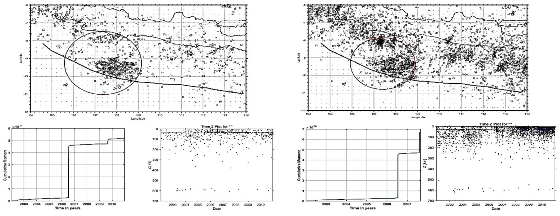


Fig. 6: Relationship of b-value and depth for the USGS data (left) and the IRISDMC data (right).

Figure 6 shows that the highest and lowest b-values are observed at depths of 0-50 km, ranging from 0.18 to 0.25 for the USGS data, while for the IRISDMC data, b-values range from 0.2 to 0.5. This figure also reveals variations in the estimated b-values between the two earthquake catalogs, with a calculation discrepancy of 0.02 to 0.25. Despite this discrepancy, the information on depth variation and the relative distribution of high b-values follows the same general trend, as do the b-value fluctuations in both catalogs.

Figures 7(a) and 7(b) show a comparison of earthquake distributions between the USGS (7(a)) and IRISDMC (7(b)) catalogs. Both cover the same depth range (up to 700 km) and show a similar alteration in cumulative seismic moment occurring in mid-2006. The cumulative moment analysis for the USGS data is available up to 2010, whereas for IRISDMC, it is only available until 2007, as the dataset concludes in that year. Shallow earthquakes in both catalogs are dominated by events occurring at depths of 0-100 km.



(7a) (7b)

Fig. 7: Earthquake data distribution (USGS) for 2002-2010 (7(a)) and (IRISDMC) for 2002-2010 (7(b)), which make up the source mechanism of the Pangandaran earthquake.

Meanwhile, medium depth quakes take place at a depth of 100-300 km, and there are less deep earthquakes at a depth of 600 km. Earthquakes at 0-100 km depth are mainly taking place on the southern part of Java and are directly related to tectonic convergence area, while earthquakes taking place at depths of more than 300 km are deep quakes located on the northerly side compared to those of 0-100 km depth. Nonetheless, some shallow earthquakes also shook mainland Java and caused severe damage. Other earthquake distributions will further be analyzed using spatial b-value in Fig. 9 and Fig. 10.

Table 3 gives empirical equation from Wells and Coppersmith to be used in modeling surface length, rupture area, and displacement observed for the Pangandaran earthquake of 2006 using the IRISDMC catalog at magnitudes ≥5.

Figure 8 shows b-values for the USGS and IRISDMC data that have been homogenized into the M_w scale. Data taken from both catalogs are earthquakes of M ≥ 3 magnitude with a maximum depth of 600 km. The b-value from USGS data is 1.38 ±0.04, whereas from IRISDMC data, the figure is 0.90 ±0.02. Mc value for the USGS data is 4.9, while for the IRISDMC data, it reads M_c=4.3. Figures on the right side of the magnitude window show that after homogenization, earthquakes of certain magnitude become ≤3. Nonetheless, distribution at scale M_w ≥ 4.5 for the USGS catalog is of the same trend as that of the M_w ≥ 4.0 scale of the IRISDMC data.

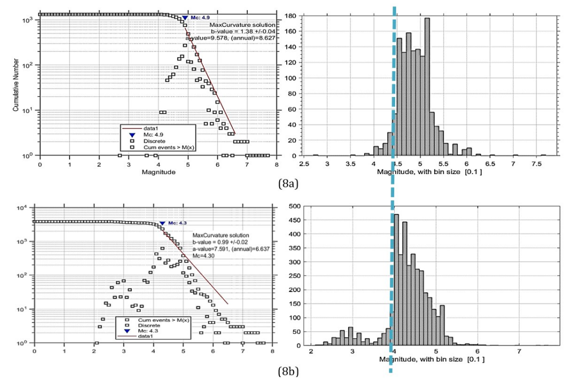


Fig. 8: (a) b-value and earthquake magnitude distribution from the USGS data for 2002-2010. (b) b-value and earthquake magnitude distribution from the IRISDMC data for 2002-2010

Table 3: Empirical relationship between M_c (Moment magnitude) and Surface rupture length L (km), Rupture area A (km²), and Maximum surface displacement D (m).

Fault Movement	Number of Events	Relationship	σM_ω	Relationship	$\sigma \log L, A, D$
Strike-slip	43	$M_\omega = 5{,}16 + 1{,}12 \log L$	0.28	$Log\ L = 0{,}74\ M_\omega - 3{,}55$	0.23
Reverse	19	$M_\omega = 5{,}00 + 1{,}22 \log L$	0.28	$Log\ L = 0{,}63\ M_\omega - 2{,}86$	0.20
Normal	15	$M_\omega = 4{,}86 + 1{,}32 \log L$	0.34	$Log\ L = 0{,}50\ M_\omega - 2{,}01$	0.21
All	77	$M_\omega = 5{,}08 + 1{,}16 \log L$	0.28	$Log\ L = 0{,}69\ M_\omega - 3{,}22$	0.22
Strike-slip	83	$M_\omega - 3{,}98 + 1{,}02 \log A$	0.23	$Log\ A - 0{,}90\ M_\omega - 3{,}42$	0.22
Reverse	43	$M_\omega = 4{,}33 + 0{,}90 \log A$	0.25	$Log\ A = 0{,}98\ M_\omega - 3{,}99$	0.26
Normal	22	$M_\omega = 3{,}93 + 1{,}02 \log A$	0.25	$Log\ A = 0{,}82\ M_\omega - 2{,}87$	0.22
All	148	$M_\omega = 4{,}07 + 0{,}98 \log A$	0.24	$Log\ A = 0{,}91\ M_\omega - 3{,}49$	0.24
Strike-slip	43	$M_\omega = 6{,}81 + 0{,}78 \log D$	0.29	$Log\ D = 1{,}03\ M_\omega - 7{,}03$	0.34
Reverse	21	$M_\omega = 6{,}52 + 0{,}44 \log D$	0.52	$Log\ D = 0{,}29\ M_\omega - 1{,}84$	0.42
Normal	16	$M_\omega = 6{,}61 + 0{,}71 \log D$	0.34	$Log\ D = 0{,}89\ M_\omega - 5{,}90$	0.38

Figures 9(a), 9(b), 9(c), 9(d), 9(e) and 9(f), which depict b-value, standard deviation, and a-value for the IRISDMC and USGS catalogs, a range of scales as given in Table 4 are shown.

Table 4: Scale range of spatial maps

Catalog Name	Scale Range		
	b-value	**Std b-value**	**a-value**
IRISDMC	0.4 – 1.8	0.05 - 0.3	4.0 - 11.0
USGS	1.8 – 2.8	0.15 – 0.6	8.0 – 16.0

The USGS and IRISDMC data have a discrepancy of 0.1 and 0.1-0.3 for standard deviation and 4 – 5 for a-value.

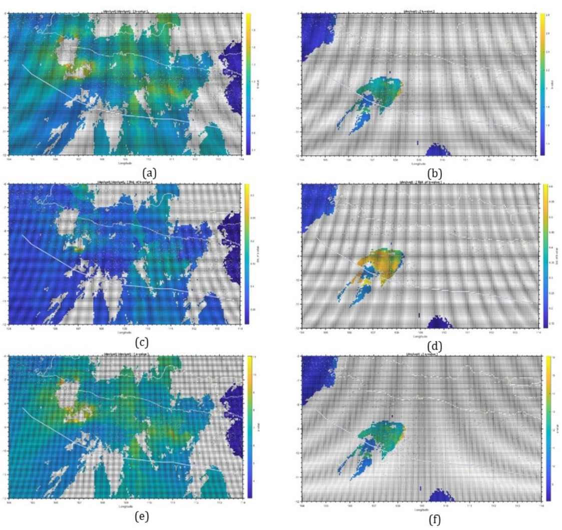


Fig. 9: Depiction of b-value, b-value standard deviation, and a-value for the IRISDMC (right) and USGS (left) data.

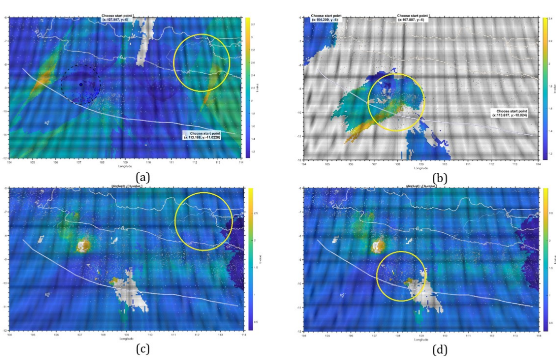


Fig. 10: Comparison of spatial b-values for different sample positions analysis for the USGS (top) and IRISDMC (down).

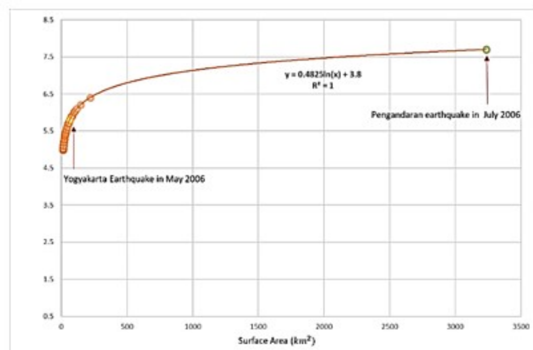
A spatial analysis was conducted to compare the compactness of earthquake events with b-value readings. This was done by calculating b-values for areas with less frequent seismicity (Figs. 10(a) and 10(c)) and comparing them with areas of higher seismicity (Figs. 10(b) and 10(d)).

The results show the following scale ranges:

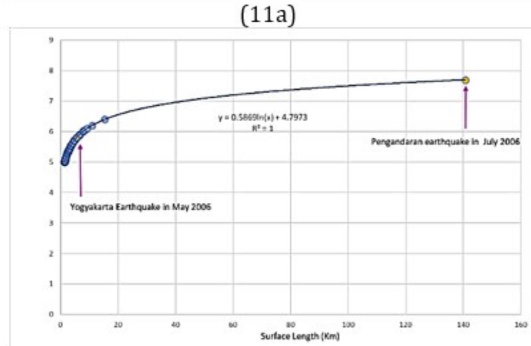
1. Figure 10(a) (IRISDMC data): a range of 1.2–3.9 (variation width of 2.7)
2. Figure 10(b) (USGS data): a range of 0.5–2.5 (variation width of 2.0)
3. Figure 10(c) (IRISDMC data): a range of 1.2–2.4 (variation width of 1.2)
4. Figure 10(d) (USGS data): a range of 0.5–2.5 (variation width of 2.0)

The IRISDMC data exhibit higher and more evenly distributed b-values, with a variation width of up to 2.7 in less active areas and 1.2 in more active areas. In comparison, the USGS data show a consistent variation width of 2.0 across both seismic regimes.

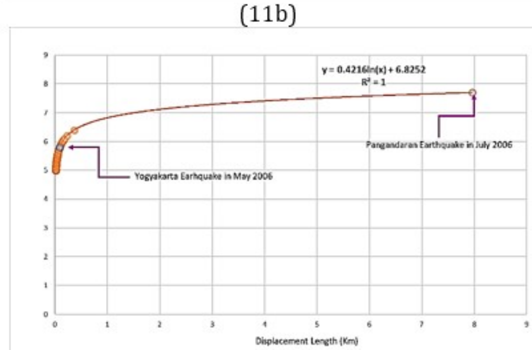
Deformation area estimates for the regions affected by the Pangandaran and Yogyakarta earthquakes were derived by filtering the 2006 seismic events for magnitudes of Mw ≥ 5. A total of 242 earthquakes from the IRISDMC catalog were used in the Wells and Coppersmith empirical equations (Table 3). The resulting deformation estimates for the affected areas are presented in Figures 11(a), 11(b), and 11(c).



(11a)



(11b)



(11c)

Fig. 11: Estimated damage due to the Yogyakarta and Pangandaran earthquakes of 2006 using the Wells and Coppersmith equation. (11(a)) Surface area estimation, (11(b)) Surface length estimation, (11(c)) Displacement length estimation.

Figure 9 shows that earthquakes of magnitude Mw ≥ 5 in 2006 conform to logarithmic relationships for area, length, and displacement. For the Pangandaran earthquake, the affected area follows the logarithmic equation y = 0.4825 ln(x) + 3.8, corresponding to an area of 3,235.94 km^2. The fault length follows y = 0.5869 ln(x) + 4.7973, resulting in a length of 140.60 km. The displacement is described by y = 0.4216 ln(x) + 6.8252, yielding a value of 7.96 m.

The analysis reveals that b-values from the USGS and IRISDMC catalogs exhibit similar trends, despite differing in their exact values. Testing indicates that interpretation based on spatial and temporal b-values from a single catalog may lead to ambiguity. Therefore, seismicity analysis for a region should incorporate data from multiple catalogs.

The seismicity analysis of Java for 2002–2010 could be enhanced by combining data from various catalogs to improve the robustness of mainshock identification. It is expected that integrating different catalogs will help determine optimal declustering parameters and Mc values that more accurately represent field conditions.

The analysis of the Pangandaran tsunami is based on two approaches from the research of Hebert et al. [13] and Priadi et al. [17]. Hebert et al. [13] used satellite imagery (SPOT 5 and Quickbird) and event records to model the tsunami source mechanism, proposing it was triggered by an earthquake followed by a landslide that generated destructive waves, particularly affecting Nusakambangan. However, this conclusion lacks support from bathymetric models of the research area, which would be necessary to confirm the potential for a marine landslide.

In contrast, Priadi et al. [17] used a Finite Fault Solution Model, indicating that the energy released by the tsunami was greater than that accounted for by the fault mechanism alone. Using the Community Model Interface for Tsunami (ComMIT), they determined parameters of strike 290°, dip 10°, and rake 102°, with a dominant slip direction to the north-northwest and a maximum slip of 1.7 m. The fault plane was estimated to be 280 km long and 102 km wide. This model, however, produced inundation and run-up estimates significantly smaller than field observations, suggesting possible fault plane segmentation. Incorporating fault type and area justifications could improve this model's efficacy.

Calculations using the Wells & Coppersmith method yielded a fault length different from that of Priadi et al. [17]. A comparison of these models and their estimated parameters is provided in Table 5.

Based on the three analyses of the tsunami source, it can be concluded that the Wells and Coppersmith approach effectively estimates the rupture area using statistical analysis of earthquake data. However, these results require support from additional methods. The ComMIT simulation, which estimates the deformation area using inundation and run-up data, produced different results but is limited by incomplete knowledge of the fault type and dimensions. Meanwhile, satellite image modeling suggests that the Pangandaran tsunami's energy resulted not only from fault displacement but also from a marine landslide.

Table 5: Pangandaran Tsunami Models using Wells & Coppersmith, Community Model Interface, and High-Resolution Satellite Imaginary & Numerical Modelling.

	Wells & Coppersmith	**Community Model Interface**	**Satellite Imaginary and Num Mod**
Rupture Area	3235.94 km	X	X
Surface Length	140.60 km	280 km	X
Surface Displacement	7.96 km	X	X
Width	X	102 km	X
Strike	X	290°	X
Dip	X	10°	X
Rake	X	102°	X
Max value slip pointing up	X	1.7 m	X
Run-up high observation in Permisan Prison Nusakambangan	X	X	5-20 m

It can be said that the type of fault for the Wells and Coppersmith method is strike-slip, based on the assumption that strike-slip fault often causes landslides [13, 18-23]. Such an assumption requires further support from other historical information. Nonetheless, this assumption is supported by results from Priadi et al., which show that the type of fault put into their modelling is strike-slip, instead of reverse fault.

4. Conclusion

This research concludes that the b-values and magnitude of completeness (Mc) derived from the USGS catalog are 1.38 ± 0.04 and 4.9, respectively, while those from the IRISDMC catalog are 0.99 ± 0.02 and 4.3. The IRISDMC catalog provides more diverse and evenly distributed seismicity data; however, for the source mechanism of the 2006 Pangandaran earthquake, the USGS catalog yielded a sharper b-value calculation. A key finding is that catalog incompleteness can lead to an overestimation of the b-value, particularly in spatial analysis. Furthermore, applying the Wells and Coppersmith equations to the 2006 events yielded logarithmic relationships from which the Pangandaran earthquake was estimated to have a rupture area of 3,235.94 km^2, a rupture length of 140.60 km, and a displacement of 7.96 m.

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References

[1] B. P. S., "Jumlah Penduduk Menurut Provinsi di Indonesia (Ribu Jiwa), 2024" Statistics Indonesia (BPS) of North Sulawesi Province, (2024).

[2] B. K. M. G., "Katalog Gempabumi Signifikan dan Merusak" Pusat Gempabumi dan Tsunami BMKG, (2018).

[3] B. Gutenberg and C. Richter, Seismicity of the Earth and Associated Phenomena 2, Princeton University Press, (1954).

[4] P. Nuannin, O. Kulhanek, and L. Persson, "Spatial and temporal b value anomalies preceding the devastating off coast of NW Sumatra Earthquake of December 26, 2004" Geophys. Res. Lett., 32(11), L11307, (2005).
[5] C. H. Scholz, "Earthquake and Friction Laws" Nature, 391(6662), 37–42, (1998).
[6] R. Lewerissa, R. Rumakey, Y. A. Syakur, and L. Lapono, "Completeness Magnitude (Mc) and b-value Characteristics as Important Parameters for Future Seismic Hazard Assessment in the West Papua Province Indonesia" Arab. J. Geosci., (2021).
[7] W. Marzocchi, I. Spassiani, A. Stallone, and M. Taroni, "How to be Fooled Searching for Significant Variations of the b-value" Geophys. J. Int., 220(3), 1845–1856, (2020).
[8] J. Bohme, "Estimation of Source Parameters by Maximum Likelihood and Non-linear Regression" in Proc. IEEE Int. Conf. Acoust. Speech Signal Process. (ICASSP), (1984).
[9] S. Roy and A. Ram, "A Correlation Integral Approach to the Study of 26 January 2001 Bhuj Earthquake, Gujarat, India" J. Geodyn., 41(5), 385–399, (2006).
[10] T. C. Hanks and H. Kanamori, "A Moment Magnitude Scale" J. Geophys. Res., 84(B5), 2348–2350, (1979).
[11] E. M. Scordilis, "Empirical Global Relations Converting Ms and Mb to Moment Magnitude" J. Seismol., 10(2), 225–236, (2006).
[12] D. L. Wells and K. J. Coppersmith, "New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement" Bull. Seismol. Soc. Am., 84(4), 974–1002, (1994).
[13] H. Hebert, P. E. Burg, R. Binet, F. Lavigne, S. Allgeyer, and F. Schindele, "The 2006 July 17 Java (Indonesia) Tsunami from Satellite Imagery and Numerical Modeling: A Single or Complex Source" Geophys. J. Int., 191(3), 1255–1271, (2012).
[14] C. Reyes and S. Wiemer, "ZMAP7, A Refreshed Software Package to Analyze Seismicity" (2009).
[15] A. L. Ramadhani, "Seismicity in Java, Indonesia: Spatial & Temporal Study using Fractal Dimension b-Value" Master Thesis, Gadjah Mada University and University of Twente, (2012).
[16] U. R. Vetter, J. P. Ake, and R. C. Laforge, "Seismic Hazard Evaluation for Dams in Northern Colorado, U.S.A." Nat. Hazards, 14(3), 227–240, (1996).
[17] R. Priadi, D. Yunus, B. Y. Andrianto, and R. Margiono, "Analysis of Tsunami Inundation due in Pangandaran Tsunami Earthquake in South Java Area Based on Finite Faults Solutions Model" J. Penelit. Fis. Apl., 10(2), 114–124, (2020).
[18] M. Carvajal, C. Araya-Cornejo, I. Sepúlveda, D. Melnick, and J. S. Haase, "Nearly instantaneous tsunamis following the Mw 7.5 2018 Palu earthquake" Geophys. Res. Lett., 46(10), 5117–5126, (2019).
[19] A. Muhari, F. Imamura, T. Arikawa, A. R. Hakim, and B. Afriyanto, "Solving the puzzle of the September 2018 Palu, Indonesia, tsunami mystery: Clues from the tsunami waveform and the initial field survey data" J. Disaster Res., 13(sc20181108), (2018).
[20] Y. Altınok, S. Tinti, B. Alpar, A. Armigliato, V. Yalciner, and F. Ergin, "The Tsunami of August 17, 1999 in Izmit Bay, Turkey" Nat. Hazards, 24(2), 133–146, (2001).
[21] A. C. Yalciner, Y. Altınok, C. E. Synolakis, D. Borrero, H. K. C. Kanoğlu, B. Alpar, U. Kuran, A. Tüfekçi, S. Ersoy, E. N. Tüzecan, G. Güler, G. Özyurt, and J. Bardet, "Tsunami Waves in Izmit Bay" Earthq. Spectra, 16(s1), 55–62, (2000).
[22] C. E. Synolakis, J. C. Borrero, H. L. Davies, E. A. Okal, G. J. F. Silver, and D. Tappin, "The slump origin of the 1998 Papua New Guinea Tsunami" Proc. R. Soc. A, 458(2020), 763–789, (2002).
[23] A. Elbanna, M. Abdelmequid, X. Ma, F. Amlani, H. S. Bhat, C. Synolakis, and A. J. Rosakis, "Anatomy of strike-slip fault tsunami genesis" Proc. Natl. Acad. Sci. U.S.A., 118(19), (2021).