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Research Article

Assessment of Liquefaction Potential Based on Subsurface Characteristics and Seismic Vulnerability Indices in Ampenan District, Mataram City

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Abstract: This research aims to determine the liquefaction potential based on subsurface characteristics and seismic vulnerability values in the Ampenan area of Mataram City, West Nusa Tenggara. The research uses data from groundwater level depth measurements, resistivity geoelectrics, and microtremor data from the PGS Bandung study in 2013 in the Mataram area. The results obtained indicate that the range of well depth values from 20 measurement points is between (0.25 – 1.60) meters from the ground surface, falling into the category of shallow groundwater that is susceptible to liquefaction potential because it can affect the saturation level of the overlying lithology. Micotremor data produces a seismic vulnerability index (K_g) with a value range of 3.41 – 123.91, including danger and disturbance-prone zones. This is related to the type of subsurface lithology at the research site, which consists of sand with a resistivity value of 42 – 300 Ωm, located in a layer structure up to a depth of 9.56 meters, with an average soil layer thickness of 8 meters according to the geoelectric results from 10 measurement lines. The three measured parameters indicate that Ampenan District has the potential to experience liquefaction.

Keywords: Amplification Factor; Dominant Frequency; Shallow Groundwater Surface; Seismic Vulnerability Value.

1. Introduction

Indonesia is an archipelagic country that stretches from Sabang in the west to Merauke in the east [1]. There are 17,000 islands throughout the territory of the Republic of Indonesia recorded as of 2021 [2], where among the tens of thousands of islands, Lombok Island is included in an active seismic zone, making it highly vulnerable and prone to natural disasters such as earthquakes [3]. The earthquake that occurred on Lombok Island in 2018 was the longest in the world, with a total of 585 seismic events recorded from July 29 to August 5, 2018 (more than one month) with the strongest magnitude reaching 7 SR [4]. This condition can cause the island of Lombok to experience liquefaction events from the earthquake. An earthquake with strong vibrations can disrupt the soil structure and cause the soil to lose its strength, especially if it occurs over a long period and with high vibration intensity. This water-saturated soil is likely to experience liquefaction when vibrations reduce the friction between soil particles, causing the soil to turn into a liquid. Liquefaction can pose risks and damage buildings and infrastructure above it [5].

In general, the phenomenon of liquefaction occurs in saturated granular soil layers and soil deposits that receive silicate loads in the form of fine sand, silty sand, and loose sand. Liquefaction generally occurs near rivers, bays, or other bodies of water [6]. The conditions for the occurrence of liquefaction events are as follows: consisting of layers of sand or silt, the soil layer is saturated with water, and the soil layer is loose or non-compacted [7]. Some examples of earthquake cases that triggered liquefaction include the Good Friday earthquake in Alaska in 1964, the Niigata earthquake in Japan in 1964, and the Van Norman earthquake in Southern California in 1971. Meanwhile, one of the liquefaction incidents that occurred in Indonesia was due to the earthquake on May 27, 2006, in the Special Region of Yogyakarta [8]. Another liquefaction event that has also garnered significant attention is the major earthquake with a magnitude of 7.4 SR that occurred in Central Sulawesi Province on September 28, 2018. The earthquake that occurred is known as the Palu earthquake, which claimed approximately 2,045 lives, centered around 26 km north of Donggala and 80 km northwest of the city of Palu, with half of the casualties caused by liquefaction events [9].

The impact caused by an earthquake will be very dangerous if the condition of an area is unknown regarding its vulnerability and the potential that triggers liquefaction. Therefore, to anticipate and mitigate disasters, it is necessary to analyze the liquefaction potential of an area, which in this study was conducted in the Ampenan District. Geologically, Ampenan District is located in the coastal area of Mataram City with alluvial rock formations consisting of gravel, sand, coral clay, and a dominance of sandy soil. Then, topographically, the Ampenan District area from west to east has varying locations and elevations ranging from 0 to 20 meters above sea level. The western region of Ampenan District is a lowland area that falls within the coastal zone. Based on the geological and topographical conditions of the area, the region is likely to trigger liquefaction.

To ensure this, tests were conducted by measuring the depth of the groundwater table, measuring resistivity using the geoelectric method, and using microtremor data to determine soil characteristics based on the dominant frequency value and amplification factor to obtain the seismic vulnerability index. The results of this study are expected to provide a good understanding of the potential for liquefaction in the area, as well as to minimize the impact and losses that may occur in the future.

2. Method

The research was conducted from September 2021 to June 2022 in the Ampenan District, Mataram City, West Nusa Tenggara. The locations of the measurement points are shown in Figure 1.

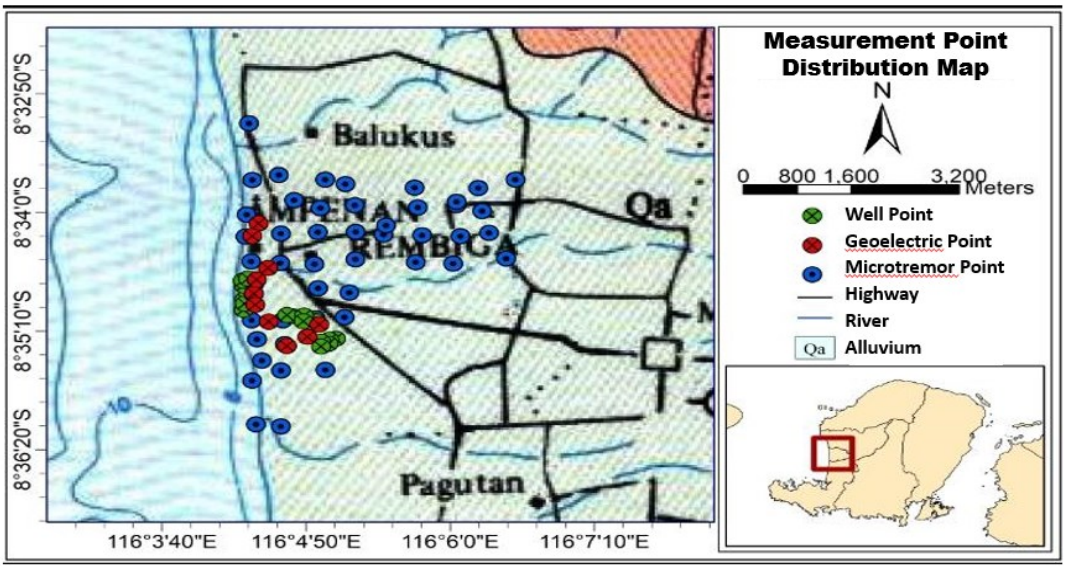

Figure 1. Map of Measurement Point Locations

In this study, the data used are primary and secondary. Primary data is obtained from the measurement of groundwater levels and the measurement of resistivity values in the field. Meanwhile, the secondary data consists of microtremor results from previous research by the Geological Survey Center (PSG) in 2013. The stages of measurement and data collection were carried out as follows:

2.1 Measurement of Groundwater Level Data

The location of the groundwater level measurement point is in South Ampenan Village (Penghulung Agung area), and in the Irigai 4 area of Taman Sari Village. Groundwater level measurements were conducted in residents' dug wells with a total of 20 sample points spread across the Ampenan District.

2.2 Geoelectric Method

The measurement of resistivity values was conducted using the geolistic method of the Wenner configuration with 10 lines measuring 57 - 72 meters in length in the East-West and

North-South directions. This method is carried out by flowing current below the surface through electrodes and measuring the potential difference between two points.

2.3 Microtremor Method

The microtremor data was obtained from research conducted by PSG Bandung in 2013. The data obtained consists of 49 measurement points in the form of 3-component digital signals (north-south, east-west, and vertical components). This data was collected through a field microtremor survey. The recording duration is approximately 15-30 minutes.

3. Measurement Result Data

The results of the groundwater level and resistivity measurements were adjusted according to the microtremor results measured by PSG to determine the liquefaction potential in the Ampenan district. The results obtained are as follows:

3.1 Results of Groundwater level Measurements

The measurement data shows that the research location is an area with shallow groundwater distribution, ranging from a depth of 0.25 to 1.6 meters (Figure 2). This indicates vulnerability to the potential occurrence of liquefaction because it can affect the saturation level of the overlying lithology.

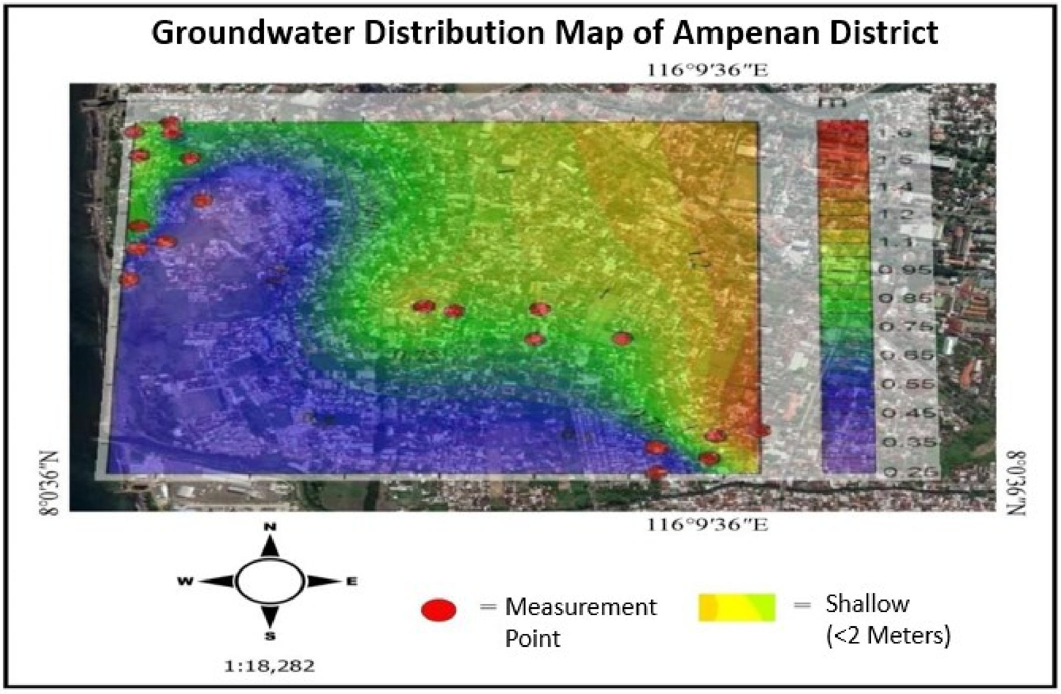

Figure 2. Groundwater Level Contour Map

3.2 Results of the Resistivity Geoelectric Measurement

Based on the results of the geoelectric measurements that have been conducted, 2D cross-sectional results for each line have been obtained as shown in Figure 3. The 2D cross-section results are adjusted to the geological data of the research area with an alluvial formation (Qa), where the formation consists of gravel, pebbles, coral, clay, sand, and silt with a dominant sandy soil condition. The resistivity values obtained from the 2D cross-section can illustrate the subsurface lithology to determine the presence of sand along each traverse. The presence of sand below the surface can then be used as a basis for analyzing the potential occurrence of liquefaction in the area. The depth of the subsurface structure obtained at each traverse is 9.56 meters from the ground surface. On lines 1 to 10 (except line 6), the sand layer is indicated by yellow color images, with resistivity values ranging from (42–300) Ωm (Table 1). Meanwhile, for line 6, the interpretation results in figure 3f show the presence of a clayey sand layer beneath the surface, with a green-colored layer having a resistivity value of (13-33) Ωm located at a depth of 1-9 meters.

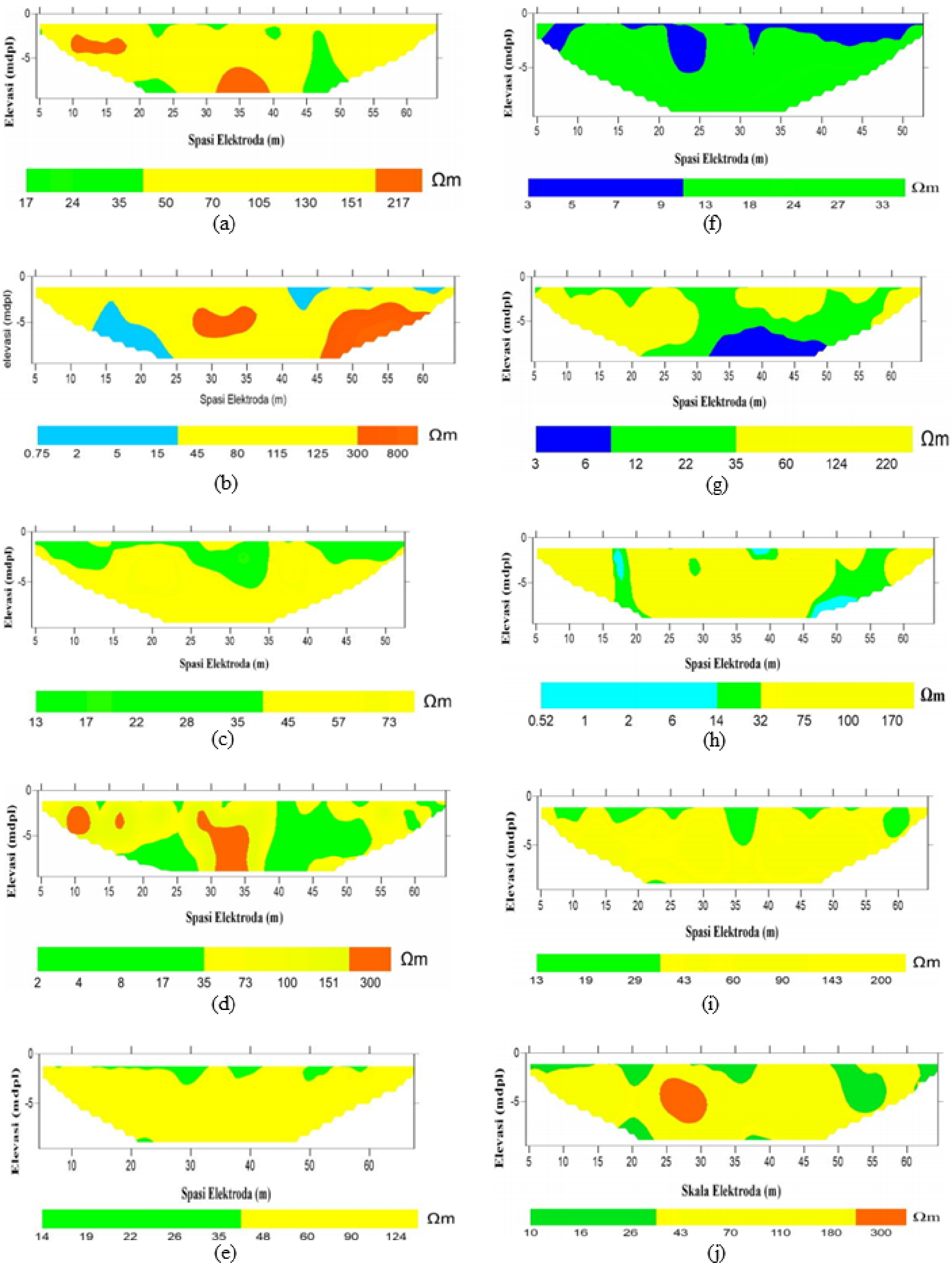

Figure 3. Cross-section of measurement results: (a) line 1, (b) line 2, (c) line 3, (d) line 4, (e) line 5, (f) line 6, (g) line 7, (h) line 8, (i) line 9, and (j) line 10.

Table 1. Position and Resistivity Values of Measurement Line

Line	Position (X, Y)		length of the line (m)	Resistivity Value (Ωm)
	Start	Finish		
1	398293,318; 9051911,817	398288,394; 9051918,367	69	50 – 151
2	399031,326; 9050843,518	399034,144; 9050930,473	69	45 - 300
3	398293,318; 9051911,817	398288,394; 9051918,367	57	45 – 73
4	397971,645; 9051450,599	398010,122; 9051438,412	69	35 - 151
5	398241,855; 9051248,358	398832,771; 9051063,858	72	48 - 124
6	397950,689; 9051617,849	398010,67; 9051623,822	57	13 - 33
7	398051,14; 9052728,944	398058,058; 9052782,737	69	35 - 220
8	398020,464; 9052428,023	398030,845; 9052499,787	69	32 - 170
9	398552,066; 9052459,978	398571,614; 9050540,154	69	43 - 200
10	398848,881; 9050700,015	398854,755; 9050774,073	69	43 - 180

3.3 Microtremor

Microtremor data were analyzed using the HVSR (Horizontal to Vertical Spectra Ratio) method. The results obtained are shown in Figure 4, which consists of a horizontal-to-vertical (H/V) spectral ratio graph to represent the dominant frequency value (f_0) and the amplification factor (A_0). The comparison of f_0 and A_0 can be used to obtain the seismic vulnerability value (K_g).

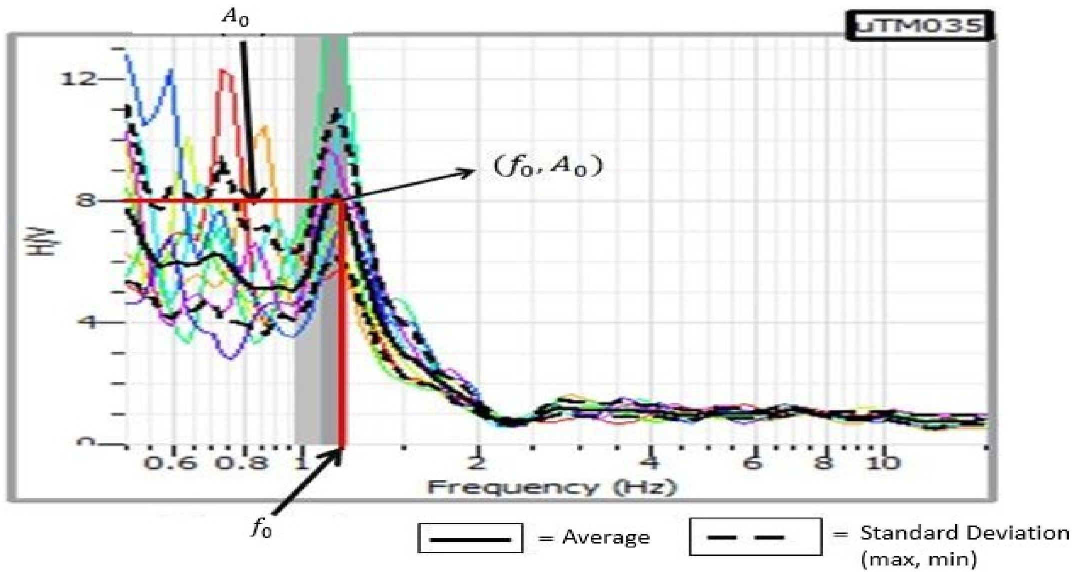

Figure 4. H/V Curve.

The analysis results of the H/V curve from 49 microtremor data show that the f_0 value is relatively uniform ranging from (0.57 - 2.44) Hz. The value of A_0 in the range is between 2.3 and 8.74. The results were then presented in the form of contour maps of the distribution of f_0 and A_0 as shown in Figure 5.

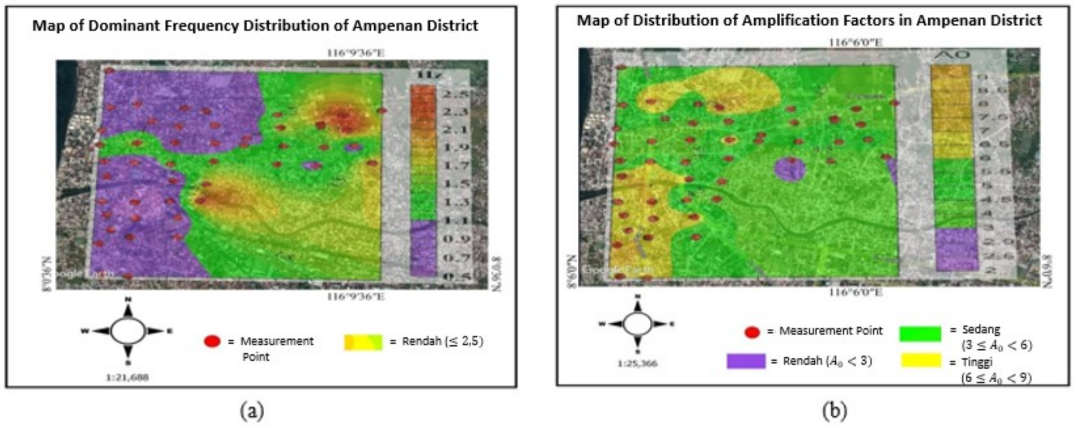

Figure 5. Contour map of distribution values (a) dominant frequency and (b) amplification factor

Based on the contour map results obtained, it is known that the distribution f_0 in Ampenan District is dominated by f_0 < 2.5, meaning this area falls within a geological condition of sedimentary rocks with f_0 values classified as type 2, subtype 4 [10 and 11], indicating a sediment thickness of more than 30 m, including alluvial rocks formed from delta sedimentation, topsoil, mud, etc. Meanwhile, the contour map results for A_0 the research area consist of 3 amplification factor zones based on the classification according to [12], dominated by green color on the contour map with a value $3 \leq A_0 < 6$ (A_0 medium), ranging from 3.05 to 5.76, indicating a less dense geological unit. Then the value $6 \leq A_0 < 9$ (A_0 high) has a range of 6.16 - 8.74, indicating a soft geological unit (yellow), and a small portion with a value A_0 <3 (A_0 low) has a range of 2.29 - 2.94, indicating that the area is a dense geological unit (purple on the contour map).

The seismic vulnerability index value (K_g) ranges from 3.41 to 123.91. The calculation K_g is obtained from the comparison between the square A_0 and f_0 [13, 14]. The value K_g indicates the level of damage in an area, presented in the form of a contour map of index K_g distribution in the Ampenan District area (Figure 6).

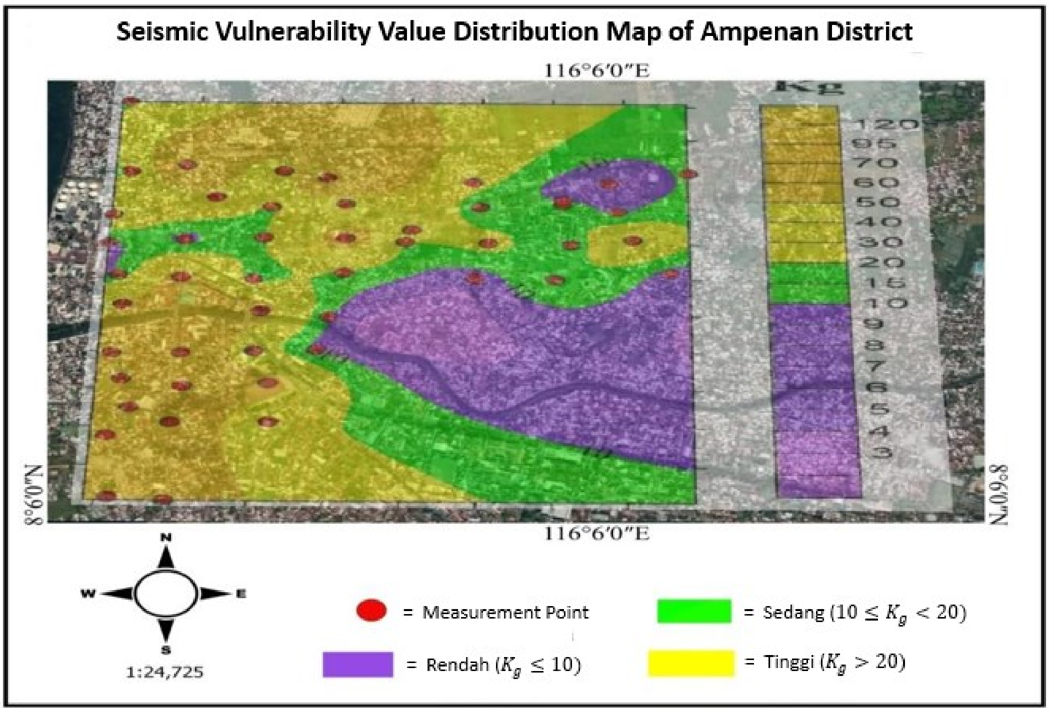

Figure 6. Map of Seismic Vulnerability Index Distribution

The results of the index contour map interpretation indicate that the research area consists of 3 zones according to the classification [7]. Zone 1 K_g< 10 (K_g lowest) has a value range of 3.41 - 9.69 (purple), indicating a safe area, located to the east of Ampenan, namely the Pajarakan Karya Village, North Ampenan Subdistrict (Jempong District), and Pejeruk Village. Zone 2 with 10<K_g<20 (K_g medium) has a value range of 11.15 - 19.41 (green), indicating areas that are prone to disasters and damage, spread across Ampenan Tengah Subdistrict (East Melayu Neighborhood, East Sukaraja Neighborhood), several points in Pajarakan Karya Subdistrict and North Ampenan Subdistrict. Zone 3 with K_g>20 (K_g high) ranges from 20.57 to 123.91 (orange), indicating areas that are very vulnerable to disasters and severe damage. This zone is spread from the western Ampenan (Bintaro Village, Bugis Village, and Telaga Emas Village), northern Ampenan (Batu Raja Village, Daya Paken Village), southern Ampenan (Banjar Village and Karang Panas Village), and central Ampenan (Sukaraja Barat Village).

The results of the analysis and interpretation of the three measurement parameters are interrelated because the positions of the measurement points are close to each other. The groundwater level measurement lines are close to the geoelectric measurement locations on lines 1, 2, 3, 4, 5, 6, 9, and 10, with groundwater depth values in the research area falling into the shallow category and composed of sandy lithology with a thickness of 8 meters. If the groundwater table is at a shallow depth in an area with a sand layer, then groundwater will more easily enter and fill the pores of the sand layer, making the sand layer more water-saturated.

The level of seismic vulnerability is determined by the condition of the lithological unit, one of the factors that can influence K_g is the characteristics of the sediment. The geoelectric measurement lines that are close to the microtremor measurements, namely lines 1, 3, 4, 5, and 6, are located in the Southern Ampenan sub-district, while lines 7 and 8 are in the Bintaro sub-district. The obtained K_g value can represent the level of damage caused by the earthquake disaster. If the value of A_0 is higher (low rock density) and f_0 is lower (thick sediment), then the value of K_g obtained is large. The greater the value of

K_g produced, the more severe the impact or damage caused, and vice versa. The research location dominate by high K_g indicates that the research location has low subsurface structural stability when there is a disturbance such as an earthquake. This K_g value is related to the type of subsurface lithology measured at the research location, which consists of sand.

3.4 Analysis of Liquefaction Potential

Based on the groundwater table depth data from the research location, it is known that the groundwater table falls into the shallow category, which is < 2 meters from the ground surface. This is consistent with the research conducted by [15] and [16], where the groundwater table depth values that have the liquefaction potential are at a depth of 1.56 - 2.05 meters.

Analysis of the 2D cross-section interpretation from all lines reveals that the type of lithology in the subsurface structure of the research area is sand, with resistivity values ranging from (42-300) Ωm. This is consistent with the research conducted [17], where based on that study, the subsurface lithology of the research area consists of alluvial lithology in the form of sand, gravel, and conglomerate with resistivity values ranging from (100-585) Ωm. The same research was also conducted [18], and it was found that the lithology of the research area is dominated by saturated sand/gravel, with resistivity values ranging from 39.16 to 97.9 Ωm. Therefore, based on the subsurface structure composed of loose and unconsolidated sand lithology, the research area has liquefaction potential.

The results of the K_g analysis indicate that the research area has the liquefaction potential. This is based on the high K_g values ranging from 20.57 to 123.91, spread across the western, southern, northern, and central parts of Ampenan. The results of this study are also consistent with the research conducted by [19], where the K_g values obtained from the study ranged from 109 to 554, indicating that the area is prone to experiencing severe damage. Then another study, conducted by [20], obtained seismic vulnerability values ranging from 20 to 100 (K_g high), indicating that the area falls into a danger zone for liquefaction. The analysis results of the three parameters above, namely groundwater level, subsurface lithology type, and the K_g value, indicate that the research area has the potential to experience liquefaction.

6. Conclusions

Based on the groundwater depth data in the research area, which falls into the category of shallow groundwater zones, i.e., < 2 meters from the ground surface, and the type of subsurface lithology in the research area consisting of water-saturated sand layers with resistivity values ranging from (42-300) Ωm, and the K_g value of the research area ranging from 20.57-123.91 (dominated by high K_g), it can be concluded based on these three parameters that the research areas in the western, southern, and northern parts of Ampenan have the potential to experience liquefaction.

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