Indonesian Physical Review
Volume 07 Issue 03, September 2024
P-ISSN: 2615-1278, E-ISSN: 2614-7904

Spatial Study of Seismic Hazard Using Classical Probabilistic Seismic Hazard Analysis (PSHA) Method in the Kendari City Area

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Article Info

Article info:
Received: 11-03-2024
Revised: 04-06-2024
Accepted: 06-06-2024

Keywords:
Classical Probabilistic Seismic Hazard Analysis (PSHA), Peak Ground Acceleration (PGA), Spectral Acceleration (SA)

How To Cite:
J. Purba, L. O. Restele, L. O. Hadini, I. Usman, Hasria, and Harisma, "Spatial Study of Seismic Hazard Using Classical Probabilistic Seismic Hazard Analysis (PSHA) Method in the Kendari City Area", Indonesian Physical Review, vol. 7, no. 3, p 300-318, 2024.

DOI:
https://doi.org/10.29303/ipr.v7i3.325.

Abstract

Kendari City is an area prone to earthquakes because it is in a seismic zone dominated by local faults such as the Lawanopo Fault, Kendari Fault, Buton Fault, Tolo Thrust and Matano Fault, as evidenced by significant seismic events like those in 2011 and 2022. The earthquake in 2011, with a magnitude of 6.0, struck Kolono District, South Konawe Regency, while the 2022 earthquake, registering a magnitude of 5.2, occurred in the sea approximately 5 km north of Soropia, Konawe Regency. With seismic activity such as the 2011 and 2022 earthquakes causing significant damage, understanding seismic hazards is critical. The research stage starts from Hazard Analysis using the Classical Probabilistic Seismic Hazard Analysis (PSHA) method to produce a hazard map that presents the distribution of peak ground acceleration on the surface, at periods 0 seconds (PGA), SA (T= 0.2 seconds) and SA (T= 1.0 seconds) for probabilities of exceedance 10% and 2% in 50 years, respectively. Classical Probabilistic Seismic Hazard Analysis (PSHA) processing uses OpenQuake Engine software. The analysis results show that the PGA value in Kendari City on the surface ranged from (0.49 - 0.68 g and 0.79 - 1.17 g), SA at T= 0.2 seconds (1.10 - 1.53 g and 1.74 - 2.09 g), and SA at T= 1 second (0.64 - 0.93 g and 1.35 - 1.91 g). This result indicates the potential for significant damage and shocks.

Introduction

Indonesia is a region with a very complex tectonic setting, as it is traversed by several tectonic plates. This makes Indonesia a region prone to earthquakes [1]. According to the United Nations Office for Disaster Risk Reduction (UNDRR), Indonesia has experienced the third greatest loss of any country in terms of earthquakes, following only Japan and the U.S. [2], especially for the Sulawesi region. Sulawesi Island is located at the meeting zone of three major plates, namely the Indo-Australian plate, Eurasian plate, and Pacific plate. These plates have different directions of motion, namely the Eurasian plate which moves relatively to the southeast, the Indo-Australian plate which moves relatively to the north, and the Pacific plate which moves relatively to the west [3]. The movement of these plates causes faults to appear on the island of Sulawesi.

The Southeast Sulawesi region is an active seismic zone [4]. According to the National Earthquake Study Center [1], active fault areas in Southeast Sulawesi are dominated by local faults such as the Lawanopo Fault, Kendari Fault, Buton Fault, Tolo Fault (Tolo Thrust) and faults in Central Sulawesi, namely the Matano Fault, the impact of whose activity is often felt until Northern Southeast Sulawesi region. Earthquakes are considered one of the most destructive events in nature. This causes vibrations, or fluctuations, in the Earth's surface, caused by a sudden release of energy beneath the Earth's surface. This release of energy often occurs along active faults. Earthquakes often cause changes in the structure or position of the Earth's surface, called deformation. Deformation can be divided into three types based on when it occurs: postseismic (after an earthquake), coseismic (during an earthquake), and interseismic (before an earthquake) [5]. The destructive earthquake that occurred in Southeast Sulawesi was recorded on April 25 2011. The epicenter of the earthquake was 55 km southeast of Kendari, precisely in Kolono District, South Konawe Regency with a magnitude of 6.0. Based on information from the National Disaster Management Agency. [6], it is known that as a result of the earthquake, 4,000 people were displaced, 19 victims were slightly injured, 270 houses were heavily damaged, 119 houses were moderately damaged, and 344 houses were slightly damaged. The last other damaging earthquake occurred on March 26 2022 at 21:16:40 WITA located in the sea at a distance of 5 km north of Soropia, Konawe Regency, Southeast Sulawesi with a strength of M 5.2 at a depth of 10 km. The earthquake experienced 71 aftershocks. Based on macroseismic observations, there was moderate damage to the agricultural lab building at Halu Oleo University Figure 1. Distribution of earthquake epicenters can be seen in Figure 2 [7].

Figure 1. Moderate damage to the agricultural lab building at Halu Oleo University

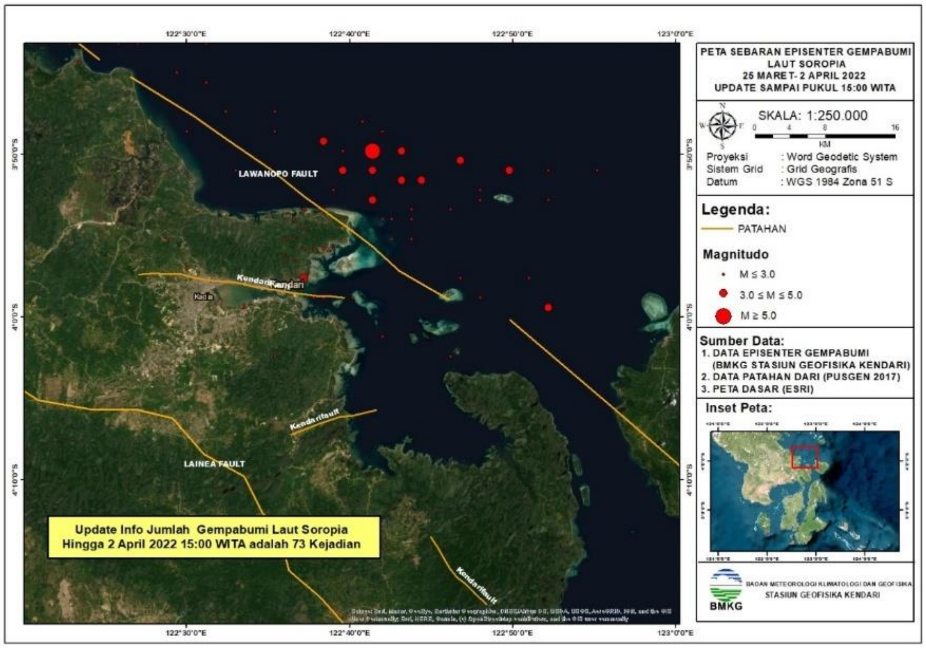

Figure 2. Distribution of earthquake epicenters [7]

According to McGuirre [8], Seismic Hazard Analysis is the most common way to estimate the level of ground motion intensity associated with earthquake events, thereby providing fundamental input into the decision-making process to mitigate earthquake losses. To assess the earthquake hazard for a given place, two methodologies can be used: Probabilistic (PSHA) and Deterministic (DSHA).

DSHA determines ground motion parameters based on the maximum earthquake magnitude and closest distance from the earthquake source to the observation point, allowing for calculation of worst-case scenarios [9,10]. In contrast, Probabilistic Seismic Hazard Analysis (PSHA), pioneered by Cornell [11], focuses on the probability of earthquakes occurring at various intensity levels. Unlike DSHA, PSHA considers multiple scenarios and incorporates the frequency of each ground movement scenario, enabling predictions of the likelihood of worst conditions. PSHA offers advantages such as integrating all seismic sources, accounting for uncertainty in earthquake parameters through probability distributions, and addressing spatial uncertainty factors like earthquake size, location, and frequency [12, 13]. For nearly half a century, governments and industries have heavily relied on Probabilistic Seismic Hazard Analysis (PSHA) in critical decision-making processes that involve the safety of lives and property, defining safety criteria for nuclear power facilities [14,15,16], developing official national hazard maps [1,4], defining building code requirements [41], and calculating earthquake insurance premiums [17].

Given the reliance on Probabilistic Seismic Hazard Analysis (PSHA) in crucial decision-making processes, such as establishing safety standards for nuclear power plants, creating official national hazard maps, setting building code requirements, and calculating earthquake insurance premiums, it becomes imperative to extend this methodology to regions like Kendari City, the capital of Southeast Sulawesi. Furthermore, considering the 2011 and 2022 earthquakes and the absence of sufficient earthquake hazard assessments in Kendari City, it is imperative to undertake comprehensive studies to better understand and anticipate potential seismic risks. These efforts involve conducting thorough earthquake hazard analyses utilizing updated seismic data, ground motion prediction equations (GMPE), and site-specific ground characteristics. The final result of the PSHA calculation is the PGA (Peak Ground Acceleration) value on the surface. Maps are an important tool to support impact reduction processes. The map is used to identify weak points after an earthquake in order to identify potential damage in the event of a similar earthquake [18]. These results are then interpreted in the form of a thematic map (hazard map) to make it easier for users to understand.

The most significant differences of this study compared to PSHA analyses that have been conducted in Indonesia [1, 20, 21, 22, 23] are three things. First, the level of analysis conducted in this study is more in-depth, including surface seismic hazard analysis to provide a more comprehensive understanding, and can be used for infrastructure planning. Secondly, this study utilizes the latest Ground Motion Prediction Equations (GMPE), which indicates the application of more current and relevant ground motion prediction methods. Thirdly, the latest software, OpenQuake [19,26], whereas most other researchers are still using the USGS PSHA 2007 software, where the GMPE module has not been updated [24]. With a more detailed approach, up-to-date GMPE and the latest software, this research is expected to provide a more accurate and informative contribution related to earthquake hazards in Kendari City.

Theory and Calculation

A. Probabilistic Seismic Hazard Analysis (PSHA)

PSHA is used to statistically assess the risk of ground movement levels using the total probability method. Total probability theory considers magnitude (M) and distance (R) to be continuous independent random variables [11]. The total likelihood is computed by multiplying all of the probabilities determined in the preceding phases; in other words, the total probability is a function of distance, magnitude, and attenuation [24]

$$P[IM \geq x] = \int_{mmin}^{mmax} \int_{0}^{rmax} P[IM \geq x|m, r] f_M(m). f_r(r)\, drdm \qquad (1)$$

The analysis of seismic hazard is fundamentally reliant on several probabilistic functions that characterize earthquake occurrences and their impacts. The probability function of magnitude f_M describes the likelihood of an earthquake occurring with a specific magnitude M. Similarly, the probability function of distance f_r characterizes the likelihood of an earthquake's hypocenter being at a particular distance R from the site of interest. A critical aspect of seismic hazard assessment is quantifying the conditional probability $P[IM \geq x|m, r]$, which denotes the probability that the intensity measure (*IM*) at a given location will exceed a threshold value x, given an earthquake of magnitude M and a hypocentral distance R. This conditional probability function integrates the effects of both earthquake magnitude and distance on ground shaking intensity, providing a comprehensive understanding of the seismic hazard for the region under study.

B. Classical Probabilistic Seismic Hazard Analysis (PSHA) In Open Quake Engine

Analysis using the Classical PSHA method follows classical integration procedures [8][11] which was then formulated by Field et al [25]. In the OpenQuake engine, with this method the output is obtained in the form of a hazard curve which can then be compiled into a threat map (hazard map) and uniform hazard spectra/UHS.

$$\lambda(GroundMotion > gm) = \sum_{i=i}^{N_S} v_i \int M \int R\, P[GM > gm|m,r] f_M(m)\, f_R(r|m) dm\, dr \tag{2}$$

In the context of Classical Probabilistic Seismic Hazard Analysis (PSHA), the parameter $\lambda(GroundMotion > gm)$ represents the annual rate at which ground motion intensity exceeds a specified threshold gm at a given location. This parameter integrates contributions from multiple seismic sources that are capable of producing ground shaking levels above gm. The term v_i denotes the average rate at which ground motions exceed a given intensity level for the i-th source, reflecting the activity rate of that source. The conditional probability $P[GM > gm|m,r]$ describes the likelihood that the ground shaking intensity will exceed gm given an earthquake of magnitude m and hypocentral distance r, as determined by ground motion prediction equations. The probability density function $f_M(m)$ characterizes the distribution of earthquake magnitudes within the region, while $f_R(r|m)$ represents the conditional probability density function of distances from the seismic source to the site, given a specific magnitude m. These functions collectively contribute to the comprehensive probabilistic framework of PSHA, allowing for the estimation of seismic hazard by integrating the rates of occurrence, magnitudes, distances, and resulting ground motions from potential earthquakes.

C. Determining the Earthquake Hazard Level on the Surface using the Classical Probabilistic Seismic Hazard Analysis (PSHA) method

In determining the level of earthquake hazard on the surface, the steps that must be taken are:

1. In the framework of Classical Probabilistic Seismic Hazard Analysis (PSHA), the input model structure is meticulously designed to ensure comprehensive and accurate hazard assessment. The input data primarily consists of three key components: configuration files, seismic source system files, and ground motion system files. Configuration files serve as the backbone of the PSHA model, defining the parameters and settings that govern the analysis process. The seismic source system file is critical as it contains a set of initial models along with associated epistemic uncertainties, which are essential for simulating earthquake activity within the region of interest. This file encapsulates the spatial distribution, frequency, and magnitude of potential seismic sources. Complementing this, the ground motion system file comprises a collection of ground motion prediction equations tailored to different types of tectonic zones. These equations are crucial for modeling the expected ground shaking intensity at various locations in the area under study. Together, these inputs form a robust foundation for PSHA, enabling a detailed and probabilistically sound evaluation of seismic hazards.

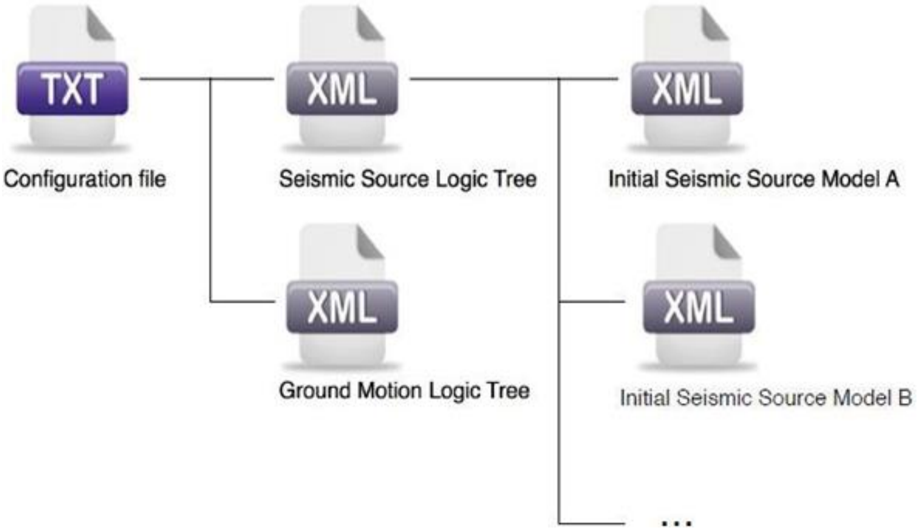

Figure 3. PSHA Input Model Structure [19,26]

2. Earthquake Sources

   The earthquake sources used for earthquake hazard analysis are: Active shallow crust sources. The Active shallow crust model used is Simple fault source (Figure 4). The parameters used can be seen in Table 1. The data used as parameters for the Active Shallow Crust fault model in this analysis were obtained from two main sources, namely the Meteorology, Climatology and Geophysics Agency (BMKG) and the National Earthquake Study Center (PuSGeN). BMKG and PuSGeN, as official Indonesian government agencies, provide the latest seismic information, including fault geometric parameters.

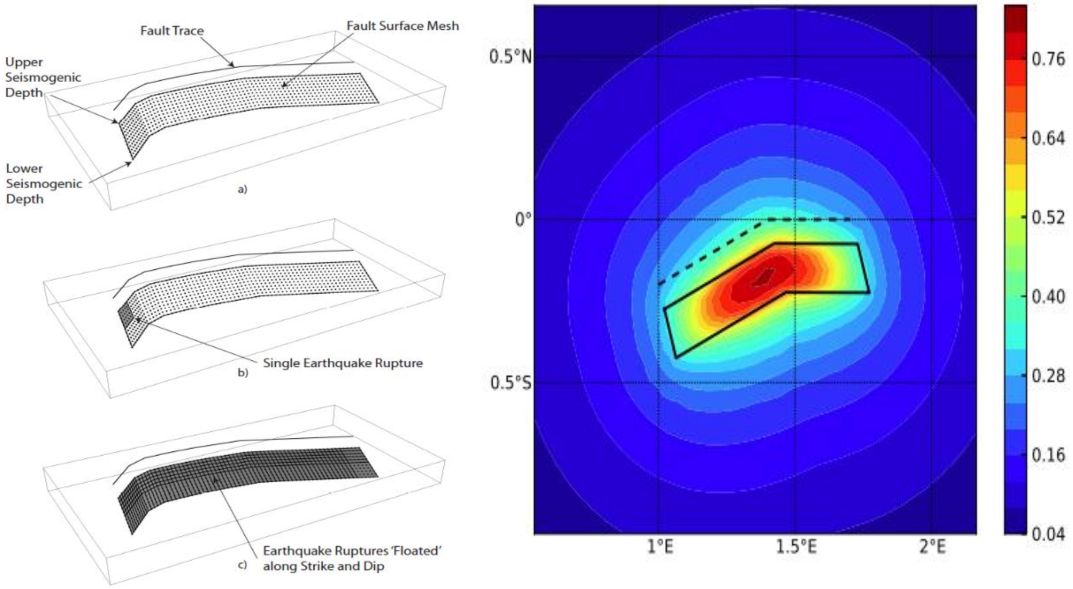

Figure 4. Simple Fault Source [19,26]

The following is a list of active fault earthquake sources in Southeast Sulawesi used in the calculations [1,4]:

Table 1. Active fault in Sulawesi, Southeast Sulawesi

No	Fault Name	Dip	Slip-rate mm/year	Length (Km)	Mmax
1	MATANO FAULT Kuleana	90	7	22	6.6
2	MATANO FAULT Pewusai	90	7	46	6.9
3	MATANO FAULT Matano	90	7	35	6.8
4	MATANO FAULT Pamsoa	90	7	44	6.9
5	MATANO FAULT Ballawai	90	7	26	6.7
6	MATANO FAULT Geressa	91	7	80	7.2
7	LAWANOPO	90	0.1	130	7.5
8	TOLO THRUST	45W	1	120	7.4
9	KENDARI FAULT North	90	-	24	6.5
10	KENDARI FAULT Central	90	-	11	7.4
11	KENDARI FAULT South	90	-	10	6.3
12	BUTON A	60	0.1	29	6.2
13	BUTON B	90	0.1	60	7.1

3. Logic tree Ground Motion Model

A ground motion model is a model that calculates ground movements on a surface at a certain point based on the rupture properties. In simpler terms, the ground motion model usually matches the ground motion prediction equation (GMPE). However, when dealing with complex Probabilistic Seismic Hazard Analysis (PSHA) input models, the ground motion model consists of multiple GMPEs. Each GMPE corresponds to a specific tectonic zone and is referred to as a Ground Shaking Intensity Model (GSIM). In this study, the GMPE used was adapted to the preparation of the Indonesian Earthquake Hazard Deaggregation Map for Planning and Evaluating Earthquake-Resilient Infrastructure [27] and PSHA input model documentation for Indonesia [28].

Table 2. Ground Motion Prediction Equation (GMPE)

Ground Motion Prediction Equation (GMPE)
BooreAtkinson2008 (0.2) [29]
CampbellBozorgnia2008 (0.2) [30]
ChiouYoungs2008 (0.2) [31]
BooreEtAl2014 (0.133) [32]
CampbellBozorgnia2014 (0.133) [33]
ChiouYoungs2014 (0.134) [34]

4. Hazard Computing with OpenQuake Using the Classical Probabilistic Seismic Hazard Analysis (PSHA) Method

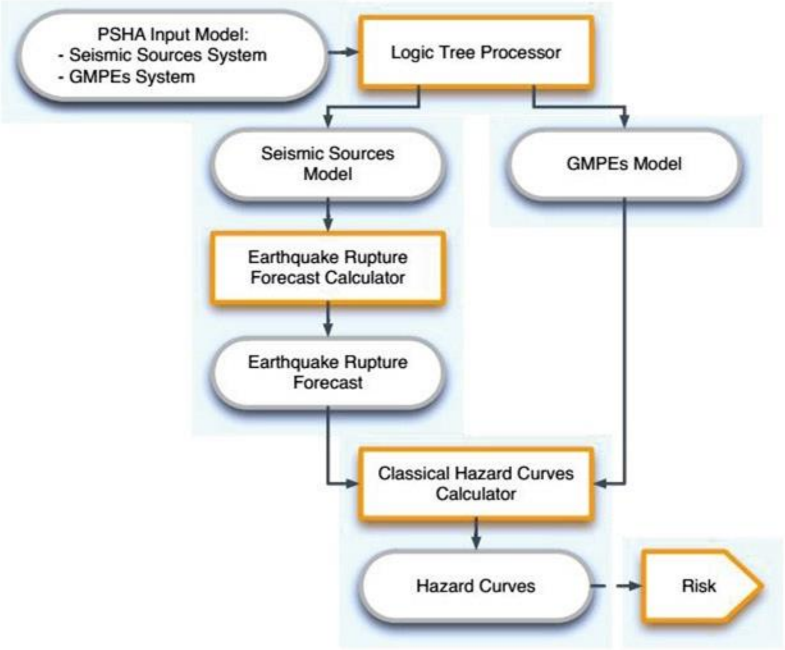

Figure 5. Classical PSHA calculation flow using OpenQuake Engine [35]

To carry out the Classical PSHA method, two sets of data are utilized: the seismic source system and the GMPEs System. Logic Tree Process (LTP) is employed to handle the PSHA input model data. This processor oversees two logic tree structures, one for creating a model of seismic source (SSM) and another for producing a model of GMPE. Using the information initial model of seismic source, the Logic Tree Processor generates samples of epistemic uncertainty, which eventually contribute to the building of a Seismic Source Model. This model precisely characterizes the geometry and amount of activity of each seismic source, with no epistemic uncertainty. Following the same procedure, LTP does ground motion modeling by considering the corresponding GMPE (Ground Motion Prediction Equations) data structure associated with each tectonic zone. After inputting the Seismic Source Model into the Earthquake Rupture Forecast/ERF calculator, an ERF is generated. This ERF provides a comprehensive list of all ruptures in the source model, along with their corresponding probabilities of exceedance. To determine the hazard curve for each location, the Classical Hazard Curves Calculator utilizes both the ERF and GMPE models. When conducting surface hazard analysis using OpenQuake, site-specific soil conditions, specifically the input Vs30, are taken into account. These parameters play a crucial role in analyzing the hazard on surfaces. Site specific parameters considered in surface hazard analysis using OpenQuake are as follows:

1. The average ground shear acceleration at a depth of 30 meters from the surface (Vs30) is used in this study from USGS [36], where Vs30 data is generated based on topography and confirmed against the findings of field measurements conducted in nearly every country in the globe.
2. Geological factors and basin impacts are determined as rock depth parameters with a shear velocity of 1000 m/sec (Z1.0) and rock depth with a shear velocity of 2500 m/sec (Z2.5), using the Chiou & Young formula for California [37]:

$$\ln \mathrm{Z1.0} = \frac{-7.15}{4}\, x \ln\left(\frac{Vs30^4 + 571^4}{1360^4 + 571^4}\right) \tag{3}$$

$$\ln \mathrm{Z2.5} = 7.089 - 1.144 lnVs30$$

Result and Discussion

A. Site Conditions in Kendari City

Earthquake activity in Kendari City is mostly influenced by the Kendari North, Central, South, and Lawanopo Faults. The Kendari City area is dominated by earthquakes with varying magnitudes and depths dominated by earthquakes with magnitudes less than 5 and shallow depths less than 60 km [38]. Recent research shows that most of the earthquakes that occur in this area are related to the movement of these faults. This is in line with source data from the National Center for Earthquake Studies [1] that records fault movement activity in the region. The fault source map prepared by PuSGeN shows the distribution and characteristics of faults in Kendari City. Interestingly, when the geological fault map [39] is compared with the PuSGeN fault map, there is a striking correspondence between the two. The agreement between the fault map of the National Earthquake Study Center (PuSGeN) and the geological fault map in Kendari City provides strong support for this study. The geological fault map details the rock formations and geological structures in the area, while the PuSGeN fault map records the distribution and characteristics of active faults. These two maps, when juxtaposed, show striking consistency, corroborating the assumption that tectonic movements in the area influence earthquake activity.

The shear wave velocity can reflect the profile used to a depth of 30 meters. This is based on the reference used by civil engineering to determine site classification or building structure design by considering soil characteristics in the form of shear wave velocities at depths of up to 30 meters as outlined inside SNI-1726-2019, the Indonesian National Standard, because the magnification of seismic waves can be determined by the surface layer to a depth of 30 meters [40]. More clearly the site classification following SNI-1726-2019 can be seen in table 3 [41].

Table 3. Site Classification (SNI-1726-2019)

Site class	$\overline{V}_s$ **(m/s)**	or $\overline{N}_{ch}$	$\overline{S}_u$**(kPa)**
SA (bed rock)	>1500	N/A	N/A
SB (rock)	750 s/d 1500	N/A	N/A
SC (hard, very dense soil and soft rock)	350 s/d 750	>50	≥100
SD (medium-sized soil)	175 s/d 350	15 s/d 50	50 s/d 100
SE (moist soil)	<175	<15	<50
	or any soil profile that has more than three meters of dirt in it that has any of the following qualities: 1. Plasticity index, *PI* > 20. 2. Moisture content, *w* ≥ 40%. 3. Undrained shear strength, s_u < 25 kPa.		
SF (unique soils, necessitating particular geotechnical investigations and site-specific response analysis as outlined in Article 0)	Any soil layer profile that possesses one or more of the following conditions: 1. Liquefaction-prone soils, very sensitive clays, or poorly cemented soils are examples of soils that are vulnerable to failure or collapse under seismic pressure. 2. Peat and/or highly organic clays thicker than three meters. 3. Very high plasticity clays with a thickness greater than 7.5 meters and a Plasticity Index, *PI* > 75). 4. Soft to firm clay layers with a thickness greater than 35 meters and an undrained shear strength with s_u < 50 kPa .		

The parameters used on the USGS map to determine the Vs30 value are slope data obtained from SRTM satellite imagery. According to Matsuoka and Wakamatsu [42], the Vs30 value will be higher, if the area is located at an altitude, the steeper the slope and the closer the distance from the mountains or hills. The contour map in Figure 6 shows the distribution of Vs30 values based on USGS map results. It appears that the northern part of Kendari City (Kendari and West Kendari Districts) is predominantly composed of hard soil which is included in the SC class classification and is characterized by green to light green contours. Meanwhile, the southwest part of Kendari City (North-South part of Nambo District and other sub-districts is dominated by medium and soft soil which is included in the SD and SE soil classifications, marked by dark red to orange contours. Data obtained from the USGS map shows that the results match with a map of Vs30 distribution processing results from previous research results in Kendari City. Based on the results of previous research using microtremor measurements, the ratio value of the difference between the results of microtremor measurements and the topographic model (USGS) is not significantly different.

Even though based on the Vs30 value of the two methods there is a difference in speed value > 100 m/s at several measurement points, but the range of differences in these values is still in the same material type category. Based on the Vs30 value, it is suspected that the subsurface conditions in Kendari City have the potential for shocks and high levels of building damage if an earthquake occurs because it is dominated by material quite thick soft soil [43].

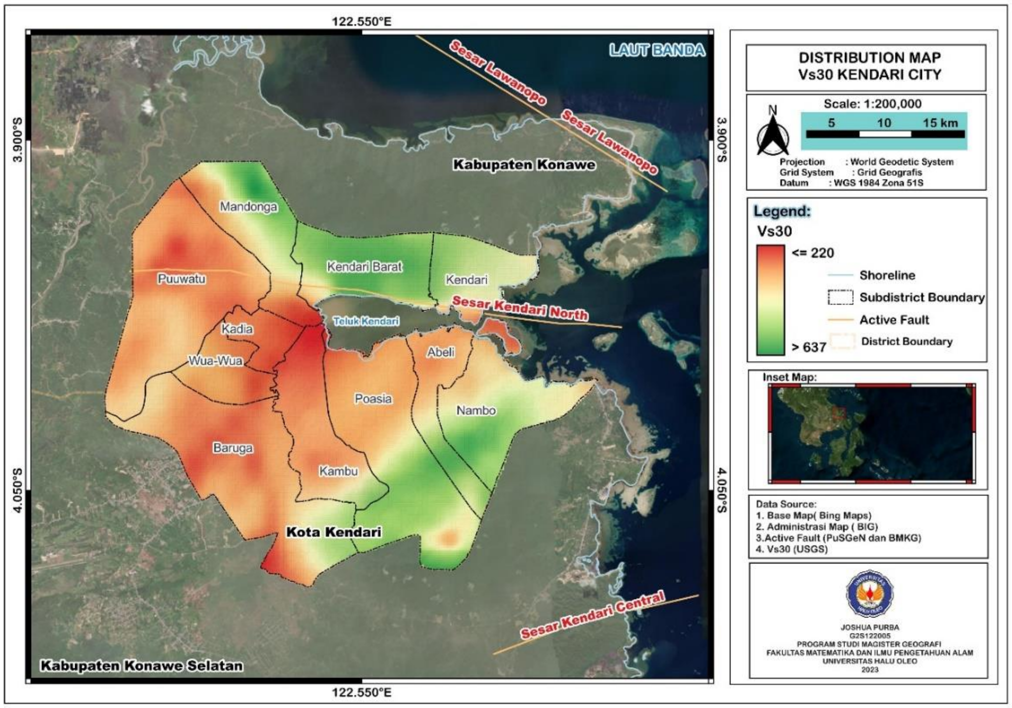

Figure 6. Kendari City Vs30 Distribution Map

B. Results of Earthquake Hazard Analysis Using the Classical PSHA Method on the Surface

Figures 7 and 8 represent the map of 0 seconds (PGA) at the surface with a chance of 10% and 2% exceedance in 50 years, respectively. According to the analysis findings, the highest ground acceleration value on the surface in the Kendari City region is 0.49 g to 0.68 g with a 10% chance of surpassing in 50 years, while the peak ground acceleration value with a 2% chance of exceeding in 50 years is 0.79 to 1.17 g.

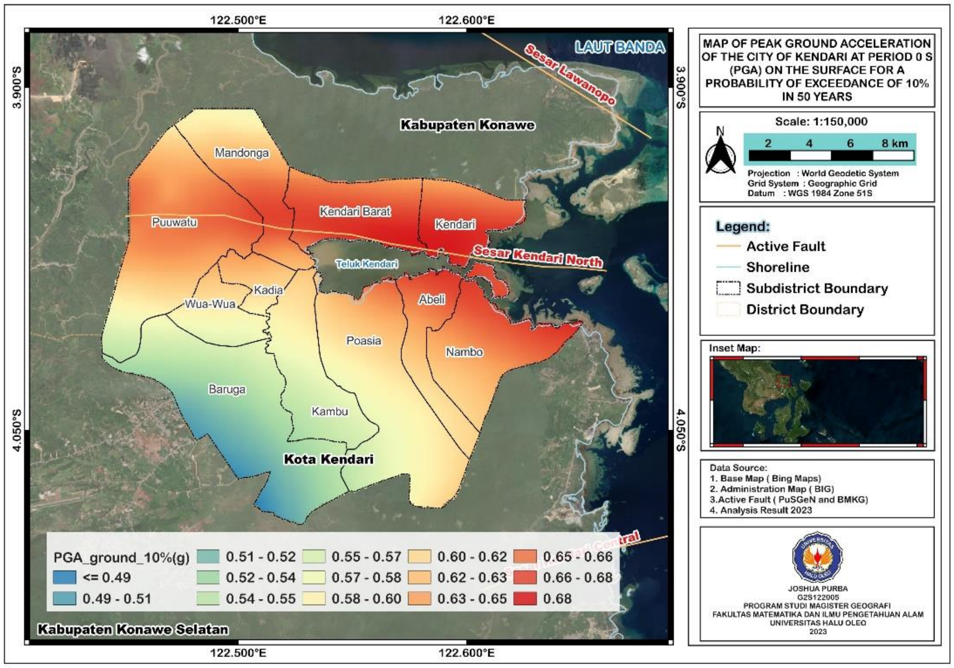

Figure 7. Map of the (PGA) at the surface at 0 seconds with a 10% probability of being exceeded within 50 years

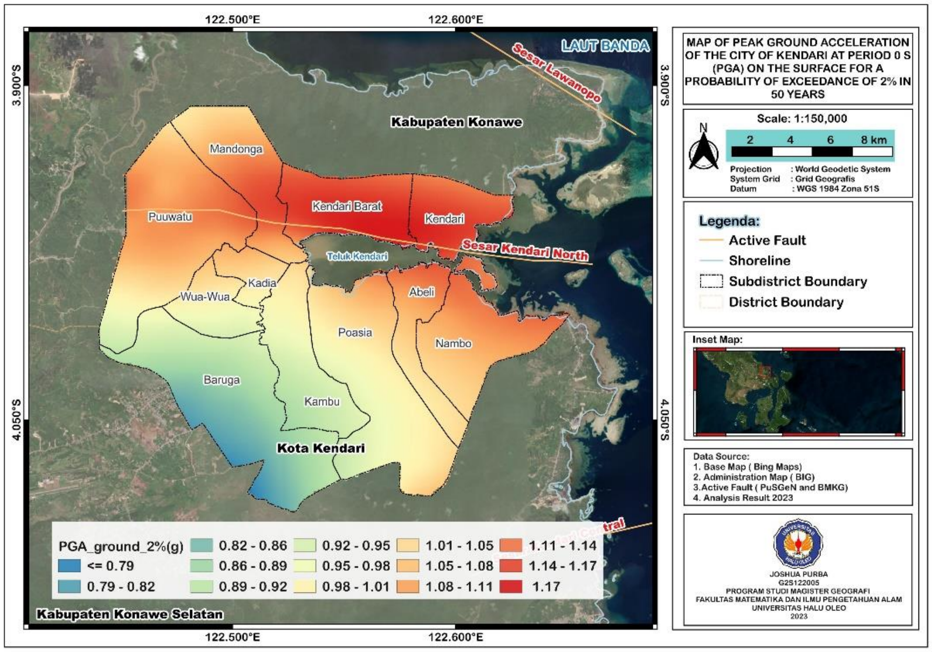

Figure 8. Map of the (PGA) at the surface at 0 seconds with a 2% probability of being exceeded within 50 years

Figures 9 and 10 represent a map of a period 0.2 seconds (SA 0.2) on the surface for the Kendari City region. The study findings reveal that the maximal ground acceleration value in Kendari City at the surface for T=0.2 seconds is 1.10 g to 1.53 g for a 10% probability of exceedance in 50 years, and 1.74 to 2.09 g for a 2% risk of exceeding in 50 years.

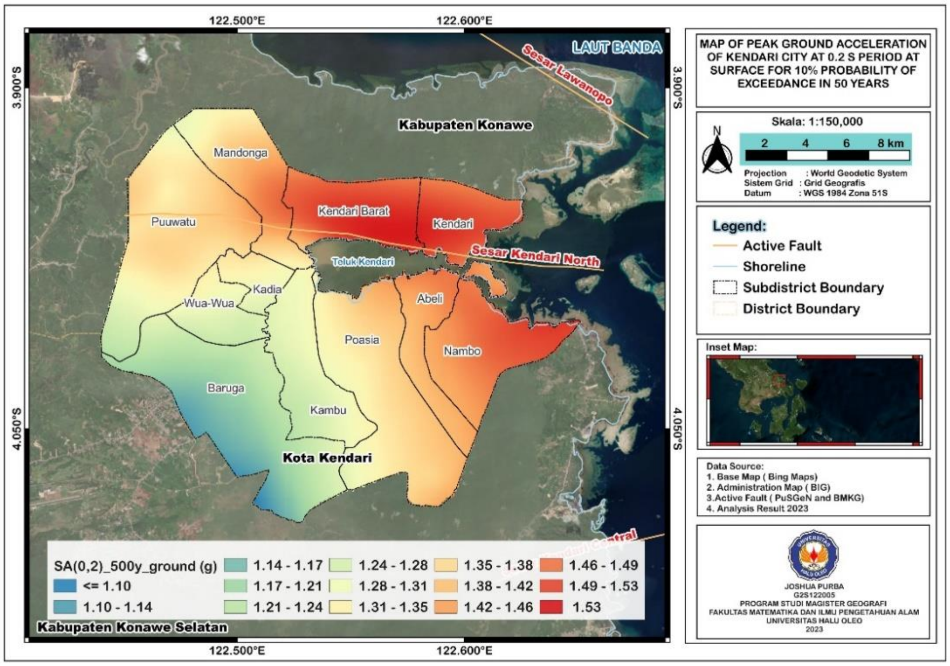

Figure 9. Map of a period 0.2 seconds (SA 0.2) on the surface with a 10% probability of being exceeded within 50 years

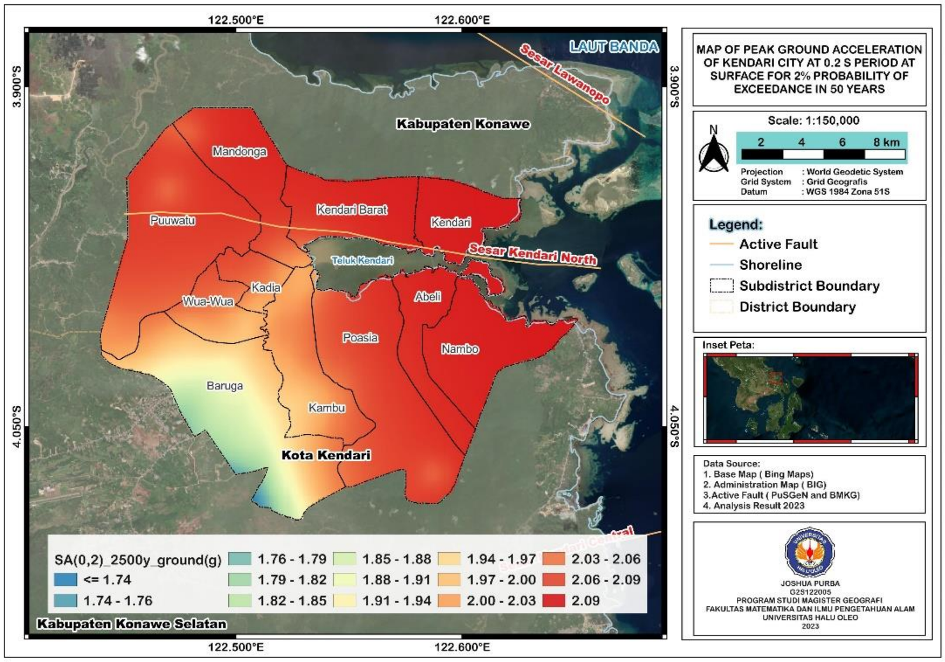

Figure 10. Map of a period 0.2 seconds (SA 0.2) on the surface with a 2% probability of being exceeded within 50 years

Figures 11 and 12 represent a map of a period 1 seconds (SA 1) on the surface for the Kendari City region. The study findings suggest that the highest ground acceleration value in Kendari City at the surface for T=1 seconds is 0.64 g to 0.93 g with a 10% probability of exceeding in 50 years, and 1.35 to 1.91 g with a 2% chance of exceeding in 50 years.

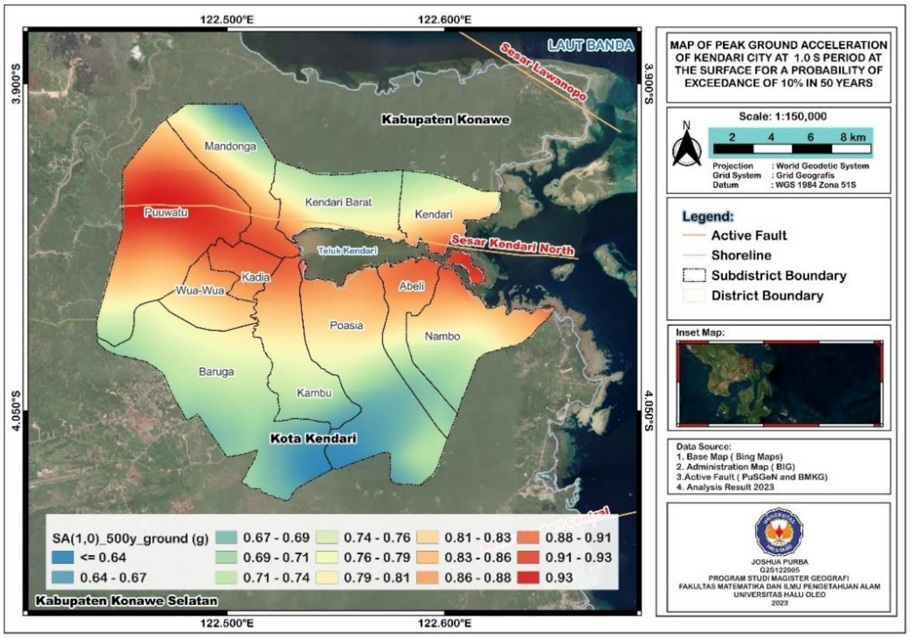

Figure 11. Map of a period 1 seconds (SA 1) on the surface with a 10% probability of being exceeded within 50 years

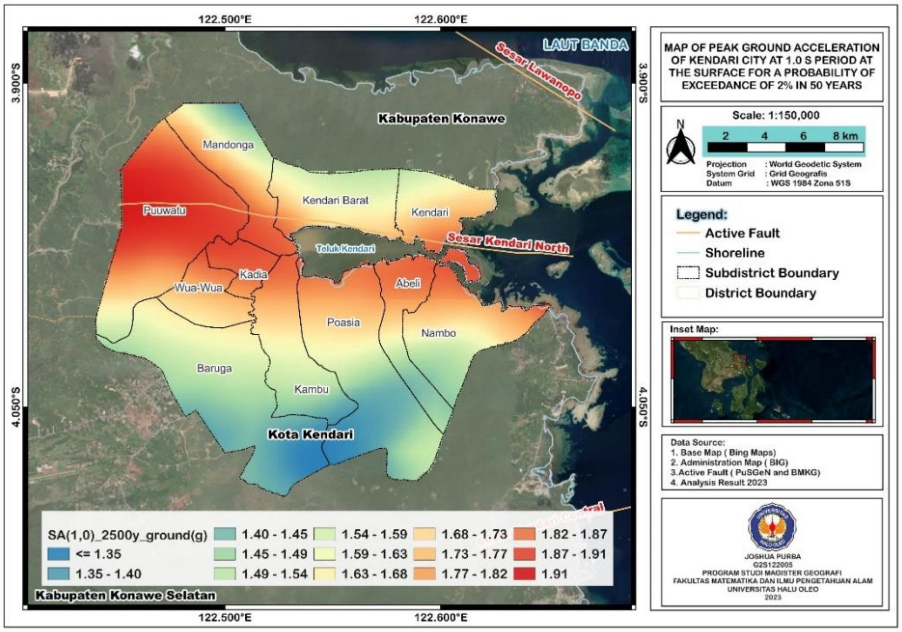

Figure 12. Map of a period 1 seconds (SA 1) on the surface with a 2% probability of being exceeded within 50 years

C. Discussion

The peak ground acceleration (PGA) and spectra acceleration (SA) at periods (T = 0.2 s) and (T = 1 s) on the surface for a 10% and 2% probability of exceedance in 50 years shows a high range of hazard values in almost every sub-district because it is located in an area close to the fault plane (Shallow Crustal), namely Lawanopo Fault, Kendari North Fault, Kendari Central Fault, and Kendari South Fault. This fault affects almost all areas in Kendari City. On the hazard map of areas where faults are present, the maximum acceleration value on the surface in that area will also experience an increase in the pattern of the range of values, for example at the Kendari North fault location, the further the distance from the fault, the smaller the maximum acceleration on the surface will be (Southwestern part). Acceleration in almost all areas experienced an increase in intensity/amplification, this is due to the influence of site-specific parameters, namely Vs30 values below 340 m/sec (SD Class) and even below 175 m/sec (SE Class). Whereas in areas with Vs30 > 340 m/sec to 760 m/sec (Class SC), the shock acceleration experienced a slight amplification. This is in line with previous research in Kendari [43], Surakarta [44] and West Jakarta [45].

The maximum ground acceleration map in the periods of 0.2 seconds and 1 second for probabilities of 2% and 10% exceedance in 50 years shows that all sub-districts in Kendari City were affected by the earthquake, both in the short period (0.2 seconds) and the long period (1 second). Kendari City itself has a land use area for buildings of 9.43 square kilometers [46]. This means that settlements (buildings where people live) in Kendari City are vulnerable to earthquakes because most of the area has the potential to experience significant ground acceleration during an earthquake. The distribution of PGA maps at various periods from PSHA results is a tool used to measure the intensity of ground vibrations that may occur during an earthquake, and in this case, shows that all residential areas in Kendari City are in zones that have the potential to be significantly impacted. In the context of civil engineering, knowledge of vibration theory is crucial in evaluating potential damage that may occur to building structures due to earthquakes. Earthquake waves contain various frequencies, which are then used by engineering to calculate the expected acceleration at a particular frequency. This analysis is important for planning buildings that are resistant to earthquake shocks. However, it is crucial to note that the frequency or duration of vibrations experienced by a building is highly dependent on its physical characteristics. There is a phenomenon known as resonance, where the dominant frequency of ground vibrations or loads due to an earthquake approaches the vibration frequency of the building. When resonance occurs, the risk of damage to the structure increases significantly. Multi-storey buildings tend to be more sensitive to shocks in long periods (1 second), while non-storied buildings are more susceptible to shocks in short periods (0.2 seconds). From the peak ground acceleration map at (0.2 seconds), it can be seen that a high peak acceleration (1.7-2.1 g) indicates a greater potential for damage and shock. Therefore, in planning and designing building structures, it is important to taking into account the potential for resonance and ensuring the strength of the building complies with the Indonesian National Standard (SNI) 1726-2019 [41] to minimize the risk of damage or collapse during an earthquake.

Conclusion

Based on the results and discussion in this study, it can be concluded that the Peak Ground Acceleration (PGA) values in Kendari City on the surface ranged from 0.49 to 0.68 g and 0.79 to 1.17 g, with corresponding values for the period (T= 0.2 seconds) (SA 0.2) ranging from (1.10 to 1.53 g and 1.74 to 2.09 g), and for the period (T= 1 second) (SA 1) ranging from (0.64 to 0.93 g and 1.35 to 1.91 g). These findings strongly suggest the potential for significant damage and seismic shocks within Kendari City. The seismic events of 2011 and 2022 in Kendari City serve as stark reminders of the imperative need to reassess current building infrastructure. While the seismic hazard map provides invaluable insights into ground acceleration levels, the analysis underscores the necessity for a thorough re-evaluation of existing structures. Without comprehensive seismic analysis and retrofitting measures, current buildings remain vulnerable to potential seismic hazards. Therefore, it is paramount to prioritize the reassessment of the structural integrity of buildings in Kendari City to mitigate the risk of damage and ensure the safety of inhabitants. By conducting detailed seismic hazard assessments and revisiting building codes and standards in light of updated seismic data, Kendari City can implement proactive measures to enhance structural resilience and minimize the impact of future seismic events. Additionally, incorporating seismic retrofitting strategies into urban planning initiatives will contribute to the creation of a more resilient and disaster-resistant built environment in Kendari City.

Acknowledgment

A big thank you goes to Dr. Ir. M. Asrurifak, M.T. and Dr. Garup Lambang Goro as the Seismic Hazard Analysis Working Group team of the National Earthquake Study Center provided the opportunity to learn about the use of OpenQuake software and has helped complete this research.

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