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Microzoning of Hazard Vulnerable Using Microseismic Method with HVSR (Horizontal to Vertical Spectral Ratio) Analysis in Bayat District, Klaten, Indonesia

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Abstract

The Yogyakarta earthquake in 2006 caused damage in several areas, especially in the area of Klaten Regency. As a result, many infrastructures, houses, health facilities and casualties have been damaged. The research was conducted with the target of knowing the level of earth's hazard by microzoning soil vulnerability areas in the Bayat District, Klaten, Central Java. This study used the microseismic method with the HVSR (Horizontal to Vertical Spectral Ratio) analysis method. Where are the natural/dominant frequency parameters, natural amplification, and earthquake vulnerability index as measured parameters? This study aims to carry out microzonation of disaster vulnerability risks which are interpreted from the results obtained, namely amplification maps (A_0), dominant frequency (f_0), earthquake vulnerability (Kg), and shear wave velocity maps at a depth of 30 meters (Vs_{30}). Data acquisition was carried out at 19 measurement points with a spacing between points having a distance of 1-2 km using a portable TDS seismograph. The acquisition results obtained varied values with A_0 values 0.9 – 8.8, f_0 values 1.0 – 13.8 Hz, Kg values 0.4 – 38.5, and Vs_{30} values 228.1 – 1635.4 m/s. From these results it can be categorized as zoning regarding the value of the level of disaster vulnerability based on the value of earthquake vulnerability (Kg) obtained to minimize damage and casualties.

Introduction

Indonesia is an island that has a high level of seismicity. This is because Indonesia is located in the Pacific Circumference which is the meeting point of three tectonic plates, namely the Eurasian plate in the north, the Pacific plate in the east and the Indo-Australian plate in the south [1]. Indonesia is the meeting point between three major plates namely India-Australia, Eurasia, and Pacific. The relative movement of these three plates results in collisions between the plates that form subduction zones in several places, such as on the West coast of Sumatra Island, the South coast of Java, and several areas in Eastern Indonesia [2].

On 27 May 2006, an earthquake measuring 6.3 on the Richter scale with a depth of 17 km below the ground shook the Special Region of Yogyakarta and Central Java. As a result of the earthquake, more than 5800 people died, 37,000 people were injured, 84,000 houses were flattened, and more than 200,000 houses suffered minor, moderate, or severe damage. The sub-districts of Imogiri, Jetis, Pleret and Piyungan and the sub-districts of Wedi, Gantiwarno, and Bambanglipuro suffered the most severe damage [3]and [4].

Based on geological conditions, the Klaten Regency area is dominated by alluvial deposits and volcanic deposits of Mount Merapi, which are generally in the form of clays, gravel sand, gravel, and frozen boulders. As a result of the 2006 Yogyakarta Earthquake, 1,045 people died and 18,127 were injured in Klaten Regency, while 32,277 houses were severely damaged, 63,165 houses were slightly damaged, 298 educational facilities and 111 health facilities were damaged. In addition, there are several indications of active faults around the research location of Bayat Subdistrict, Klaten [5]. Mitigation efforts need to be done in order to reduce and minimise damage and the number of victims, one way to do this is to conduct soil vulnerability mapping using microseismic geophysical methods.

Microseismic is a geophysical method to characterize the vulnerability of overburden layers to deformation during earthquakes [6]. Soil vulnerability can be used to predict weak zones during earthquakes [7] and [8], and fractures due to earthquakes [9]. Earthquake vulnerability and landslide potential calculated based on natural frequency and rock amplification values. so that the value of earthquake vulnerability, peak ground acceleration and thickness of weathered layer can be calculated. The microseismic measurement results obtained are used to estimate soil characteristics so that it can be used to see its influence on the condition of the soil layer and local geological conditions. The characteristics of the soil layer greatly affect the vulnerability index and ground acceleration in a specific area.

The HVSR (Horizontal to Vertical Spectral Ratio) method is a microseismic survey approach used to estimate the amplification value and natural frequency value of a place that can be estimated through the peak period of the H/V microseismic comparison [10]. The sediment thickness of the Klaten area (h) ranges from (5.105 - 113.648) meters. The area with relatively high thickness is in part of the Klaten area. Areas of relatively high thickness are found in parts of the Wedi District with a thickness of up to 110.0 meters. Areas of average thickness (60.0 – 90.0) meters are located in the Gantiwarno sub-district, Prambanan sub-district, and the southern part of Jogonalan sub-district. In the Bayat sub-district a low thickness (5.0 to 30.0) meters are located in the hills and mountains of the Paseban area and the tomb of Sunan Pandanaran. From this it is known that the areas of great thickness of sediment, namely in Wedi sub-district, will have a high level of earthquake vulnerability [11].

The purpose of microseismic research in the Bayat Subdistrict is to determine the distribution of A_0, f_0, Kg, and Vs_{30} maps for hazard analysis. In addition, to know the condition of the soil with the level of disaster vulnerability to earthquakes that occur.

Location and Geology of Research Area

A total of 19 measurement data points were taken in the Bayat, Wedi, Cawas, Kalikotes, South Klaten, and Trucuk sub-districts (Figure 1). The data used is secondary data obtained from BMKG Geophysical Station Yogyakarta.

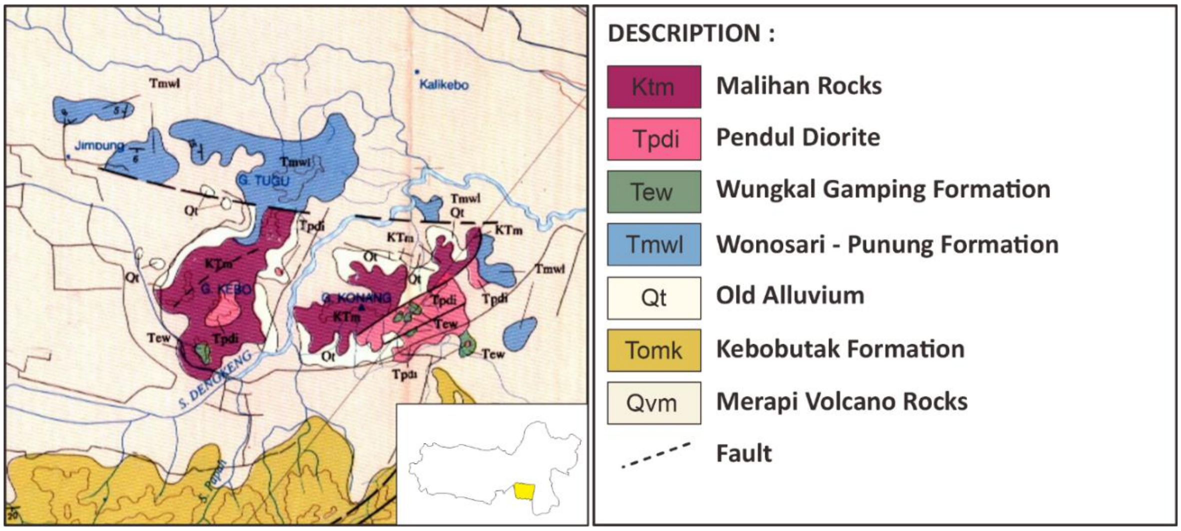

Figure 1. Geological Map of Surakarta-Giritontro Sheet [12]

The geological condition of the research location is in the Wonosari - Punung formation which has lithologies such as limestone, tuffaceous sandstone. Then the formation of malihan rock which is composed of lithology of schist, alabaster, malih volcanic rock, batusabak. Furthermore, the Pendul diorite formation is composed of diorite. Then in the form of Merapi volcanic rocks which are composed of volcanic breccia lava and tuff. Then the old Aluvium which is composed of conglomerate, sandstone, silt and clay [12].

Methods

Microseismic is a geophysical method to characterize the vulnerability of overburden layers to deformation during earthquakes [6]. Soil vulnerability can be used to predict weak zones during earthquakes [7] and [8], and fractures due to earthquakes [9].

The acquisition was carried out with a total of 19 measurement points spread over a distance of (1.0 - 2.0) kilometres. The instrument used in the measurement was a TDS 303 seismograph. The determination of points in this study was based on the impact of earthquake damage that was quite severe in this area, because on the geological map the research location has a rock lithology that tends to be compact.

Field data were processed using geopsy software as shown in Figure 3 then data quality control was carried out by calculating the value of clear peak requirements based on the reliability requirements of the SESAME Europian Research Project on the HVSR curve obtained.

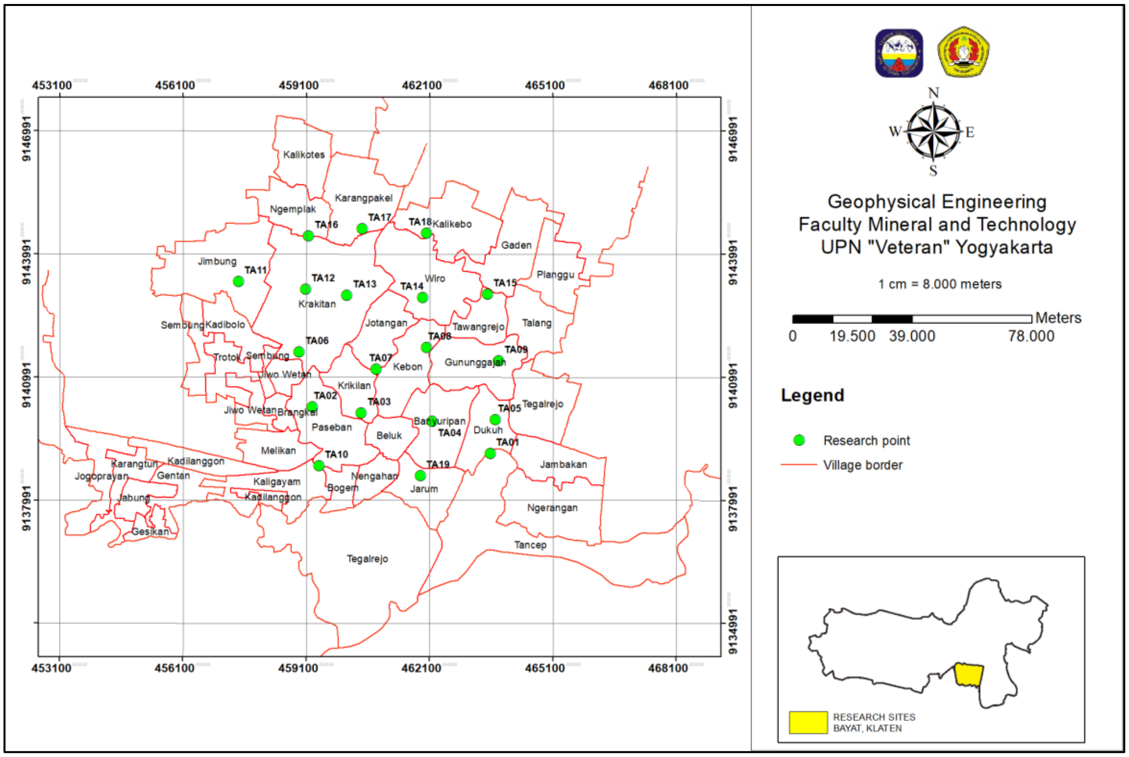

Figure 2. Research Plan Map

Horizontal to Vertical Spectral Ratio (HVSR)

The HVSR analysis method approach used to estimate the amplification value and natural frequency value of a place that can be estimated through the peak period of the H/V microseismic comparison [10]. HVSR is a method based on the assumption that the ratio of horizontal and vertical spectra of surface vibration is a function of displacement. It also shows that the dynamic characteristics of the surface layer can be roughly understood at the observed point if the microseismic waveform observations are made on three components, namely two horizontal components and one vertical component [10]. An observation that station recordings on hard rock can be assumed to be bedrock, the maximum value of the horizontal to vertical component spectrum ratio is close to 1 [13], shown in equation (1) :

$$\frac{S_{HB}}{S_{VB}} \approx 1 \qquad (1)$$

Where S_{HB} is the spectrum of horizontal motion at the base of the soil layer and S_{VB} is the spectrum of vertical motion in the rock mass.

Because the spectral ratio of the horizontal to vertical components of bedrock is close to 1 the Rayleigh wave effect removes surface disturbances leaving only local geologic structures and terrain effects (T_{SITE}). T_{SITE} shows the amplification peak at the fundamental frequency of a location [14]. Based on equation (1), the amount of T_{SITE} is obtained as:

$$T_{SITE} = HVSR = \frac{S_{HS}}{S_{VS}} \quad (2)$$

Where T_{SITE} is the Site Effect, S_{HS} is the spectrum of horizontal motion components at ground level and S_{VS} is the spectrum of vertical motion components at ground level [14].

Frequency Natural

Frequency natural means the basic frequency of a place in transmitting vibrations or waves, in this case vibrations that propagate in the local geology (Jaya & Sungkono, 2013). The lower the natural frequency value and the higher the amplification value, the greater the soil vulnerability value. It can be seen in Table 1 soil classification based on the dominant frequency value.

Table 1. Microseismic soil classification table based on natural frequency value [15]

Soil Classification	Frequency Dominant (Hz)	Kanai Classification	Description
Type I	6,7 - 20,0	Tertiary or older rocks. It consists of hard sandstone, gravel etc.	Surface sediments are very thin in thickness and dominated by hard rock.
Type II	4,0 - 6.7	Alluvial rock with a thickness of 5,0 cm. Includes sand gravel sand hard clay and more.	The thickness of its surface sediments ranges from 5,0 to 10,0 m.
Type III	2,5 – 4,0	Alluvial rocks with a thickness > 5,0 cm. It consists of sandy pebbles, hard clay sandy, clay, etc.	Its thickness of surface sediments falls into the medium category of 10-20 metres
Type IV	< 2.5	Sedimentary rocks are formed by alluvial mud from the deposition of deltas etc. at a depth of 30 meters or more.	The thickness of surface sediments is very thick.

Earthquake Vulnerability Index

Ground or site amplification is the response of rock layers, in this case the surface layer to seismic waves. Amplification describes the amount of gain a wave receives as it travels through a given medium. The amplification of a wave when travelling through a medium is directly proportional to the ratio of the horizontal spectral to the vertical spectral. The Soil Vulnerability Index (Kg) determines the level of weakness of the soil layer subject to deformation due to earthquake using equation (3) [16] and [17]:

$$Kg = \frac{{A_0}^2}{f_0} \quad (3)$$

Where Kg is Earthquake vulnerability, A_0 is Amplification and f_0 is the frequency natural (Hz).

Shear Wave Velocity

Soil dynamic characteristics such as estimating Vs values for multi-dimensional depths are conventionally used by borehole geophysical methods for seismic microzonation [18]. The estimation of Vs values and the estimation of damage distribution due to earthquakes can be used for earthquake mitigation and the determination of earthquake-resistant building standards.

The National Earthquake Hazard Reduction Program (NEHRP) indicates that layers have shear wave velocities that classify 5 (five) soil classes, namely hard rocks, rocks, soft rocks, hard soils, medium soils and soft soils are shown in table 2.

Table 2. Soil classification based on Vs_{30} value [19]

Soil Class	Description	Vs (m/s)
SA	Hard Rocks	>1500
SB	Rocks	750 – 1500
SC	Hard Soils and Soft Rocks	350 – 750
SD	Medium Soil	175 – 350
SE	Soft Soil	<175

Processing of data

The data are synthetic data obtained from BMKG geophysical station class I Sleman Yogyakarta. This is then processed using Geopsy software to average the Horizontal Vertical Spectral Ratio (HVSR) curve. On the HVSR curve there is the value of the A0 and f0 components, after which the value is entered into Microsoft excel and then calculations are carried out to obtain the Kg (Earthquake Vulnerability) value..

Then to get the value of Vs30 using the HVSR curve Dinver software that entered the parameter value. After that, the Vs value of each point that has a depth is obtained and picking at a depth of 30 meters. Then in making maps of A0, f0, Kg, and Vs30 using ArcGis software.

Maps are created using Inverse Distance Weighting (IDW) interpolation because it is good in conditions where points tend to be many and close together. Furthermore, data interpretation is carried out with reference to the geological conditions of the research location.

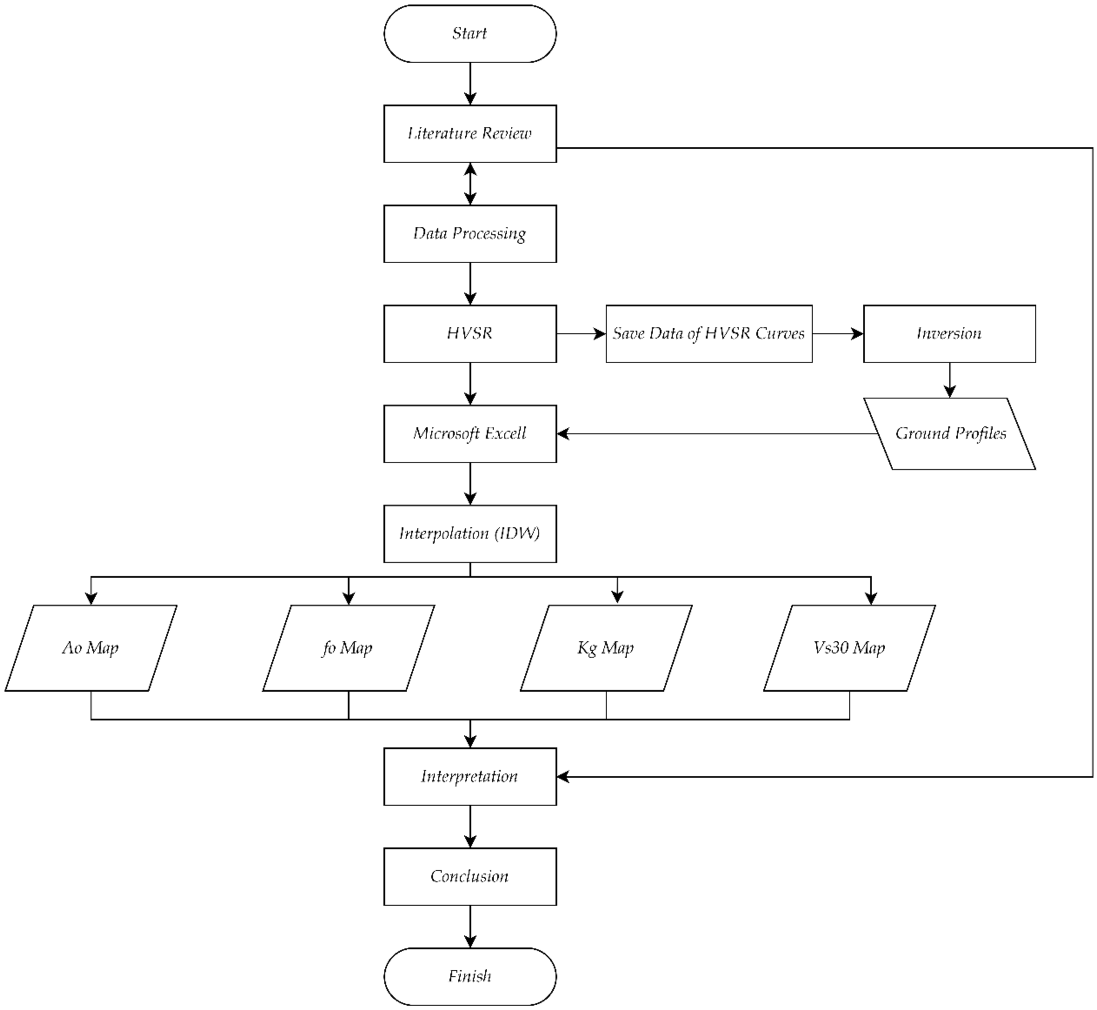

Figure 3. Research Flowchart

Result and Discussion

Figure 4 is a map of the distribution of A_0 values at the survey sites in Bayt sub-district, Klaten. In Figure 4, there is a variation in soil amplification values as indicated by the different colours on the map. The lowest value in Figure 2 is 0.9, and the largest value is 8.8.

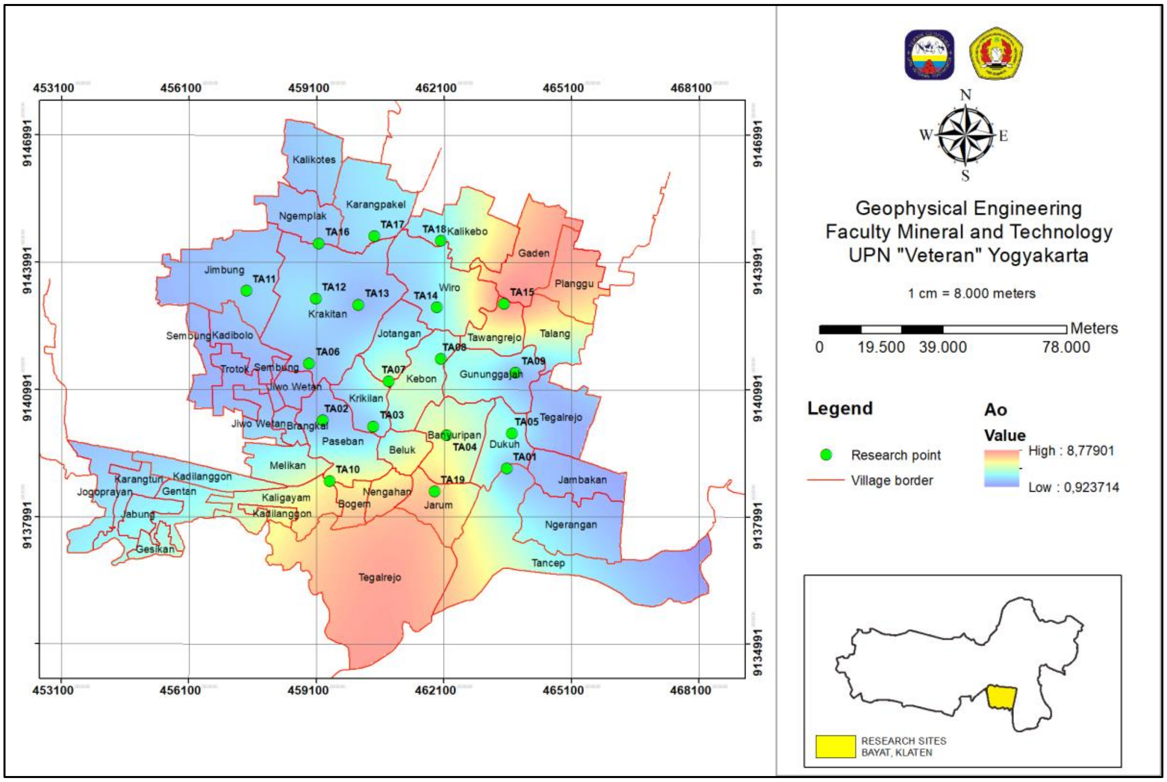

Figure 4. Distribution Map of Measurement Point Distribution and A_0 Value Distribution Bayat, Klaten, Central Java

In the map can be done microzonation that some areas have low and high amplification values as in table 3 classification according to [20].

Table 3 Amplification Value Classification [20]

Classification	Description	Regional Coverage
< 3.0	Low	Gununggajah, Dukuh, Sembung tegalrejo, Krakitan, Jimbung, Krikilan
$3.0 < A_0 < 6.0$	Medium	Banyuripan, Kebon, Jotangan, Wiro, Beluk,
6.0 <	High	Tawangrejo, Gaden, Jarum, Nengahan

The amplification value has several classifications, namely the low amplification level (< 3.0) covering the villages of Gununggajah, Dukuh, Sembung Tegalrejo, Krakitan, Jimbung, Krikilan this correlates with the geological conditions at the location of the point is in metamorphic rocks. Then the area with a medium amplification value ($3.0 < A_0 < 6.0$) includes the villages of Banyuripan, Kebon, Jotangan, Wiro, Beluk, while there is a zone with a high amplification value ($6.0 < A_0 < 8.8$) which includes Tawang Rejo village, Gaden village, Jarum village, Nengahan village which indicates that the subsurface layer tends to be a soft layer which is supported by its geological condition which is in the Merapi volcano rock layer.

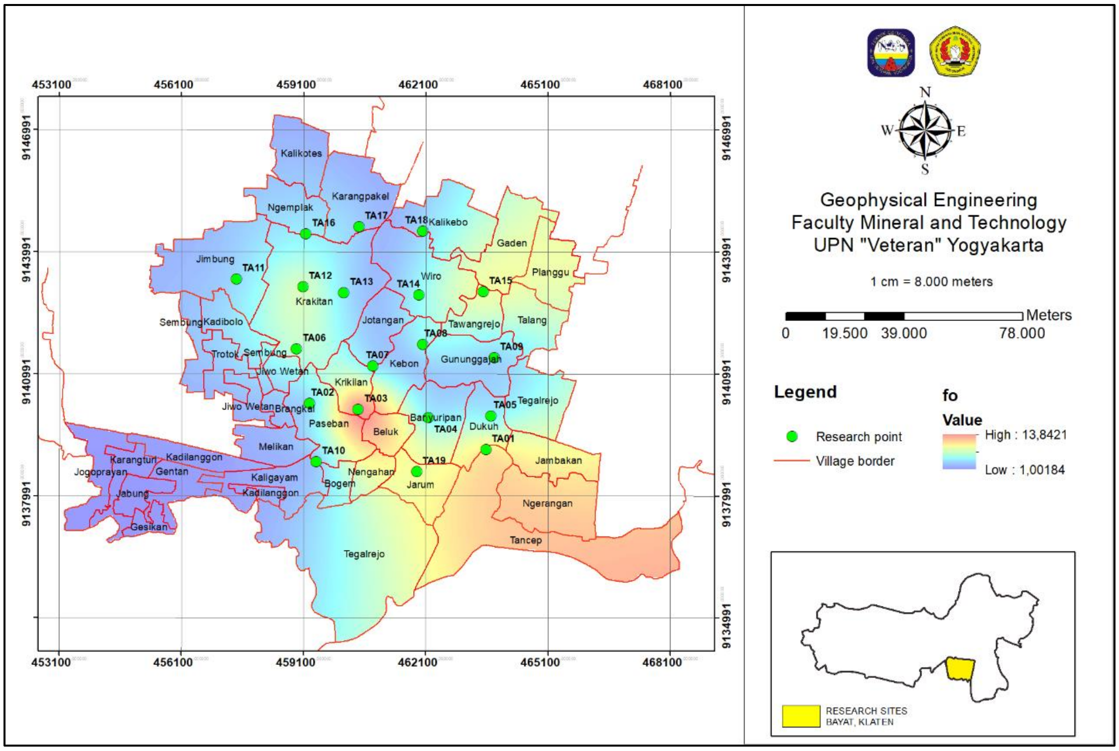

Figure 5. Distribution of Measurement Points and Distribution of f_0Values Bayat, Klaten, Central Java

Figure 5 is a distribution map of the dominant frequency value of research in the Bayat sub-district, Klaten. It can be observed that the distribution value above has a numerical variation from 1.0 Hz to 13.8 Hz. It can be observed that the dominance of the frequency value tends to be low, wich can be done add by zoning with type I with Kanai classification according to Arifin, which is in the following table.

Table 4. Kanai's f_0 classification [15]

Classification	Description	Regional Coverage
Type I	(6,7 – 20.0) Hz	Nengahan, Banyuripan, Tawangrejo, Gaden, Kalikebo, Dukuh, Jarum, Tancep, dan Krakitan
Type II	(4.0 - 6,7) Hz	Gunung gajah, Kebon, Jotangan, Jiwo wetan, Brangkal, dan Paseban.
Type III	(2.5 – 4.0) Hz	Tawangrejo, Gaden, Jarum, Nengahan
Type IV	(< 2.5) Hz	Melikan

In the value range of (6.7 - 20.0) Hz, there are Krikilan, Beluk, Nengahan, Banyuripan, Tawangrejo, Gaden, Kalikebo, Dukuh, Jarum, Tancep, and Krakitan villages. The type I level shows that the frequency value tends to be high, it is indicated that the thickness of the sedimentary surface layer tends to be thin and dominated by hard rock, this is reinforced by geological data that in the research location there are metamorphic rocks. Then the type II zone with a value range of (4.0 - 6.7) Hz includes the villages of Gunung Gajah, Kebon, Jotangan, Jiwo Wetan, Brangkal, and Paseban. which can be interpreted that the indication of the thickness of the sedimentary surface layer tends to be medium around (5 – 10) meters. The zone type III with a value of (2.5 – 4.0) Hz includes the villages of Banyuripan, Wiro, and Karangpekel, which indicates that the thickness of the surface sediment layer tends to be (10 –

20) meters thick. Then in zone type IV with a value of < 2.5 Hz which includes Melikan village has a dominant distribution. This is an indication that the sediment thickness at the research location is very thick.

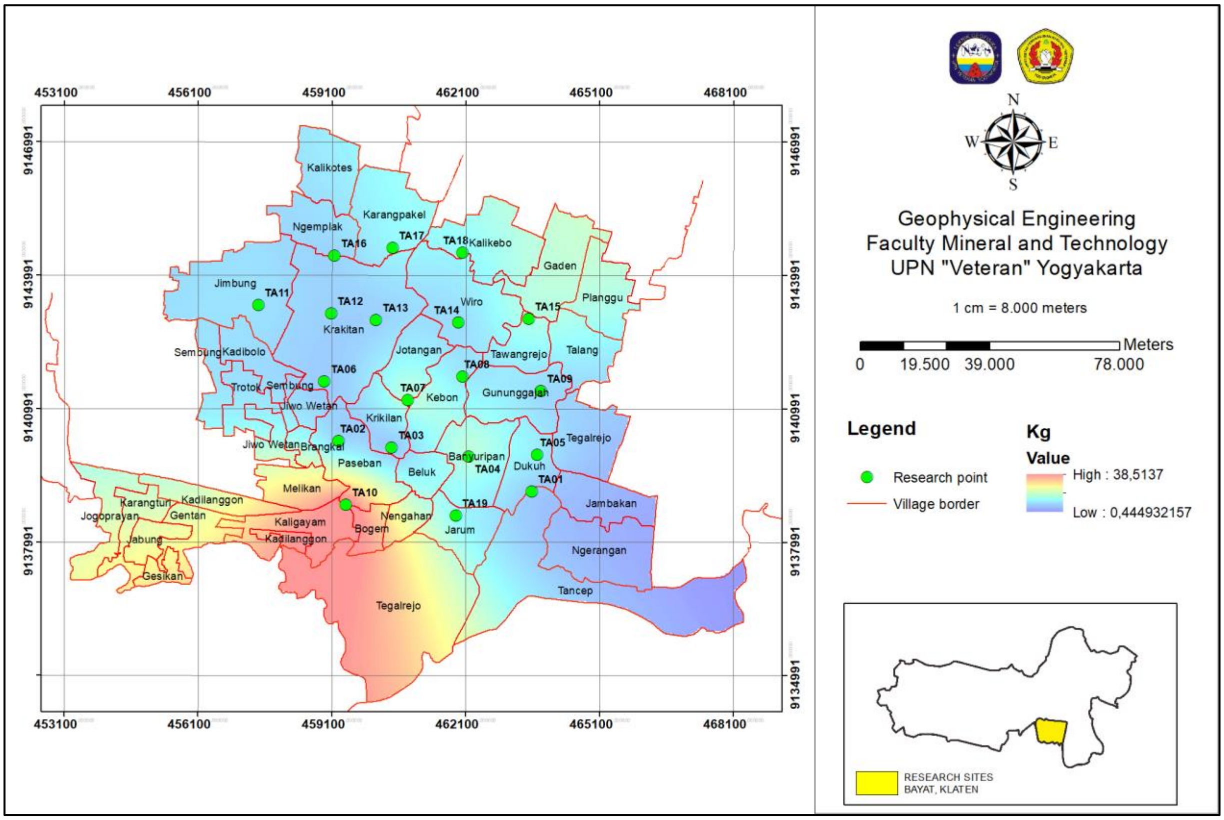

Figure 6. Measurement Point Distribution Map and Value Distribution of Kg Bayat, Klaten, Central Java

Figure 6 is a map of the distribution of earthquake vulnerability values at the Bayat sub-district research site. The map has a range of values varying from 0.4 to 38.5, the earthquake vulnerability map shows potential/vulnerable areas affected by shaking. Looking at the microzonation of the area, there are two main zones, namely zone I with high earthquake vulnerability, which includes the villages of Melikan, Jiwo Wetan, Brangkal, Paseban, Kadilanggon, Kebon, Banyuripan, Tawangrejo, and Kaligayam. Indicating a zone with a high earthquake vulnerability value, indicates that the zone has the greatest level of earthquake vulnerability, which has the potential for greater shaking due to the soft sediment layer. Zone II includes the villages of Sembung, Krakitan, Wiro, Dukuh, and Jimbung. Zone II is a zone with a low level of vulnerability, indicating that the zone has a lower level of shaking because the low Kg value can indicate that the surface layer tends to be more compact.

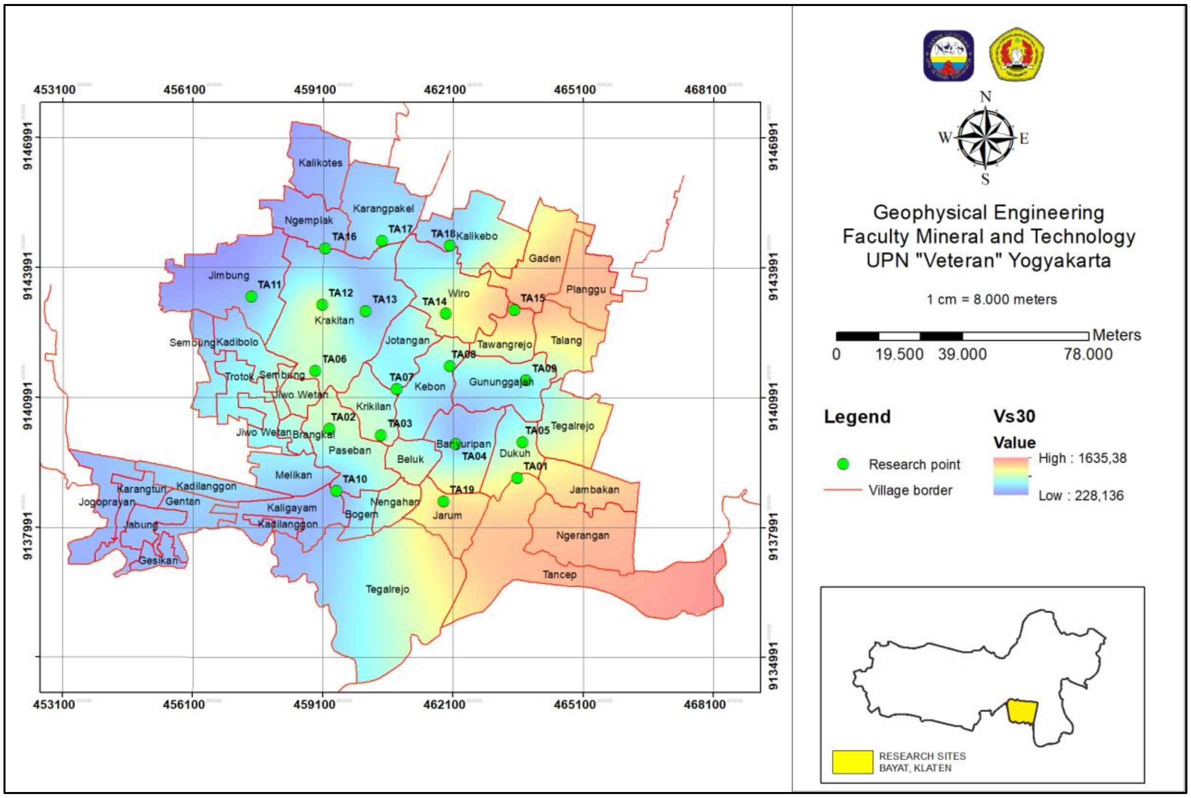

Figure 7. Distribution Map of Measuring Point Distribution and Vs_{30} Value Distribution Bayat, Klaten, Central Java

Figure 7 is a map of the distribution value of Vs_{30} which has a microzonation that can be divided into 2 zones, namely in the first zone of soil type B about to (750.0 – 1500.0) m/s which is medium rock covering the village areas of Krakitan, Sembung, Jiwo wetan, Krikilan, Dukuh, Tancep, Tawangrejo, and Wiro. which in the condition of the research location is metamorphic rock according to the local geological map. Then in the second zone is soil type C about to (350.0 – 750.0) m/s with soft rock or hard soil which includes Banyuripan, Kebon, Jotangan, Jimbung, Melikan, and Kalikebo villages. In the Vs_{30} distribution map in Figure 5, it can be seen that the distribution of measurement zones is dominated by soil type C, which is a zone of soft rock and hard soil. This is an indication that the research location has sedimentary layers that tend to be varied about to (20 – 50) meters.

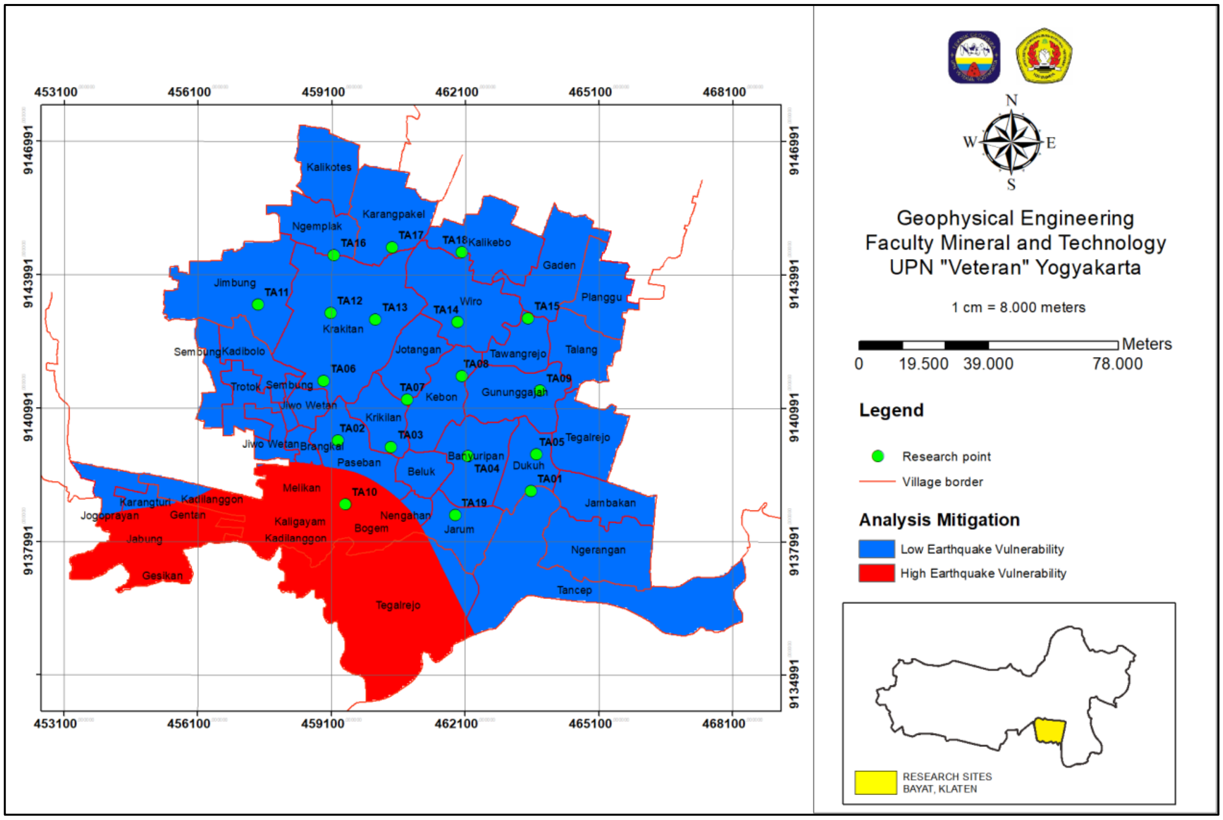

Figure 8. Hazard Analysis Earthquake Vulnerability

Figure 8 is the result of hazard analysis earthquake vulnerability from the distribution of Kg values. This value is a reference that the level of soil vulnerability due to vibration, so that blue-coloured areas have a low level of earthquake vulnerability. This shows that the blue-coloured area has a good level of safety. Then the red-coloured area has a high earthquake vulnerability value. This indicates that the area has a relatively low level of safety.

Conclusion

The level of earthquake vulnerability of the Bayat, Klaten area based on component analysis, namely the value of A_0, f_0, and Vs_{30} indicates the level of thickness and compactness of the rock or subsurface constituent layers. The results of microzonation and earthquake vulnerability analysis of the research area are divided into 2 zones, namely zones I and II. Zone I with high earthquake vulnerability includes the villages of Melikan, Jiwo wetan, Brangkal, Paseban, Kadilanggon, Kebon, Banyuripan, Tawangrejo and Kaligayam. Zone II with low earthquake vulnerability includes the villages of Sembung, Krakitan, Wiro, Dukuh, and Jimbung.

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References

[1] Ibrahim, Gunawan and Subardjo, Pengetahuan Seismologi, Jakarta: Badan Meteorologi dan Geofisika, 2005.

[2] I. Kurniawati, "Analisis Mikrotremor untuk Mikrozonasi Indeks Kerentanan Seismik di Kawasan Jalur Sesar Sungai Oyo Yogyakarta," Skripsi. Program Studi Fisika. Jurusan Pendidikan Fisika. Fakultas MIPA. UNY, Yogyakarta, 2016.

[3] B. G. Luehr, T. Walter, J. Wassermann, R. Wang, D. Wagner, A. Anggraini, S. Parolai, J. Zschau, P. J. Prih Harjadi, Brotopuspito and S. Kirbani, "The Surprising Mw 6,5 Bantul Earthquake 2006," *Geophysical Research Abstrack. Germany : GFZ,* vol. 10, 2008.

[4] D. P. Luthfiana, "Kompas.com," Kompas, 27 Mei 2022. [Online]. Available: https://www.kompas.com/tren/read/2022/05/27/073358965/hari-ini-dalam-sejarah-mengenang-16-tahun-gempa-yogyakarta-27-mei . [Accessed 5 Desember 2022].

[5] BPS Klaten, Buku Putih Sanitasi Klaten, Klaten: Badan Pusat Statistik Kabupaten Klaten, 2010.

[6] Y. Nakamura, "On The H/V Spectrum," in *The 14th World Conference on Earthquake Engineering*, Vancouver, B.C. Canada, 2008.

[7] J. Saita, M. Bautista and Y. Nakamura, "On Relationship Between The Estimated Strong Motion Characteristic of Surface Layer and The Earthquake Damage -Case Study at Intramuros, Metro Manila," in *13th World Conference on Earthquake Engineering*, Vancouver, B.C.Canada, 2004.

[8] E. D. Gurler, Y. Nakamura, J. Saita and T. Sato, "Local Site Effect of Mexico City based on Microtremor Measurement," in *6th International Conference on Seismic Zonation*, Palm Spring Riviera Resort. California, USA, 2000.

[9] Daryono, "Indeks Kerentanan Seismik Berdasarkan Mikrotremor pada Setiap Satuan Bentuklahan di Zona Graben Bantul, Daerah Istimewa Yogyakarta," Disertasi. Program Pascasarjana Fakultas Geografi. Universitas Gadjah Mada, Yogyakarta, 2011.

[10] Y. Nakamura, "A Method for Dynamic Characteristic Estimation of Subsurface using Microtremor on The Ground Surface," *Q.R. of RTRI,* vol. 30, no. 1, pp. 25-33, 1989.

[11] A. M. Arifudin, "Kecepatan Gelombang Geser (Vs) Dan Ketebalan Sedimen," *ISSN,* Vols. 2746-0185, pp. 0853-8557, 2021.

[12] Surono, T. B and S. I, Peta Geologi Lembar Surakarta-Giritontro, Bandung: Pusat Penelitian dan Pengembangan Geologi, 1992.

[13] Y. Nakamura, "Clear Identification of Fundamental Idea of Nakamura's Technique and Its Application," in *The 12nd Word Conference on Earthquake Engineering*, Tokyo, 2000.

[14] S. Slob, Micro Seismic Hazard Analysis, Earthquake Vulnerability and Multi-Hazard Risk Assessment: Geospatial Tools for Rehabilitation and Reconstruction Efforts, The Netherland: ITC, 2007.

[15] S. S. Arifin, B. Mulyanto, Marjiyono and R. Setianegara, "Penentuan Zona Rawan Guncangan Gempa Bumi Berdasarkan Analisis Nilai Amplifikasi HVSR Mikrotremor dan Analisis Periode Dominan Daerah Liwa dan Sekitarnya," *Geofisika Eksplorasi,* vol. 2, no. 1, 2012.

[16] Y. Nakamura, "Seismic Vulnerability Indices for Ground and Structures using Microtremor," in *World Congress on Railway Research*, Florence, 1997.

[17] H. C. Huang and Y. S. Tseng, "Characteristics of soil liquefaction using H/V of microtremorsin Yuan-Lin Area, Taiwan," *TAO,* vol. 13, no. 3, pp. 325-338, 2002.

[18] A. Mufida, B. J. Santosa and D. D. Warnana, "Profiling Kecepatan Gelombang Geser Vs Surabaya Berdasarkan," *Jurnal Sains Dan Seni Pomits,* vol. 2, 2013.

[19] SNI 1726, Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung, Jakarta: BSN, 2019.

[20] Marjiyono, "Estimasi Karakteristik Dinamika Tanah Dari Data Mikrotremor Wilayah Bandung," Thesis ITB, Bandung, 2010.