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Integrating new GMPE and Seismic b-value for comprehensive hazard analysis in Central, West, and South Sulawesi, Indonesia

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सार– भूकंपीय खतरे का विस्तृत विश्लेषण उन क्षेत्रों की पहचान करने का एक महत्वपूर्ण घटक है जहां भूकंप का खतरा अधिक है। परिणामस्वरूप, भूकंपीय-विवर्तनिक मापदंडों (बी-मान) का अनुमान लगाना और किसी क्षेत्र की स्थानीय विशेषताओं को दर्शाने वाले भू-गति पूर्वानुमान समीकरणों (जीएमपीई) का विकास भूकंपीय खतरे के विश्लेषण में चरम भू-त्वरण (पीजीए) का आकलन करने के लिए आवश्यक है। जीएमपीई मॉडल आमतौर पर न्यूनतम वर्ग व्युत्क्रम रैखिक समाश्रयण दृष्टिकोण का उपयोग करके बनाया जाता है, जबकि बी-मान का अनुमान अधिकतम संभावना विधि के माध्यम से लगाया जाता है। इस अध्ययन के निष्कर्ष बताते हैं कि शोध क्षेत्र में पीजीए मान 0.77 से 8.36 गैल के बीच हैं, और बी-मान 0.11 से 1.86 के अंतराल में आते हैं। उच्च पीजीए मान वाले क्षेत्र सक्रिय फॉल्ट के आसपास पाए जाते हैं, जो बड़े भूकंपों की घटना को सुगम बना सकते हैं, साथ ही कमजोर भूवैज्ञानिक स्थितियों वाले क्षेत्रों में भी पाए जाते हैं। इसके अलावा, कम बी-मान के परिणाम कुछ क्षेत्रों में तनाव संचय की संभावना का संकेत देते हैं, जिससे मध्यम से बड़े परिमाण के भूकंप आ सकते हैं।

ABSTRACT. Detailed seismic hazard analysis is a critical component in identifying regions with elevated earthquake risk. Consequently, the estimation of seismotectonic parameters (b-value) and the development of ground motion prediction equations (GMPEs) that capture the local characteristics of an area are essential for assessing peak ground acceleration (PGA) in earthquake hazard analysis. The GMPE model is typically constructed using a least squares inversion linear regression approach, while the b-value is estimated through the maximum likelihood method. The findings of this study indicate that the PGA values in the research area range from 0.77 to 8.36 gal, and the b-values fall within the interval of 0.11 to 1.86. The areas with high PGA values are observed in the vicinity of active faults, which can facilitate the occurrence of large earthquakes, as well as regions with weaker geological conditions. Furthermore, the low b-value results suggest the potential for stress accumulation in certain areas, which may lead to the occurrence of moderate to large magnitude earthquakes.

Key words– Seismic Hazard; Seismotectonic; Ground motion prediction equations; Peak ground acceleration.

1. Introduction

The tectonic configuration of Sulawesi Island is characterized by a complex geological setting, particularly in the Central, West, and South Sulawesi regions. This complexity is attributed to the island's location between three major tectonic plates: the Pacific Plate, the Indo-Australian Plate, and the Eurasian Plate. The dynamic interactions and movements of these flanking plates have significantly influenced the tectonic evolution of Sulawesi Island (Socquet *et al.*, 2006; Patria & Putra , 2020). The convergence of these three plates has resulted in the formation of microblocks within the island's geological structure (see Fig. 1) (Hinschberger *et al.*, 2000; Bellier *et al.*, 2006; Socquet *et al.*, 2006). Consequently, the intricate geology, structural features, and tectonic processes have contributed to a high level of seismicity (earthquake occurrence) in the three regions of Sulawesi Island.

Earthquakes are natural phenomena that cannot be entirely prevented, yet proactive measures can be implemented to mitigate the potential impact of future occurrences (Astuti *et al.*, 2021). Earthquake disasters are intrinsically linked to ground movement, which can be quantified through the parameter of PGA (Tao *et al.*, 2020). PGA represents the maximum ground accelerationexperienced at a specific location during a seismicevent,

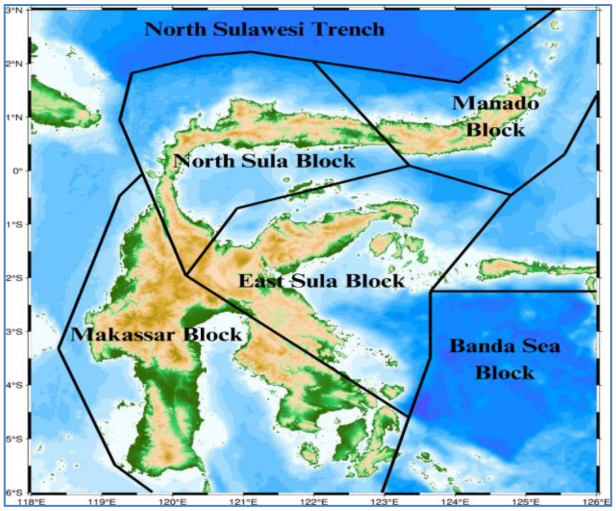

Fig. 1. Microblocks found in Sulawesi which are the result of the manifestation of the collision of the Eurasian, Indo-Australian and Pacific plates (modified from Socquet et al, 2006).

occurring within a defined time frame (Razin *et al*., 2021; Wajedy *et al*., 2024). The higher the PGA value, the more severe the potential consequences of the earthquake (Anugrayanti *et al*., 2021; Wajedy *et al*., 2024).

Comprehensive studies to assess earthquake risk through PGA value calculations have been extensively conducted, particularly in disaster-prone regions. However, the derivation of the PGA equation is predominantly based on data from outside Indonesia, as there is no specific PGA equation developed within the Indonesian context. Consequently, studies on earthquake risk levels in Indonesia often rely on equations obtained from other regions, assuming geological and tectonic similarities between the areas (Lestari *et al*., 2021). Ground motion prediction equations serve as crucial tools for understanding and forecasting the ground motion characteristics of earthquakes, providing essential inputs for earthquake risk assessment (Gogoi *et al*., 2023).

Several regional seismic hazard assessments have been carried out across Indonesia to characterize local ground motion behavior and tectonic influence. For example, Wajedy *et al*. (2024) analyzed low-risk seismic zones in North Maluku using locally calibrated GMPEs; Lestari *et al*. (2021) mapped PGA distribution in the Banten region of western Java; Razin *et al*. (2021) evaluated PGA–PGV relationships in West Nusa Tenggara for microzonation purposes; and Zera *et al*. (2021) estimated ground motion parameters in Sumatra using the Donovan model. These studies collectively highlight the importance of developing region-specific GMPEs and seismotectonic models to improve the accuracy of hazard predictions across Indonesia.

To assess the potential hazard of earthquake disasters in a specific region, it is necessary to measure the PGA and seismotectonic parameters. Seismotectonic parameters are numerical values that can be used as a measure of the level of seismicity in an area (Gui *et al*., 2019; Nanjo & Yoshida, 2021). One such parameter is the b-value, which represents the level of rock fragility, and can be obtained from statistical data on tectonic earthquakes that occurred in the study area over a specific time period (Nanjo & Yoshida, 2018). Based on this, an empirical approach should be conducted to derive the landslide prediction equation, as well as to map the distribution of PGA and b-value, which are crucial for analyzing earthquake hazards in the future. This study focuses on the Sulawesi region, particularly Central Sulawesi, West Sulawesi, and South Sulawesi.

2. Data and methodology

The present study was conducted in three provinces of Sulawesi, namely South Sulawesi, West Sulawesi, and Central Sulawesi, as depicted in Fig. 2. Two types of data were utilized in this research: PGA data recorded by the BMKG (Meteorology, Climatology, and Geophysics Agency) accelerograph network during the 2017-2021 period, with magnitudes ranging from 2.9 to 7.5; and geological data obtained from an ESDM (Ministry of Energy and Mineral Resources) map, accessible through the Kegeologian website (esdm.go.id), which was employed in determining the GMPE equation. Additionally, earthquake catalog data from the USGS (United States Geological Survey) and the ISC-GEM (International Seismological Center - Global Instrumental Earthquake) for the 1990-2020 period, with magnitudes ranging from 3.2 to 7.9, were utilized for mapping the distribution of PGA and b-value in the South Sulawesi, West Sulawesi, and Central Sulawesi regions.

2.1. *GMPE determination*

The characteristics of ground motion induced by seismic events can be quantitatively represented by a multitude of parameters that encapsulate the inherent complexity of ground motion. Through the utilization of empirical relationships,stronggroundmotionrecordsfrom earthquakes are processed to determine various ground motion parameters for a specific location in GMPE investigations. It is widely accepted that factors such as location, distance, and earthquake magnitude significantly influence the amplitude of ground motion parameters (*e.g*., PGA). Furthermore, the assessment of ground motion parameters enhances the characterization of ground motion, encompassing seismic hazard evaluation and the development of ground motion design standards (Gogoi *et al*., 2023).

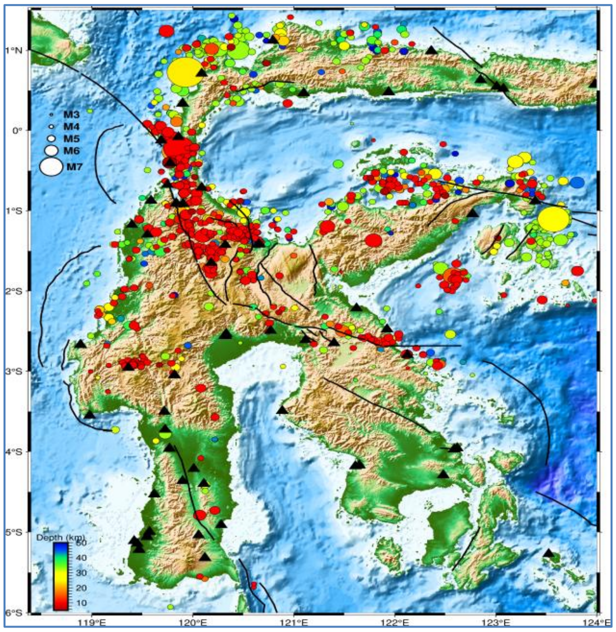

Fig. 2. Research location and earthquake events for the period 1990–2020. The color scale represents the focal depth of each earthquake, with circular markers indicating earthquake events. Triangular symbols denote BMKG seismic stations located across Sulawesi

The existing literature on GMPEs has been extensively explored. Douglas (2021) compiled a comprehensive dataset of spectral coordinates of elastic responses published between 1964 and 2021, as well as the empirical GMPEs used to determine maximum ground acceleration (PGA) during earthquakes, such as those developed by Donovan (1973), Fukushima and Tanaka (1990), and Esteva (1974). The majority of empirical damping relationships for ground motion are obtained through numerical analysis. GMPEs are typically expressed as a function of earthquake distance and magnitude, utilizing predicted linear relationships. The number of parameters employed in these models depends on the completeness of the data used to generate the GMPE. In some cases, additional factors, such as local site conditions, focal mechanism, and fault style, are incorporated into the models (Gogoi *et al*., 2023). As noted by Kramer (1996), predictive linear relationships often describe GMPs as a function of magnitude, distance, and occasionally additional factors:

$$Y = (M, R, Pi) \qquad (1)$$

The ground motion parameter of interest, denoted as Y, can be estimated using a generalized equation derived from Equation (1), as outlined by Gogoi *et al*. (2023). This equation incorporates the earthquake's magnitude (M), the distance measured from the source to the location (R), and additional variables (Pi).

$$Log\ (Y) = f_1 M + f_2(r) + f_3 E + f_4 F \pm \varepsilon \qquad (2)$$

In this context, log (Y) represents the amplitude of ground motion parameters (GMP), while $f_1(M)$ denotes the function of magnitude, $f_2(r)$ represents the function of distance, $f_3(E)$ corresponds to the tectonic environment, and $f_4(F)$ accounts for the fault type. The term Ɛ represents the uncertainty associated with Log(Y).The equation presented above represents a general form that has been utilized in several previous studies, including those conducted by Campbell (1981), Joyner & Boore (1988), Abrahamson & Litehiser (1989), Fukushima *et al*. (1990), Sharma (1998), Baruah *et al*. (2009), Anbazhagan *et al*. (2013), Ramkrishnan *et al*. (2020) & Gogoi *et al*. (2023). In this equation, the variable represents the GMP amplitude, is the magnitude function, is the distance function, is the tectonic environment function, is the fault type function& is a variable that accounts for any uncertainties. Initially, the investigation established a relationship between the GMP amplitude & the epicentral distance& subsequently, the relationship between GMP&magnitude was explored, in line with the findings of previous studies such as Sharma (1998), Anbazhagan *et al*. (2013), Ramkrishnan *et al*. (2020), and Gogoi *et al*. (2023).

$$Log\ (Y) = b_0 + b_1 \log(X) + b_2 M + b_3 E \pm \varepsilon \qquad (3)$$

With the PGA value represented as Y, the magnitude as M, the geological environment as E, the regression coefficients as b, the distance function as X, and the variable representing any uncertainty or RMSE (root mean square error) as ε, the predicted PGA values were calculated using equation (2) based on Gogoi *et al*. (2023) after obtaining the constant values and regression coefficients.

2.2. *b-value Calculation*

The determination of the b-value can be achieved through two primary methods: the maximum likelihood technique and the least squares approach. However, the least squares method assumes that all data points hold equal weight and exhibit Gaussian-distributed residuals, which can introduce bias in the results, particularly at greater magnitudes (Letamo *et al*., 2023). To mitigate these skewed outcomes, the equation proposed by Aki (1965) can be employed in conjunction with the recommendeThe greatest likelihood technique and the least squares method are two approaches employed to determine the b-value (Letamo *et al*., 2023). However, the least squares technique assumes that all data points have equal weight and exhibit Gaussian-distributed residuals, which can introduce bias in the results, particularly at greater magnitudes (Letamo *et al*., 2023). To mitigate these skewed outcomes, the suggested maximum likelihood method (Aki, 1965) can be utilized in conjunction with the following equation (Gui *et al*., 2019):

$$b = \frac{Log\ e}{\left[\bar{M} - (M_C - \frac{\Delta M}{2})\right]} \tag{4}$$

In this case, e = 0.434, ΔM = 0.1, b is the b-value, $\bar{M}$ the average magnitude, and Mc the completeness magnitude which is calculated using the Zmap application (Wiemer & Zuniga, 1994). A region's B-value represents its tectonic constant. Low-magnitude earthquakes may occur in regions with a high b-value because these areas have a high degree of rock fragility. Significant earthquakes may occur in areas with low b-values, however (Gadkari and Mukherjee 2023).

3. Results and Discussion

3.1. *Ground motion prediction equation (GMPE)*

The regression analysis conducted on the empirical GMPE formula (3) yielded the corresponding regression coefficients (Table 1). The values representing each coefficient were subsequently derived.

TABLE 1

Constants and regression coefficients for GMPE

Site effect	b_0	b_1	b_2	b_3
Alluvial	-0.1144653	1.01442472	0.35349527	0.04426099
Rock	0.044632	0.356263	0.01935	-0.01098

Therefore, the empirical GMPE formula can be written as:

(i) For alluvial soil sites
$\log(Y) = -0.1144653 - 1.01442472 \log(X) + 0.35349527M + 0.04426099E + \varepsilon$

(ii) For rocky soil sites
$\log(Y) = 0.044632 - 0.356263 \log(X) + 0.01935M - 0.01098E + \varepsilon$

where Y is the maximum acceleration value in gal, M magnitude, X the epicenter distance dan E is the soil site (with alluvial and rock values of 2.91 and 0.34, respectively).

The validation of PGA results was conducted through the utilization of the root mean square error (RMSE) metric, which was employed to assess the discrepancy between a newly developed empirical GMPE and an existing PGA formula. The analysis was based on a dataset comprising 1.425 PGA accelerograph recordings, which were obtained from earthquake events occurring within the research area encompassing South Sulawesi, West Sulawesi, and Central Sulawesi. The performance of the new GMPE was then benchmarked against several well-established models, including those developed by Donovan (1973), Fukushima and Tanaka (1990), and Esteva (1974).

TABLE 2

RMSE of PGA values Empirical formula against observed PGA values

Empirical formula	Donovan	Fukushima&Tanaka	Esteva	New GMPE
RMSE	12.5559	5.55219	11.2652	1.2255

The New Ground Motion Prediction Equation (NGMPE) demonstrates the lowest root-mean-square (RMS) error among the three other ground motion prediction equations (GMPEs) examined in Table 2. This finding suggests that the NGMPE may be a suitable choice for estimating PGA in additional regions. The present study developed an empirical formula for PGA ground motion prediction equation based on the empirical formula reported in a previous investigation (Gogoi *et al*., 2023). The inclusion of the soil site factor is a crucial aspect, as the damage induced by an earthquake in a region is contingent not only on the distance from the epicenter and the earthquake magnitude but also on the surface geological conditions (surface sediment layers) of the area.

The soil site coefficient for alluvial deposits, which is 0.04426099, is significantly higher compared to the value of -0.01098 for rock. This disparity indicates the amplification and attenuation effects on the soil during an earthquake. The condition of the soft surface sediment layer (alluvial) can lead to greater damage effects in the area compared to hard rock conditions. The soft surface layer can increase the amplification effect, which manifests as a magnification of earthquake shaking when the waves travel from the bedrock (the layer below the surface sediment layer) to the surface sediment layer.

The passage of seismic wave energy through a medium results in the conversion of a portion of this energy into heat, generated by the friction between the moving medium particles and the propagating seismic waves. This energy absorption process is known as wave attenuation, which leads to a decrease in wave amplitude. The degree of attenuation is dependent on the characteristics of the medium, as expressed through the attenuation constant. In a soft medium, the attenuation constant exhibits a higher value, leading to a more pronounced weakening of the wave amplitude. This effect is in contrast to the amplification of waves that can occur in the surface layer during an earthquake. The analysis of the USGS and ISC-GEM earthquake catalog data for the 1990-2020 period reveals the following findings regarding

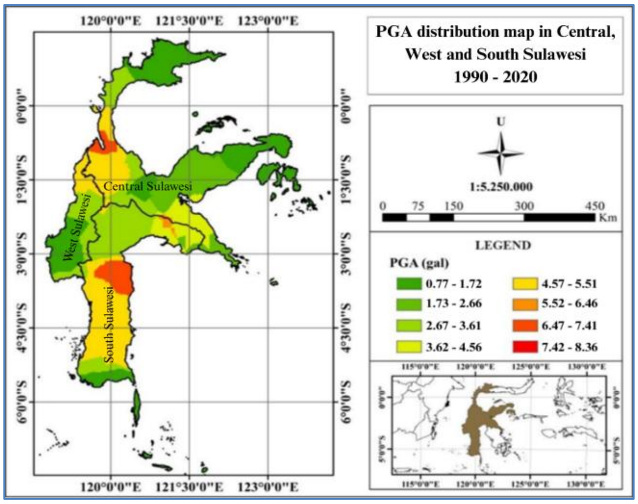

Fig. 3. PGA distribution map using the new GMPE formula. The color scale represents the spatial variation of Peak Ground Acceleration (PGA), where higher intensity areas are shown in red and lower intensity areas in green

the PGA distribution map of the research area, as determined using the New Ground Motion Prediction Equation. The PGA distribution exhibits a spatial variation within the study region, reflecting the complex tectonic and geological characteristics of the area.

The study area exhibits a range of predicted PGA values from 0.77 to 8.36, as depicted in Fig. 3, utilizing the GMPE empirical formula. These PGA predictions are relatively low compared to the values obtained from other empirical formulas. The highest PGA values, ranging from 7.42 to 8.36, are concentrated in specific locations, including the Central Sulawesi region, particularly in Palu City, and the South Sulawesi region, specifically in Luwu Regency, parts of Enrekang Regency, and Tana Toraja. Conversely, the lowest PGA values, ranging from 0.77 to 1.72, are observed in the southern parts of South Sulawesi and West Sulawesi, as well as the northern region of Central Sulawesi.

3.1.1. *South sulawesi*

The South Sulawesi region in Indonesia is characterized by active faults and has experienced numerous seismic events. Based on the results of the new GMPE analysis (Fig. 3), the region can be divided into five distinct classes of PGA values. The area with the highest PGA, ranging from 6.47 to 7.41, is located in Luwu Regency, parts of Enrekang, Sidrap, and the northern region of Wajo Regency. This elevated PGA value is attributed to the dense occurrence of earthquakes in this particular area. The second class, with PGA values between 5.52 and 6.46, is situated in the northern part of East Luwu Regency. The third class, with PGA values ranging from 4.57 to 5.51, covers the largest geographical area, extending from Tana Toraja to the southern parts of Maros and Sinjai districts. The fourth class, with PGA values ranging from 3.62 to 4.56, is located in North Luwu and North Toraja districts. The final PGA class, which includes the lowest values ranging from 0.77 to 1.72, is found in the Selayar Islands region.The diverse PGA values observed in the South Sulawesi region are influenced not only by the local fault activity but also by the distribution and magnitude of earthquake events. Additionally, the predominance of rock formations in the region contributes to the dampening of earthquake waves as they reach the surface.

3.1.2. *West Sulawesi*

Predicted PGA values obtained from GMPE reveals a distinct spatial distribution in the West Sulawesi region. The area can be divided into three distinct classes based on the PGA values. The northern part of Mamuju Regency exhibits high PGA values, ranging from 4.57 to 5.51. This elevated PGA is attributed to the combined influence of the active Palu Koro Fault and the Makassar Strait Fault, which contribute to the high seismic activity in the region. Additionally, the predominant soil type in this area, characterized by alluvium deposits, further amplifies the ground motion during seismic events. In contrast, the central Mamuju region displays relatively low PGA values, ranging from 1.73 to 2.66. Similarly, the districts of Mamuju, Mamasa, and Majene exhibit very low PGA values, ranging from 0.77 to 1.72. These lower PGA values are influenced by the relatively moderate intensity of earthquake events in these areas, as well as the prevalence of rock-based soil sites. The rock formations in these regions tend to dampen the earthquake waves, resulting in a less pronounced impact on the surface.

3.1.3. *Central Sulawesi*

The Central Sulawesi region as a whole can be identified as the area with the highest predicted PGA values compared to the other three research areas. The results of the PGA prediction analysis using a new GMPE indicate that the Central Sulawesi region is divided into six classes. The areas with the highest predicted PGA values, ranging from 7.42 to 8.36, are located in Palu City. Moderate PGA values, ranging from 4.57 to 5.51, are found in the Sigi and Donggala districts. The high PGA results are attributed to the influence of the large earthquake that occurred in Palu City in 2018, which was followed by a series of aftershocks with relatively high magnitudes, activating other faults in the vicinity. The remaining areas are categorized as having low to very low PGA, with values ranging from 0.77 to 4.56. These low PGA values are due to the relatively sparse distribution of earthquake sites and the rocky soil in the area, which dampens the waves caused by the earthquakes.

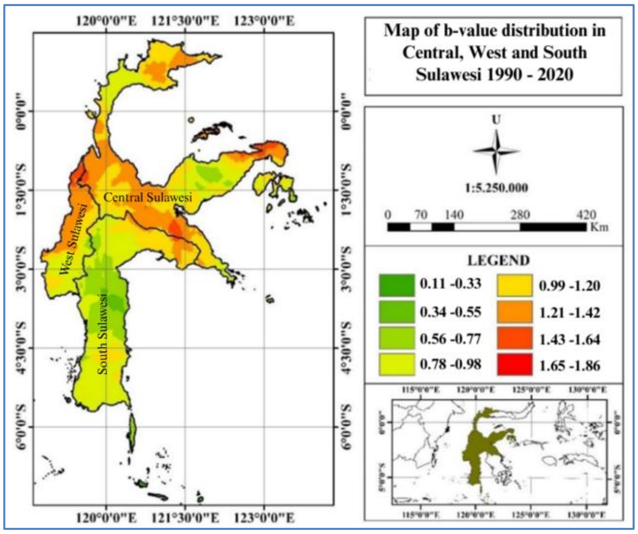

Fig. 4. Map of b-value distribution in Central Sulawesi, West Sulawesi, and South Sulawesi. The color scale represents the variation in b-value, where green indicates lower b-values and red indicates higher b-values.

Based on several studies, such as Wajedy *et al*. (2024), Razin *et al*. (2021), and Zera *et al*. (2021), PGA is influenced by several key factors, including earthquake magnitude, distance from the earthquake source, and local geological conditions. Areas with high PGA values are typically located near active fault zones, where seismic activity is more intense. The PGA value increases with greater earthquake magnitudes, as more seismic energy is released, and decreases with increasing distance from the epicenter due to the attenuation of seismic waves as they propagate through the Earth's crust.

Additionally, local geological conditions play a critical role in determining PGA. In areas with denser rock formations, seismic waves are generally dampened, resulting in lower PGA values. Conversely, in regions with softer rocks or unconsolidated soils, seismic waves tend to amplify, leading to higher PGA values. The interplay of these factors magnitude, epicentral distance, and geological conditions makes PGA a crucial parameter for assessing seismic hazard in a given region.

The results of this study show that ground motion characteristics differ distinctly between rock and soil sites, consistent with findings from previous regional studies in Indonesia. Ground motion on rock sites tends to propagate more rapidly with lower amplification, reflecting the rigidity and compactness of the underlying lithology. In contrast, soil sites particularly those underlain by young alluvial or weathered deposits exhibit slower wave propagation and higher amplification due to the presence of unconsolidated materials. These observations are in good agreement with the results of Lestari *et al*. (2021) in western Java, Razin *et al*. (2021) in West Nusa Tenggara, and Wajedy *et al*. (2024) in North Maluku, which similarly reported the strong influence of local geological conditions on seismic ground motion. This consistency supports the reliability of the developed GMPE in capturing site-dependent variations across Sulawesi.

3.2. *b-value analysis*

The seismotectonic b-value has been widely utilized in numerous studies to provide valuable insights into various aspects of Earth's crustal and tectonic dynamics. For instance, it has been used to investigate the heterogeneity of the crustal structure, offering a window into the compositional and mechanical variability within the Earth's crust (Schorlemmer *et al*., 2003; Bora *et al*., 2018; Gui *et al*., 2019). This parameter also plays a crucial role in understanding stress distribution, serving as a proxy to map variations in tectonic stress regimes across different regions (Mousavi, 2016; Nanjo & Yoshida, 2021).

Moreover, the b-value has been instrumental in examining asperity zones regions on faults that are locked and store elastic strain energy, potentially leading to significant earthquakes when released. Studies have leveraged the b-value to delineate these zones and evaluate their seismic potential (Hirose *et al*., 2002; Tormann *et al*., 2015; Nanjo & Yoshida, 2018). Additionally, the b-value has been applied to estimate frictional properties along subduction zones, shedding light on the mechanical behavior and coupling between tectonic plates in these regions (Yabe, 2003; Sobiesiak *et al*., 2007; Gosh *et al*., 2008).

Through these applications, the b-value has proven to be a versatile and powerful tool for advancing our understanding of seismic hazards and the underlying processes governing earthquake mechanics and tectonic interactions.

The data processing results, as illustrated in Fig. 4, demonstrate a relatively high b-value in the Central Sulawesi area, which is in the vicinity of the 7.5 magnitude earthquake that occurred in 2018 (Socquet *et al*., 2019). The increase in b-value at this location is attributed to the release of locked energy in the form of earthquakes after the high-magnitude event in 2018, with 637 aftershocks recorded over 60 days (Huda *et al*., 2023). Several areas with high b-values at the research site suggest a lack of significant stress accumulation. In contrast, the southern part of West Sulawesi, which experienced a 6.0 magnitude earthquake in 2018, exhibits a low b-value, indicating that the stress accumulated in the area has not been fully released. Areas with low b-values are typically associated with the potential for larger magnitude earthquakes, as the magnitude scale is influenced by the fault slip rate and the duration of energy accumulation (Huda *et al*., 2023; Li *et al*., 2021; Peng *et al*., 2021). Therefore, it is crucial to monitor regions with low b-values to mitigate the potential impact of future seismic events.

4. Conclusion

The ground motion prediction equation (GMPE) developed in this study provides a simple yet robust framework that effectively incorporates local site effects as a primary factor influencing ground motion response during earthquakes. Despite its simplicity, the proposed GMPE exhibits higher accuracy compared to several previously published models, underscoring its potential as a reliable tool for regional seismic hazard assessment. The spatial distribution of Peak Ground Acceleration (PGA) delineates critical seismic zones, particularly in Central Sulawesi, where elevated PGA values are concentrated near the epicenter of the 2018 Mw 7.5 earthquake. In South Sulawesi, high PGA values correspond to the Walanae Fault zone and areas underlain by alluvial deposits, highlighting the significance of local geological conditions in amplifying ground motion.

The b-value analysis further complements the GMPE results by elucidating spatial stress accumulation patterns. Low b-values observed in parts of South Sulawesi indicate substantial stress buildup and a heightened probability of future seismic activity, warranting prioritized monitoring and mitigation efforts. Similarly, portions of West Sulawesi, particularly near the 2018 Mw 6.0 earthquake zone, exhibit low b-values that may signal potential seismic reactivation. Conversely, regions such as Palu, Donggala, and Parigi, which experienced major stress release during the 2018 Mw 7.5 event, display relatively higher b-values, implying a current state of stress relaxation.

Overall, the integrated interpretation of GMPE and b-value analyses provides a comprehensive understanding of both ground motion characteristics and stress field variations across Sulawesi. This combined approach enhances the identification of high-risk seismic zones and offers valuable insights for disaster preparedness, land-use planning, and seismic risk mitigation in Sulawesi and other tectonically active regions of Indonesia.

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

Authors' Contributions

Muhammad Altin Massinai conceptualized the study, supervised the research, and contributed to the interpretation of results.(*email-altin@science.unhas.ac.id*)
Muh. Farid Wajedy conducted the GMPE analysis, data processing, and visualization.
Nurul Maulidah performed the b-value analysis and contributed to seismic data interpretation.(*email-nrlmaulidahh@gmail.com*).
RisdaAldia Ruslan assisted with data compilation, mapping, and figure preparation. (*email-risdaaldiaruslan@gmail.com*).
Muhammad FawzyIsmullahMassinai contributed to methodology development, result interpretation, and manuscript revision. (*email-fawzy@sci.unhas.ac.id*)
All authors reviewed and approved the final manuscript.

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