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Microtremor Microzonation Based on Seismic Vulnerability Index (Kg) Using HVSR (Horizontal To Vertical Spectral Ratio) Method in Kapanewon Berbah, Sleman, D.I.Yogyakarta

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ABSTRACT

The 2006 Bantul Earthquake centered on the Opak River Fault has caused many casualties and damage to buildings, including in Kapanewon Berbah, Sleman. Kapanewon Berbah is the most affected area in Sleman Regency, because it is located in the red zone near the Opak Fault line. This study uses the HVSR (Horizontal to Vertical Spectral Ratio) method which aims to determine the soil conditions in Kapanewon Berbah based on the dominant frequency and dominant period microzonation, as well as to determine the level of damage based on the dominant amplification value and the seismic vulnerability index. The microtremor data measured at 17 points are processed in geopsy software so that the dominant frequency and amplification values are obtained. Furthermore, the calculation is carried out on Microsoft Excel in order to obtain the value of the dominant period and the seismic vulnerability index. The dominant period is inversely proportional to the dominant frequency value, while the seismic vulnerability index value is obtained from squaring the amplification divided by the dominant frequency. These parameters are processed in surfer12 software in order to obtain a microzonation map based on each parameter. Based on the Kapanewon Berbah microzonation map, a low dominant frequency value is obtained in the range 0.65 - 2.02 hz which shows soft soil conditions in the form of thick sediment; high dominant period values in the range 0.88-1.46 s which indicates very soft soil conditions; high amplification values at the range 4.9-6.1 includes a high level of damage; and the high seismic vulnerability index value is in the range 18.9 to 41.5. The most stable location is at the TA4 measurement point in Tegaltirto Village and the most prone location to experience damage is at the TA2 measurement point in Kalitirto Village.

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1. INTRODUCTION

Indonesia is a country located between three tectonic plates, namely the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. The three plates can meet and produce a pile of energy that can reach a certain limit. The accumulation of collision energy will eventually reach a saturation point, resulting in the release of energy in the form of earthquakes, which can cause other disasters such as landslides, liquefaction, and tsunamis. An earthquake is an event where the earth's surface vibrates due to the sudden release of energy from within the earth, which is marked by the cracking of parts of the rock structure in the earth's crust [1]. Based on the cause, earthquakes are divided into 5, namely tectonic, volcanic, collapse, meteor and man-made earthquakes [2]. The vibrations caused by the earthquake then spread in all directions as seismic waves that propagate from the epicenter through the interior to the surface.

One of the earthquakes that had a major impact in Indonesia was the Bantul earthquake, DIY 2006. The earthquake that occurred at approximately 05:55 WIB for 57 seconds with an epicenter at 7.961° LS – 110.446° BT, had a scale of 6.3 Mw (Magnitude Moment) with a depth of 12.5 km and caused a lot of building damage and loss of life [3].

Kapanewon Berbah became the most affected area in Sleman Regency. This is due to the location of Kapanewon Berbah which is on the Opak Fault line and is also in contact with Merapi alluvial rocks. The data on damage due to the 2006 earthquake in Kapanewon Berbah is shown in Table 1.

Figure 1. Research Area Map

Berbah Sub-district is located at coordinates 7°48'21"S and 110°26'33"E with an area of 22.99 km2. Administratively, Berbah Sub-district borders Kalasan Sub-district and Adisucipto Air Force Base to the north, Prambanan Sub-district and Bantul Regency to the east, Piyungan Sub-district, Bantul Regency to the south, and Banguntapan Sub-district to the west. Berbah Sub-district consists of 4 villages, namely: Sendangtirto, Tegaltirto, Kalitirto, and Jogotirto Villages. According to the Central Statistics Agency of Sleman Regency, Berbah Sub-district in Figures 2014 [4], Geographically the natural conditions of Kapanewon Berbah are a fertile lowland area.

Geological conditions in D.I.Yogyakarta generally consist of surface deposits, volcanic rocks, and intrusive rocks. Specifically, regional geological conditions in Kapanewon Berbah are dominated by the Inseparable Volcanic Rock Formation. The bedrock in Kapanewon Berbah is the Semilir Formation which is estimated to be of Late Oligocene-Early Miocene age. The distribution area of the formation is in a small part of Jogotirto Village (east of the research area). The types of rocks in this formation are alternating between tuff-breccia, pumice breccia, dacite tuff and andesite tuff, and tuffaceous mudstone. Then, above the bedrock is deposited the Inseparable Volcanic Rock Formation, which is estimated to be of Quaternary age. The distribution area of the formation is in most of the research area. The types of rocks in this formation are tuff, ash, breccia, agglomerate, and inseparable lava flows.

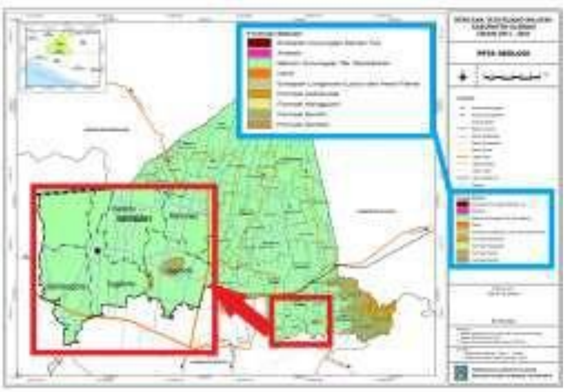

Figure 2. Geological Map of Research Area

This research is expected to be able to map the Kapanewon Berbah area, Sleman which has the potential to have a severe impact due to the earthquake disaster. So that the results of the study can be one of the disaster mitigations to minimize the impacts caused by the earthquake.

2. METHODS

2.1. Theory

2.1.1 Seismic Waves

Seismic waves are waves that propagate in the earth and on the earth's surface. Seismic waves originate from sources of seismic activity such as earthquakes, volcanic eruptions, landslides, and so on. Seismic waves can be briefly explained as consisting of 2 types, namely waves that propagate on the surface (surface waves) and in the interior depths (body waves) [5]. Seismic waves are also known as elastic waves because the vibrations produced by particles in the medium occur due to the interaction between the disturbing force and the elastic force. From this interaction process, longitudinal waves, transverse waves, and various combinations of the two emerge. [6].

2.1.2 Mikrotremor

Microtremor is a very small ground vibration that occurs continuously from various sources of vibration, both in the form of artificial disturbances and natural sources. Microtremor is a vibration that has a short period which is an accumulation of the effects of ocean waves, wind interactions with plants, and atmospheric activities [7]. The microtremor method was first introduced by Aki and Kanai (1957) with the aim of studying and understanding the characteristics of sedimentary rocks and subsurface soil structures related to dynamic areas at a measurement point [8]. Earthquake data processing is usually carried out using the microtremor method to map the level of vulnerability of an area to earthquakes.

2.1.3 HVSR

The HVSR (Horizontal to Vertical Spectral Ratio) method has been widely used in microzonation and local effect studies. The HVSR method takes into account the geological conditions in the area to estimate the natural frequency and local geological amplification based on microtremor data. [9]. In similar types of rocks, the reinforcement value can vary depending on the extent of deformation such as faults and fold cracks and weathering that occurs in the rock, where the reinforcement value is directly related to the level of deformation and weathering experienced by the rock [10]. The HVSR method itself can provide information on the dominant frequency value and also the earthquake wave amplification value. Estimation of the level of earthquake hazard vulnerability is one of the applications of this method.

2.1.4 Dominant Frequency

The dominant frequency is a frequency that often appears in an area so that it is recognized as the frequency value of the local rock layer, and indicates the type of rock or soil. The smaller the dominant frequency value, the softer a rock layer [11]. Soft soil or sediment usually enhances low-frequency ground motions, while hard rock usually does not enhance high-frequency ground motions. When there is an earthquake or disturbance that produces vibrations with the same frequency as the dominant frequency, resonance will occur, which causes an amplification of the seismic wave factor in that area [12] [13] [14].

2.1.5 Dominant Periode

The dominant period is a period that often appears in an area so that it is recognized as the period value of the local rock layer, and indicates the type of rock or soil. The smaller the dominant period value, the harder a rock layer is. The dominant period value is the time required by the microtremor wave to move through the sediment layer above or to reflect once against its reflection area towards the surface [15].

2.1.6 Amplification

Amplification is the strengthening of seismic waves caused by differences between rock layers. The greater the amplification value, the higher the level of damage caused by the earthquake. In other words, seismic waves will increase when moving from one medium to another that is softer than the previous medium. The more significant the difference between the two mediums, the greater the increase received by the waves. The amplification value will increase if the rock has undergone a change in shape that changes its physical characteristics. For similar rocks, the amplification value can vary depending on the degree of deformation and weathering that occurs in the rock mass [16].

2.1.7 Seismic Vulnerability Index

The seismic vulnerability index is an index that shows the level of vulnerability of the surface layer of the soil in a region to soil deformation due to earthquakes [15]. The greater the value of the seismic vulnerability index, the higher the level of vulnerability of a region to earthquakes. The formula for the seismic vulnerability index is

$$Kg = \frac{{A_0}^2}{f_0} \quad (1)$$

where Kg is the seismic vulnerability index, A_0 is the amplification value, and f_0 is the dominant frequency value.

2.2. Research Methodology

This study uses the HVSR (Horizontal to Vertical Spectral Ratio) method. The research data is secondary data in the form of microtremor data from measurements of 17 points in Kapanewon Berbah and its surroundings as binding points. The points are TA1, TA2, TA3, TA4. TA5, TA10, TA11, TA12, TA13, TA14, TA15, TA20, TA21, TA22, TA23, TA24, and TA25. Coordinate data for each measurement point and the .SHP basemap are needed in the mapping stage. Processing is carried out in 3 different software, namely geopsy, Microsoft Excel, and Surfer12. The research procedure consists of the following 3 stages:

2.2.1 Microtremor Data Processing

Carrying out the windowing process in geopsy software, so that an H/V curve is obtained which produces dominant frequency and amplification values..

2.2.2 H/V Curve Processing

Processing the H/V curve in the form of dominant frequency and amplification into dominant period values and seismic vulnerability index in Microsoft Excel. The dominant period value is inversely proportional to the dominant frequency, while the seismic vulnerability index value is obtained from the square of the amplification value divided by the dominant frequency.

2.2.3 Microzonation Map Creation

The dominant frequency value, dominant period, amplification, and seismic vulnerability index were mapped using microzonation together with the measurement point coordinate data and the Kapanewon Berbah basemap in the surfer12 software. Thus, 4 microzonation maps were obtained with each parameter.

3. RESULTS AND DISCUSSION

3.1 Dominant Frequency Analysis

The dominant frequency value is related to the hardness of the surface rock layer in the research area. The higher the dominant frequency value, the harder the rock that is composed of the layer. Conversely, a low dominant frequency value indicates that the area is composed of soft rock (sediment). Sedimentary rock with a thick soft surface when passed by waves from below the surface causes the passing waves to take longer to reach the surface. As a result, the frequency will show a low value when it reaches the surface. This is different from hard rock. Hard rock tends to be dense and compact so that waves will reach the surface faster with high frequency.

Based on the dominant frequency value distribution map in Figure 3, it can be interpreted that Kapanewon Berbah has a low dominant frequency value ranging from 0.65 - 2.02 Hz. This value indicates that the type of rock in Kapanewon Berbah is dominated by rocks with a soft hardness level with thick sediment (Table 2).

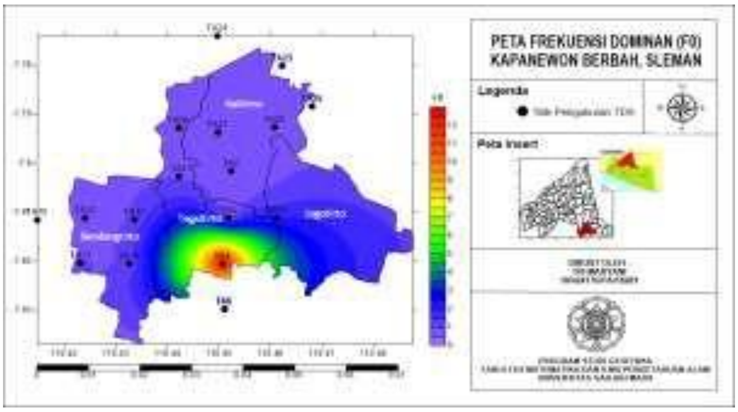

Figure 3. Dominant Frequency Map Changes

It can also be seen in Figure 3 that most of the research area is purple with dark blue gradation which indicates a small dominant frequency value of <3 Hz. However, at the TA4 measurement point with latitude longitude coordinates of -7.8205783 and 110.45076 located in the southern part of Tegaltirto Village, it has a high dominant frequency value of 12.77 Hz which is marked in red. This value indicates that the TA4 point is composed of harder rocks than other measurement locations.

3.2 Dominant Period Analysis

The dominant period value is inversely proportional to the dominant frequency value. The greater the dominant period value, the softer the rocks that are composed (thick sediments). Likewise, the smaller the dominant period value, the harder the rocks that are composed.

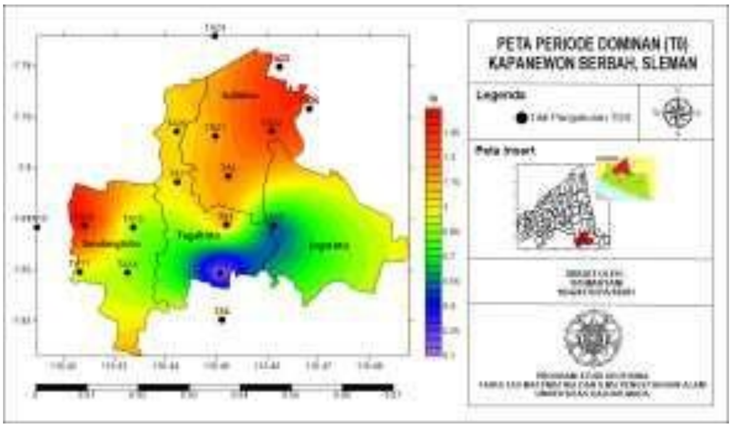

Figure 4. Map of the Changing Dominant Period

Based on the distribution map of dominant period values in Figure 4, the dominant period value in Kapanewon Berbah is quite high with a range of 0.88-1.46 s. In accordance with Table 3, this value shows that Kapanewon Berbah has soil that is included in the very soft category.

However, at the TA4 measurement point with latitude longitude coordinates of -7.8205783 and 110.45076 located in the southern part of Tegaltirto Village, it has the smallest dominant period value of 0.07 s. Based on table 3, the TA4 measurement location has a period value in the range of 0.05-0.15 s, which indicates that the TA4 location is composed of tertiary rocks or older than other measurement points, in the form of hard gravelly sandstone.

3.3 Dominant Amplification Analysis

Amplification is the enlargement of seismic waves that occurs due to significant differences between layers. Seismic waves will experience amplification when they propagate from one medium to another medium that is softer than the initial medium they pass through. The greater the difference, the greater the amplification experienced by the waves. The greater the amplitude value, the higher the level of damage experienced by the earthquake.

Based on the dominant amplification value distribution map in Figure 5, Kapanewon Berbah has a high amplification value with a range of 4.9 to 6.1. This shows that the level of damage in the Kapanewon Berbah area is relatively high with rock layers composed of soft sedimentary rocks (Table 4).

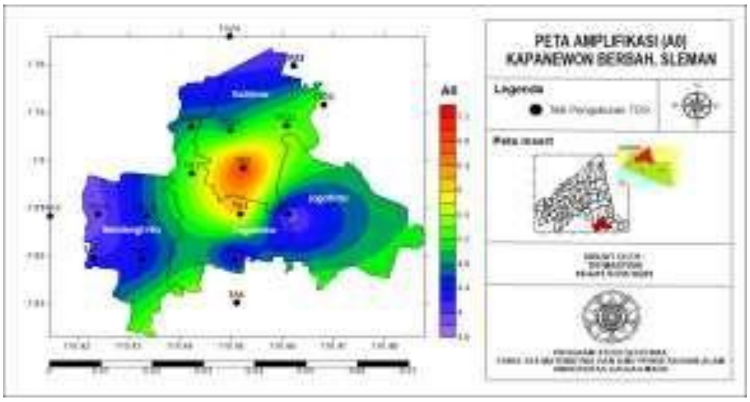

Figure 5. Dominant Amplification Map Changes

However, at the TA2 measurement point with latitude and longitude coordinates of -7.8016166 and 110.45236 located in Kalitirto Village, the amplification factor value is slightly higher, namely 6.9, which is included in the very high damage level category. This shows that at the measurement point it is composed of very soft rock layers.

3.4 Seismic Vulnerability Index Analysis

The seismic vulnerability index (kg) is a number that indicates the level of vulnerability of the soil layer to deformation. The seismic vulnerability index can identify weak zones that have the potential to experience high damage due to earthquakes. The greater the value of the seismic vulnerability index, the greater the impact of the damage caused. Conversely, the smaller the value of the seismic vulnerability index, the lower the impact of the damage experienced.

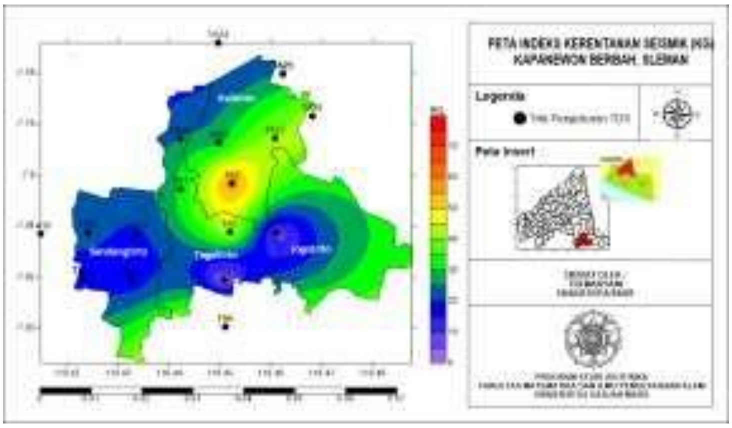

Figure 6. Berbah seismic vulnerability index map

Based on the distribution map of seismic vulnerability index values in Figure 6, the seismic vulnerability index in Kapanewon Berbah is included in the vulnerable/high category with a range of 18.9 to 41.5. This is reinforced by data on damage due to the 2006 Bantul earthquake, where the area in Kapanewon Berbah experienced moderate to severe damage to buildings. In addition, it is known that the most stable location is at the TA4 measurement point in Tegaltirto Village with a seismic vulnerability index value of 1.26. Meanwhile, the most vulnerable location is at the TA2 point in Kalitirto Village with a seismic vulnerability index of 58.82.

4. CONCLUSION

1. Kapanewon Berbah has a low dominant frequency value with a range of 0.65 - 2.02 Hz, so it can be seen that the soil layer in the area is included in the soft category in the form of thick sediment.
2. Kapanewon Berbah has a high dominant period value with a range of 0.88-1.46 s, so it can be seen that the soil layer in the area is included in the very soft category in the form of thick sediment.
3. Kapanewon Berbah has a high dominant amplification value with a range of 4.9 to 6.1, so it can be seen that the soil layer in the area is included in the high damage category.
4. Kapanewon Berbah has a high seismic vulnerability index value with a range of 18.9 to 41.5, so Kapanewon Berbah is included in an area with a high level of seismic vulnerability and is prone to severe damage.

DECLARATION

Author Contribution

This study focuses on the analysis of soil conditions and damage levels based on dominant amplification values and seismic vulnerability indexes in Kapanewon Berbah.
Conceptualization, Tri Maryani.; methodology, Tri Maryani.; software, Tri Maryani.; validation, Tri Maryani.; formal analysis, Tri Maryani.; investigation, Tri Maryani.; resources, Tri Maryani.; data curation, Tri Maryani.; writing—original draft preparation, Tri Maryani.; writing—review and editing, Tri Maryani.; supervision, Tri Maryani.; project administration, Tri Maryani. Authors have read and agreed to the published version of the manuscript.

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Conflict Of Interest

The author declare no conflict of interest.

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ATTACHMENT

Table 1. Damage Data from the 2006 Earthquake in Berbah

Parameter	Amount	Unit
Fatalities	83	Person
Serious injury	307	Person
Moderate injury	166	Person
Minor injuries	1607	Person
Buildings leveled to the ground	2014	unit
Buildings severely damaged	3628	unit
Buildings moderately damaged	839	unit
Buildings lightly damaged	2508	unit

Table 2. Classification of Rock Types

Dominant Frequency (Hz)	Soil Classification		Kanai Soil Classification	Information
	Type	Variety		
<2.5	I	I	Alluvial rocks formed from delta sedimentation. Topsoil, mud to a depth of 30m or more	The surface thickness of the sediment is very thick
2.5 - 4	III	I	Alluvial rocks with sediment thickness >5m. Consisting of sandy-gravel, sandy hard clay, loam.	The thickness of the sediment surface is in the thick category, around 10-30m
4 -10	IV	I	Alluvial rocks with a thickness of 5mm consist of sandy gravel, sandy hard clay, loam	The thickness of the surface sediment is in the medium category, 5-10m
6.667 - 20		II	Tertiary or older rocks. Consisting of hard sand, gravel	The thickness of the surface sediment tip is dominated by hard rocks

Table 3. Classification of Dominant Periods

Dominant Period (s)	Soil Classification		Information	Character
	Kanai	Omotenakajima		
0.05-0.15	Type I	Type A	Tertiary or older rocks. Consists of hard gravelly sandstone	Hard
0.15-0.25	Type II		Alluvial rock with a thickness of 5m. consists of sandy gravel, sandy hard clay, clay, loam	Intermediate
0.25-0.40	Type III	Type B	Alluvial rocks are almost the same as type II, only distinguished by the presence of bluff formation.	Soft
>0.40	Type IV	Type C	Alluvial rocks are formed from delta sedimentation, topsoil, mud, humus, delta deposits or mud deposits, which are classified as soft soil	Very Soft

with a depth of 30m or more.

Table 4. Classification of Damage Levels

Zone	Damage Level	Amplification Value
1	Very low	<3
2	Low	3-4
3	Currently	4-5
4	Tall	5-6
5	Very high	>6

Table 5. Microtremor Processing Data

Point of Measurement	Latitude	Longitude	f0 (hz)	A0	T0 (s)	KG
TA1	-7.8027416	110.44231	0.9474	5.4120	1.0556	30.9173
TA2	-7.8016166	110.45236	0.8143	6.9210	1.2281	58.8269
TA3	-7.8111633	110.45187	0.8536	6.1656	1.1714	44.5314
TA4	-7.8205783	110.45076	12.7723	4.0221	0.0783	1.2666
TA5	-7.8297349	110.45107	0.7013	7.0953	1.4260	71.7900
TA10	-7.8115666	110.41478	0.6420	3.6445	1.5577	20.6903
TA11	-7.82034	110.42318	1.0539	4.1888	0.9488	16.6484
TA12	-7.8112533	110.42406	0.6512	3.8806	1.5356	23.1254
TA13	-7.8115516	110.43362	1.1449	4.6577	0.8735	18.9485
TA14	-7.8205283	110.43257	1.1302	4.3179	0.8848	16.4961
TA15	-7.8112249	110.46122	2.0230	3.8458	0.4943	7.3108
TA20	-7.7928933	110.4422	0.9637	4.9271	1.0376	25.1901
TA21	-7.793705	110.44979	0.8598	4.9186	1.1630	28.1375
TA22	-7.7927466	110.46081	0.6914	5.3575	1.4464	41.5173
TA23	-7.7801833	110.4623	0.6821	4.1495	1.4660	25.2425
TA24	-7.7740599	110.4497	0.9436	3.7447	1.0598	14.8619
TA25	-7.7884333	110.46814	0.6991	5.4577	1.4304	42.6064