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Analyzing Peak Ground Acceleration (PGA) Distribution in IKN Development Area Using Kanai Method

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Abstract

This study examines the distribution of Peak Ground Acceleration (PGA) values in the development area of the new capital city (IKN) in Sepaku District, Penajam Paser Utara Regency, East Kalimantan. Although seismic activity in Kalimantan is lower compared to other regions in Indonesia, earthquake risks still need to be anticipated, especially with the relocation of IKN to this area. Earthquake disaster mitigation efforts are conducted through PGA mapping using the empirical Kanai approach, which provides information on potential damage risks due to earthquakes. The study utilizes seismic data obtained from microtremor measurements at 44 points, as well as earthquake data from Paser Regency in 2022 and the 2018 Palu earthquake. The data were analyzed using the Horizontal-to-Vertical Spectral Ratio (HVSR) method to calculate the natural frequency and dominant soil period, which are key input parameters in determining PGA values. The results show PGA values ranging from 0.69 to 34.29 gal, divided into two main zones: low (PGA < 2.9 gal) and moderate (PGA 2.9–34.29 gal). This information serves as a critical foundation for earthquake risk mitigation and safe development planning in the IKN area, particularly in Sepaku District, East Kalimantan.

INTRODUCTION

Various issues faced by Jakarta, such as pollution, flooding, overpopulation, and geophysical problems like land subsidence and its proximity to the subduction zone, have been significant factors in selecting the location of the new capital city (IKN)[1]. The relocation of IKN to East Kalimantan requires comprehensive studies to anticipate potential natural disasters, including earthquakes. Although Kalimantan generally has lower seismic activity due to fewer active faults compared to other islands in Indonesia, the risk must still be considered.

Now days, no instrument can accurately predict the location, time, and characteristics of earthquakes. Therefore, to mitigate earthquake risks, it is crucial to study relevant physical parameters. One of the key parameters that needs special attention is the mapping of Peak Ground Acceleration (PGA) values. These values are essential for assessing potential earthquake damage[2].

PGA measures the maximum ground acceleration during an earthquake at a specific location[3]. This acceleration significantly impacts building design, as it generates distributed moment forces on structures [4]. Consequently, PGA is a critical factor in earthquake-resistant building design calculations.

Therefore, a study on PGA values in the IKN development area is crucial as a parameter to identify potential earthquake impacts and as an initial step in mitigating the risk of earthquake-induced damage.

The findings of this study are expected to provide a solid foundation for future development planning in the Sepaku Subdistrict, particularly in the IKN development area.

RESEARCH METHODS

This study was conducted in Sepaku Subdistrict, located in North Penajam Paser Regency, East Kalimantan, to analyze the distribution of Peak Ground Acceleration (PGA) values and earthquake intensity. This area was selected as it is part of the development zone for Indonesia's new capital city. The study is crucial to support infrastructure planning and disaster risk mitigation for future earthquakes, considering the potential seismic impact on development stability.

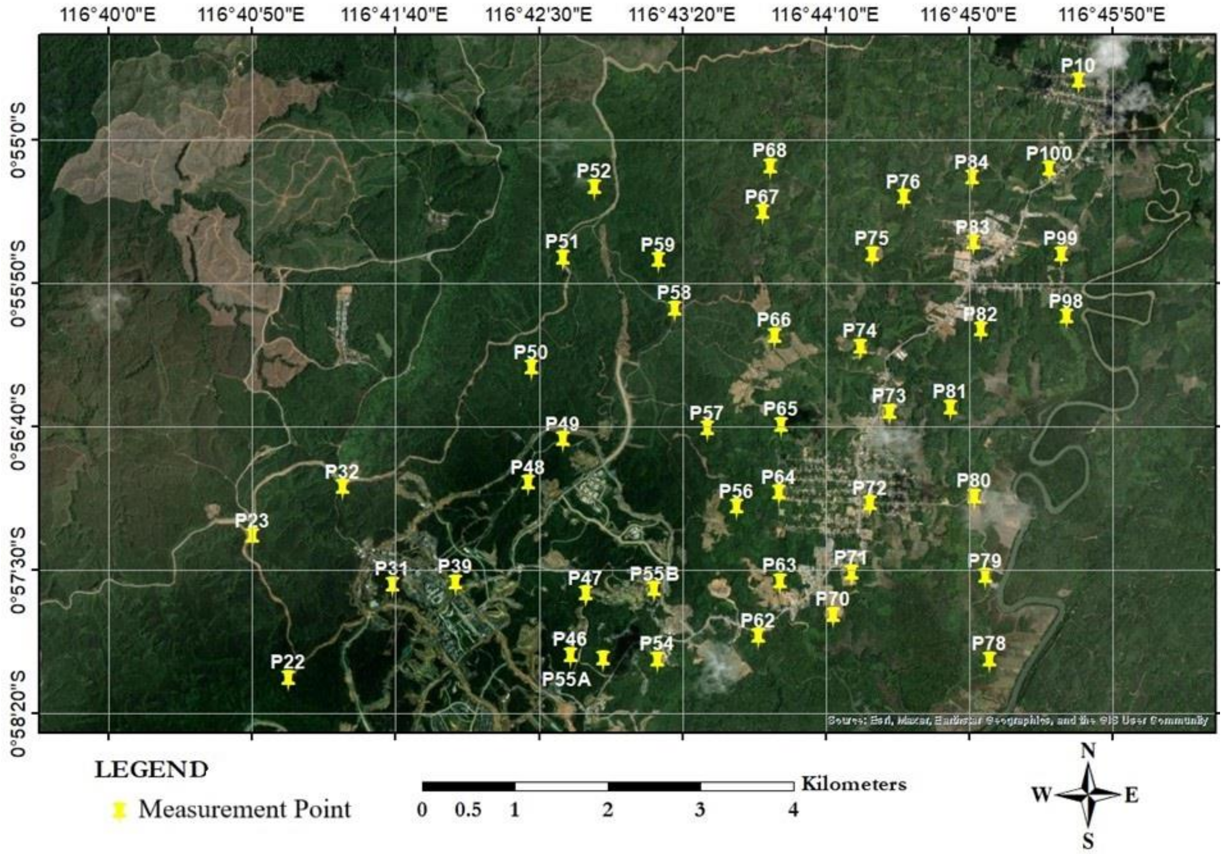

Figure 1. Research Location Map, Sepaku Subdistrict, North Penajam Paser Regency. The yellow markers on the map indicate the microtremor measurement points.

In this study, geological maps and topographical maps of the research area were used as primary references for determining survey points. The survey design was developed using ArcGIS software, which facilitates efficient visualization and planning of survey points. At each survey point, microtremor data were recorded using a seismometer, while the location of each survey point was tracked using a Global Positioning System (GPS). The GPS also served as a marker for the survey location. To ensure proper placement of the seismometer, a compass was used to determine true north as a reference for orientation. The collected microtremor data were processed using Geopsy software. Additionally, secondary data, including earthquake history such as magnitude, hypocenter, and epicenter, were obtained from Indonesian Meteorology, Climatology, and Geophysics Agency and USGS (United States Geological Survey) to support the analysis.

Microtremor data were acquired through a survey conducted at 44 measurement points, with a measurement duration of approximately 30 minutes at each point. The measurement results were automatically recorded by the instruments. The collected microtremor data were in the form of time functions consisting of three components: the vertical component (up and down), horizontal north-south, and horizontal east-west. In microtremor measurements, the desired signal is the stationary signal, which has constant amplitude and remains unchanged over time.

The raw microtremor data were processed using Geopsy software through several stages: (1) performing data corrections; (2) applying a band-pass filter in the frequency range of 0.5–20 Hz to filter the data; and (3) conducting signal windowing and using the H/V tool in Geopsy as the final step in the HVSR analysis. The Horizontal-to-Vertical Spectral Ratio (HVSR) method is an effective approach for studying ground motion amplification. This method compares the spectral ratio of the horizontal components of microtremor signals to their vertical component [5]. Mathematically, it is expressed through Equation (1) as follows.

$$\mathrm{HVSR} = \frac{\sqrt{(S_{NS})^2+(S_{EW})^2}}{(S_V)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(1)$$

S_{NS}, S_{EW}, and S_V represent the spectral amplitudes of the north-south, east-west, and vertical components, respectively. Generally, HVSR analysis yields a spectral peak at the natural frequency (f_0) and an amplification factor (A_0) to describe the dynamic characteristics of the soil [6]. The natural frequency or dominant frequency indicates the number of wave cycles occurring per unit of time. It represents the frequency most commonly observed in the study area and is derived from the horizontal axis of the H/V curve's peak [7]. Amplification refers to the increase in seismic wave amplitude caused by significant differences between rock or soil layers. The amplification factor value can increase when soil or rock layers undergo deformation, such as weathering, folding, or faulting, which alters the rock's properties. The amplification value for the same type of rock can vary depending on the degree of deformation caused by weathering [8].

The f_0 value is used to calculate the dominant period (Tg), which is an input parameter for determining the PGA value. Ground acceleration, the rate of change in velocity during seismic wave propagation, is a primary factor in earthquake damage. Higher PGA values indicate a greater risk of earthquake damage at a specific location [9]. The higher the PGA value of an area, the greater the risk of damage caused by an earthquake in that area. The PGA value can be calculated using several empirical formulas, one of which is the Kanai (1966) empirical formula [2]. The calculation of the PGA value at the measurement point is performed using Equation (2).

$$a_g = \frac{5}{\sqrt{T_g}} 10^{[(0,61M)-\left(1,66+\frac{3,6}{R}\right)\log R+(0,167\frac{1,83}{R}]} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(2)$$

where a_g is the PGA in gal, $T_g$is the dominant period of the soil at the research location in seconds ($T_g = \frac{1}{f_o}$), M is the erathquake magnitude on the Richter scale, and R is the hypocentral distance in km.

RESULTS AND DISCUSSION

The analysis of PGA is an important parameter used to predict the level of damage in an area due to an earthquake. The PGA value in the research area was calculated using an empirical formula based on the Kanai method (Equation 2). This study used earthquake data from March 1st , 2022, in Paser Regency, with a hypocenter depth of 10 km and a magnitude of 4.5 (earthquake data 1). This earthquake reflects the local seismic conditions around the IKN area, making it relevant for modeling the potential PGA generated by small to medium-magnitude earthquakes in the region. This data is also crucial for understanding the response of the soil and structures around IKN to frequent earthquakes in the area. The second earthquake data comes from the large earthquake that occurred in Palu City on September 28th, 2018, with a hypocenter depth of 10 km and a magnitude of 7.2. Although the location is relatively far from IKN, this data was selected to represent a scenario of a large earthquake with significant energy, providing insight into the potential maximum PGA that could occur. The results of the PGA analysis at the research location are shown in Table 1.1, which varies from <2.9 gal to 2.9-34.29 gal.

Table 1. PGA Values at Each Microtremor Measurement Point.

Measurment Point	F_0(Hz)	T_g (s)	PGA (gal) (Eartquake Data 1)	PGA (gal) (Earthquake Data 2)
1	13.77	0.07	3.17	33.41
2	13.51	0.07	3.11	33.09

Measurment Point	F_0(Hz)	T_g (s)	PGA (gal) (Eartquake Data 1)	PGA (gal) (Earthquake Data 2)
3	13.62	0.07	3.10	33.42
4	11.38	0.09	2.83	30.51
5	8.33	0.12	2.42	26.22
6	11.69	0.09	2.85	31.20
7	11.35	0.09	2.79	30.78
8	9.04	0.11	2.48	27.43
9	8.48	0.12	2.39	26.63
10	13.18	0.08	2.97	33.17
11	14.01	0.07	3.03	34.29
12	11.60	0.09	2.73	31.27
13	8.01	0.12	2.34	24.81
14	12.88	0.08	2.99	32.80
15	13.01	0.08	2.97	33.07
16	9.76	0.10	2.54	28.78
17	0.74	1.35	0.70	7.92
18	9.73	0.10	2.51	28.71
19	11.60	0.09	2.74	31.34
20	2.62	0.38	1.33	14.90
21	10.95	0.09	2.70	30.52
22	11.76	0.09	2.78	31.66
23	12.54	0.08	2.86	32.72
24	13.58	0.07	2.95	34.07
25	10.97	0.09	2.63	30.64
26	13.15	0.08	2.87	33.58
27	0.81	1.23	0.73	8.32
28	11.23	0.09	2.72	31.01
29	4.92	0.20	1.79	20.56
30	11.64	0.09	2.73	31.69
31	4.02	0.25	1.60	18.61
32	11.13	0.09	2.64	31.01
33	6.98	0.14	2.07	24.61
34	3.81	0.26	1.58	18.17
35	2.49	0.40	1.27	14.70
36	10.08	0.10	2.54	29.58
37	12.75	0.08	2.84	33.26
38	13.49	0.07	2.90	34.29
39	5.20	0.19	1.79	21.30
40	11.02	0.09	2.59	31.03
41	1.80	0.56	1.05	12.58
42	2.40	0.42	1.21	14.53
43	11.31	0.09	2.61	31.55
44	12.30	0.08	2.69	32.98

The calculation results were then visualized on a map to show the distribution of PGA values, as seen in Figures 2 and 3, allowing the PGA distribution pattern in the study area to be identified.

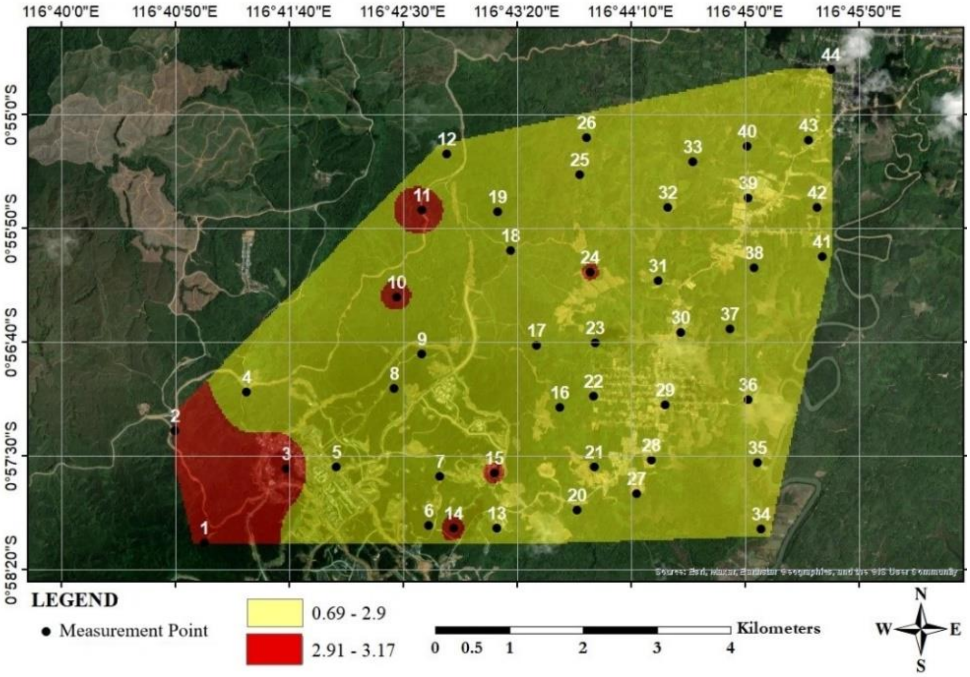

Figure 2. PGA Distribution Map Using the March 10, 2022 Earthquake Database in Paser Regency with a hypocenter depth of 10 km and a magnitude of 4.5.

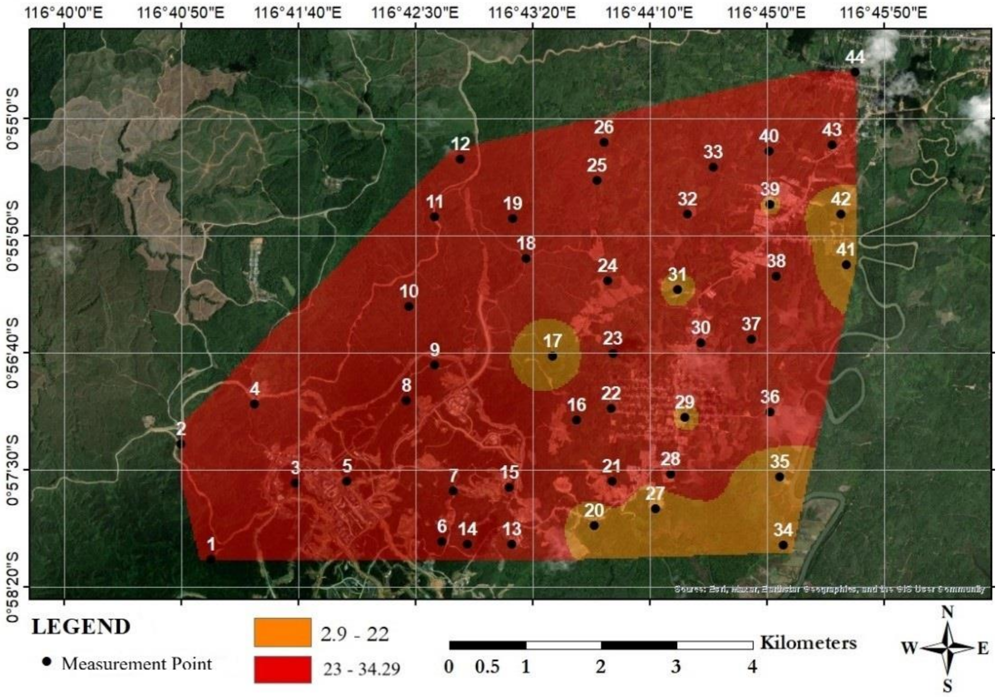

Figure 3. PGA Distribution Map Using the September 28, 2018 Earthquake Database around Palu City with a hypocenter depth of 10 km and a magnitude of 7.2.

Figure 2 displays the distribution map of low dominant PGA values, ranging from 0.69 gal to 2.9 gal. Several points show slightly higher values, within the moderate category, ranging from 2.91 gal to 3.17 gal, localized in small red-colored areas on the map. Meanwhile, Figure 3 shows the distribution of PGA values, which also fall within the moderate range, from 2.9 gal to 34.29 gal, indicated by orange to red colors. The orange areas represent PGA values between 2.9 and 22 gal, while the red areas indicate higher values, ranging from 23 to 34.29 gal.

PGA values are influenced by several factors, such as earthquake magnitude, hypocenter depth, epicenter distance, and the physical properties of rocks [4]. Earthquakes with smaller magnitudes and distant epicenters tend to produce lower PGA values, while large earthquakes at shorter distances produce higher PGA values [10]. In line with these findings, this study reveals that the 7.2 magnitude earthquake, despite being farther from the study location, produced higher PGA values compared to the 4.5 magnitude earthquake, which was closer. This is due to the significant energy generated by the larger earthquake, which results in noticeable impacts even after attenuation due to distance.

Based on the Samarinda Geological Map, the study area lies within the Pamaluan Formation and Alluvial Deposits. The Pamaluan Formation, formed during the Tertiary period, is dominated by quartz sandstone with intercalations of claystone, shale, limestone, and siltstone. On the other hand, the Alluvial Deposits consist of gravel, sand, and silt formed in river, swamp, delta, and coastal environments. These geological characteristics affect the behavior of seismic waves, which ultimately influence the PGA values in the area.

According to the BMKG Earthquake Intensity Scale (SIG) classification [11], the study location falls within Intensity Categories I (< 2.9 gal) and II (2.9–88 gal). Category I indicates that the earthquake is generally not felt or only felt by a few people, although it is recorded by instruments. Category II shows that the earthquake is felt by many people but does not cause damage. In this category, light hanging objects may sway, and window glass may vibrate. This suggests that the study area is relatively safe from earthquake risks. However, attention should still be given to areas with moderate PGA values to ensure risk mitigation measures, such as strengthening building structures and implementing earthquake risk-based planning, to reduce the impact of future earthquakes."

CONCLUSION

The maximum ground acceleration values in the IKN development area, based on earthquake data from 2022 in Paser Regency and 2018 in Palu City, range from 0.69 to 34.29 gal. The maximum ground acceleration zoning in the study area is divided into two zones: a low zone with acceleration values less than 2.9 gal, and a moderate zone with acceleration values ranging from 2.9 to 34.29 gal.

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