MALAYSIAN JOURNAL OF SCIENCE
MJS
ISSN 1394-3065

Regular Issue

Malaysian Journal of Science 43(4): 38-43 (Dec 2024) https://mjs.um.edu.my

Mapping Earthquake Vulnerable Areas Based on Microtremor Measurements Near Kebumen City

Danang Widyawarman[1a]*, Sismanto[2b], Aditya Yoga Purnama[3c]

Abstract: Kebumen, a district in Central Java, is regarded as a risky location because of the possibility of earthquakes. The risk level of earthquake hazard was assessed using a microtremor experiment in 10 subdistricts surrounding Kebumen, Java Tengah, using the characteristic soil dynamic parameters. A total of 82 points were collected using a single station seismometer, which has three components. An HVSR analysis was performed on the data. This vulnerability map also considers social, infrastructure, and economic vulnerabilities. According to the results of the microtremor analysis, the dominating frequency range is between 0.62 and 5.26 Hz. The amplification values ranged from 1,16 to 10,61. The thickness of the sediment layer ranged from 0.56 to 83.46 m. The seismic map was merged with maps of social vulnerability, infrastructure, and economics. The risk of earthquakes in the Kebumen area can be classified into three categories. The Pejagoan and Klirong sub-districts had the lowest earthquake risk. The second category area has a medium earthquake risk and predominates the experimental area, whereas the third category area has a high earthquake risk and predominates the Sruweng subdistrict.

Keywords: *Kebumen City, microtremor, HVSR*

1. Introduction

The Indonesian archipelago is situated in an active tectonic zone where three major tectonic plates—the Eurasian, Indo-Australian, and Pacific plates —meet. Indonesia is a region with high tectonic activity and forms a triple-junction due to the movement of these three plates. The Indo-Australian plate generally moves northward at 6–7 cm per year, subducting below the Eurasian plate, and the two plates meet in the Indonesian region between the southern tip of Sumatra and the Maluku Islands, as shown in Figure 1. (Sili, 2013).

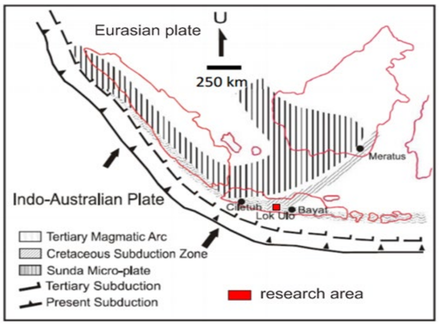

Figure 1. Regional tectonic framework (modified after Kartanegara, et al., 1987)

Authors information:
[a]Universitas PGRI Yogyakarta, Program Sarjana Teknologi Rekayasa Elektro-medis, Fakultas Sains dan Teknologi, Universitas PGRI Yogyakarta, Indonesia. E-mail: danangwidyawarman@upy.ac.id[1]
[b]Universitas Gadjah Mada Yogyakarta, INDONESIA. E-mail: sismanto@ugm.ac.id[2]
[c]Universitas Sarjanawiyata Tamansiswa, INDONESIA. E-mail: adityayoga@ustjogja.ac.id[3]
*Corresponding Author: danangwidyawarman@upy.ac.id

Because of the interaction between the Indo-Australian and Eurasian plates, the southern region of Java is one of Indonesia's highest seismically active regions. Local onshore faults, such as the Kebumen-Muria-Meratus major fault and the Cilacap-Pamanukan-Lematan major fault systems, cause earthquakes on shear faults, as shown in Figure 2. The southern region of Java is seismically active because of several tectonic factors (Tanjung et al., 2021).

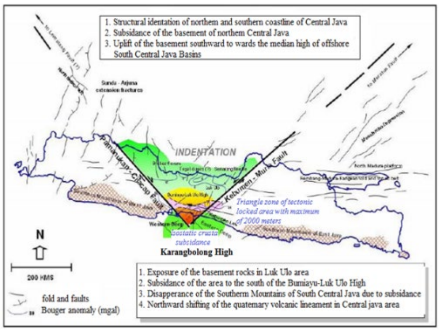

Figure 2. Two paired shear faults, the Kebumen-Muria Fault and the Pamanukan-Cilacap Fault (after Satyana, 2007)

Map of seismicity from 1900 to 2017 showing focal depths between 0–300 m and earthquake magnitudes of 5–10 on the Richter scale. In the historical record of earthquake events in Java, in the Kebumen area, an earthquake occurred on July 23, 1943. The earthquake was centered at 8.6 LS - 109.9 BT at a depth of 90 km with a magnitude of 8.1 on the Richter scale, or with an intensity of VII - VIII on the MMI scale, which caused damage in the area from West to East Java (Ashadi & Kaka, 2019; Griffin et

Received: July 13, 2023
Accepted: December 22, 2023
Published: December 31, 2024

DOI:https//doi.org/10.22452/mjs.vol43no4.5

al., 2019).

In the Kebumen area, the two ends of a significant fault system came together in opposition in the regional geological context. The major Kebumen-Muria-Meratus and Cilacap-Pamanukan-Lematan major fault systems merged to form a fault junction, as shown in Figure 2. The extensive Kebumen-Muria-Meratus fault system extends from the Meratus Mountains in South Kalimantan in the northeast to the Kebumen coast. From Kebumen's shore, the extensive Cilacap-Pamanukan-Lematan fault system runs northwest towards Lematang, in South Sumatra (Harun, 2018). The Kebumen–Muria and Cilacap–Pamanukan faults caused the appearance of a depressed morphology on the Central Java coastline.

The two major fault systems are now inactive, except for a small segment of the large Cilacap-Pamanukan-Lematang Fault, including the Kroya, Bumiayu, and Baribis faults. Even though they were dead, the activities of the two in the past made the Kebumen area "locked" so that it was uplifted to the extreme, which made the Luk Ulo melange complex rise to the surface. This lifting also formed the South Gombong Mountains or Karangbolong, which have a height of more than 2,000 m; however, erosion has reduced these mountains to a height of approximately 600 m (Ansori & A Wardhani, 2019). The mainland of Kebumen has an old Kedungkramat fault, often known as the Kedungbener fault, as shown in Figure 3.

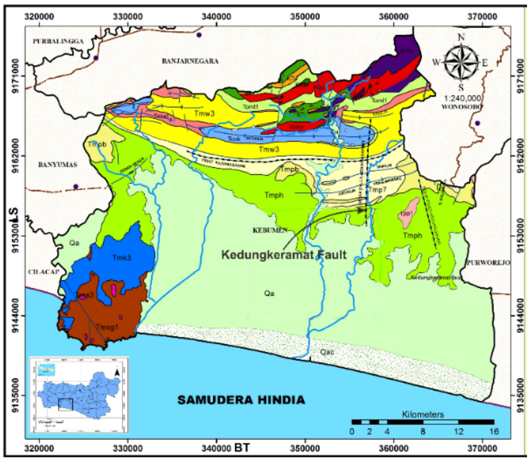

Figure 3. Regional Geologic Map of Kebumen Regency and Kedungkeramat Fault

The Kedungbener Valley is a relatively straight north-south trending valley that stretches for about 8 kilometers from the eastern side of the city of Kebumen to the hilly areas of Karanggulung. This valley is an expression of a fault on the Earth's surface currently called the Kedung Bener Fault or the Kedungkramat Fault. This fault is suspected of being responsible for the emergence of hot springs and the Alian geothermal reservoir system.

In the historical record of earthquake events in Java in the Kebumen region, an earthquake occurred on July 23, 1943. The earthquake was centered at 8.6 South Latitude - 109.9 East Longitude or more precisely the Bantul area at a depth of 90 km with a magnitude of 8.1 on the Richter scale and an intensity of VII - VIII on the MMI scale; it caused damage in the West to East Java regions (Devi Riskianingrum, 2013). Every earthquake incident produces ground shaking, which can be identified by the value of the ground vibration acceleration at a certain location. The greater the value of ground vibration acceleration at a place, the greater the danger of an earthquake occurring at that place. The value of the ground vibration acceleration is one of the factors that can indicate the level of earthquake risk. The map of earthquake-prone areas was made based on the weighting of four parameters: geology (rock, morphology, and geological structure), intensity of earthquakes that have occurred, seismicity, and earthquake wave acceleration. Based on these parameters, earthquake disaster zones were created as very low, low, medium, and high earthquake hazard zones.

Microtremor measurements were performed because in the Kebumen Regency, there is a confluence of the two ends of a large fault system, which makes this area a zone of high earthquake shocks. From the microtremor measurements, the dominant frequency and amplification values were obtained, which were used to map the level of earthquake hazards using the vulnerability index parameter. A high vulnerability index indicates a high potential hazard caused by an earthquake.

2. Research Method

This study was conducted in Kebumen Regency, Central Java Province. Kebumen Regency is geographically located between 7°27' and 7°50' South latitude and 109°33' and 109°50' East longitude as shown in Figure 4.

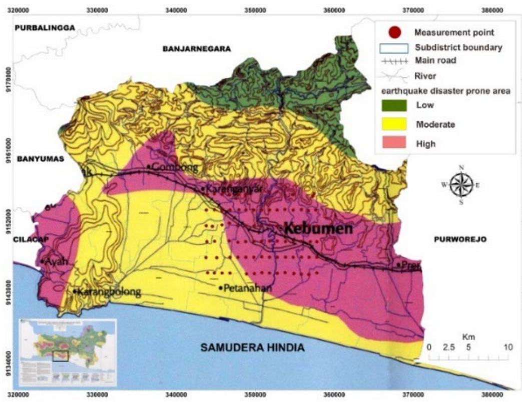

Figure 4. Map of the study area

The Purworejo Regency and Wonosobo Regency border the Kebumen Regency to the east, Banjarnegara Regency to the north, Banyumas Regency and Cilacap Regency to the west, and the Indonesian Ocean to the south. The 82 points of microtremor measurements for this investigation were obtained between September 15 and 24, 2017. Area measures are implemented in places vulnerable to disasters. Figure 5 shows the location map

DOI:https//doi.org/10.22452/mjs.vol43no4.5
Malaysian Journal of Science 43(4): 38-43 (December 2024)

and measurement sites.

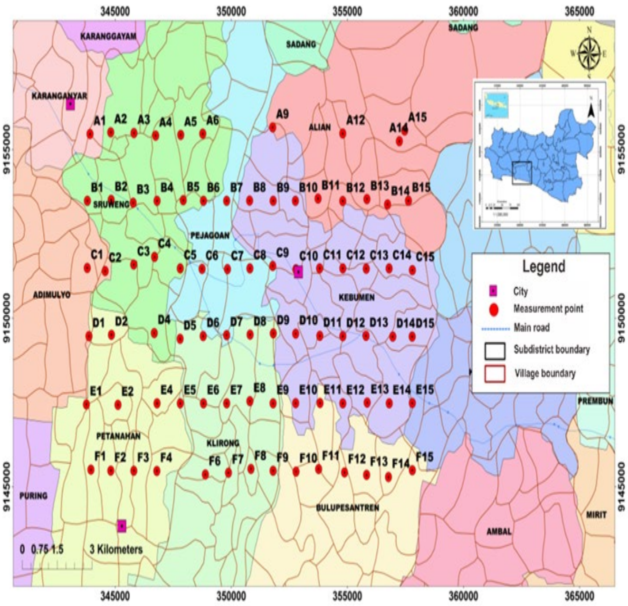

Figure 5. Map of locations and microtremor measurement points

The measurement area includes the ten districts of Karanganyar, Sruweng, Kebumen Kota, Pejagoan, Adimulyo, Petanahan, Klirong, Buluspesantren, Alian, and Kutowinangun, which surround Kebumen City's central business district. A single-station microtremor was used to collect measurement data. The locations were spaced 1000 m apart in a west-east direction and 2000 m apart in the north-south direction. A sample frequency of 100 Hz was used during the 35-minute measurement at each point.

The microtremor data sample locations in the research area were chosen after considering several criteria related to the norms established by the SESAME European Research Project (Alamri et al., 2020). A general layout of the study flowchart is shown in Figure 6. The acquired single-station microtremor data were represented by signals with three components: north-south (N-S), east-west (E-W), and vertical (Z). Figure 7 depicts the input signals for the three parts of the microtremor measurement results. The measurement data remain in the time domain because the data derived from the measurements are time series data. The output signal consists of a stationary signal and a transient signal. A steady signal, or one with the same amplitude, and no time-dependent variations, is required for microtremors.

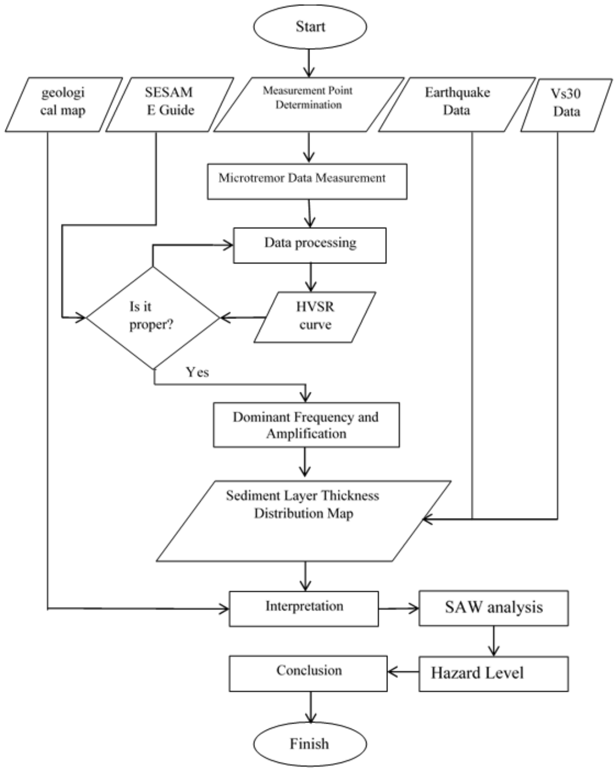

Figure 6. Research flowchart in general

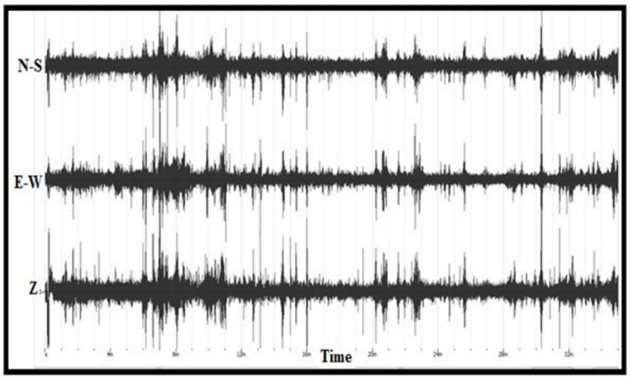

Figure 7. Raw 3-component single-station microtremor data in the time domain at point B-10

Figure 7 shows that processing in Geopsy software begins by displaying 3-component single station microtremor data in the time domain. Next, windowing was performed, which is a technique used to cut the signal to a limited number of sample points. The data in the window of each component were Fourier-transformed to obtain the average spectrum of each component. The resultant horizontal component, consisting of the north-south component and the east-west components, was divided by the vertical component to obtain the HVSR curve, as shown in Figure 8.

DOI:https//doi.org/10.22452/mjs.vol43no4.5
Malaysian Journal of Science 43(4): 38-43 (December 2024)

The HVSR (Horizontal to Vertical Spectral Ratio) curve is used to determine the natural frequency (fo) and amplification (Ao) values, which are then used to compute the maximum ground vibration acceleration (PGA), seismic vulnerability index (Kg), sediment layer thickness value (h), and ground shear strain (Ɣ) values. The two HVSR curve criteria suggested by SESAME were used to analyze the HVSR curve after processing using GEOPSY Software (Abdel-Rahman et al., 2012). The analysis was based on trustworthy HVSR curve criteria and SESAME's proposed HVSR curve criteria with distinct peaks (Abdel-Rahman et al., 2012). Eighty-two measurement points were obtained and an accurate HVSR curve was constructed by analyzing the HVSR curve. Twenty-four measurement points were obtained from the HVSR curve analysis results, in accordance with the requirements for a clear HVSR curve (clear peak).

3. Research Results

The results obtained from this research are natural frequency (fo) and amplification (Ao) values at 82 measurement points in the Kebumen Regency, which are located in 10 subdistricts: Karanganyar, Sruweng, Kebumen Kota, Pejagoan, Adimulyo, Petanahan, Klirong, Buluspesantren, Alian, and Kutowinangun. The HVSR curves of the measurement results are shown in Figure 8.

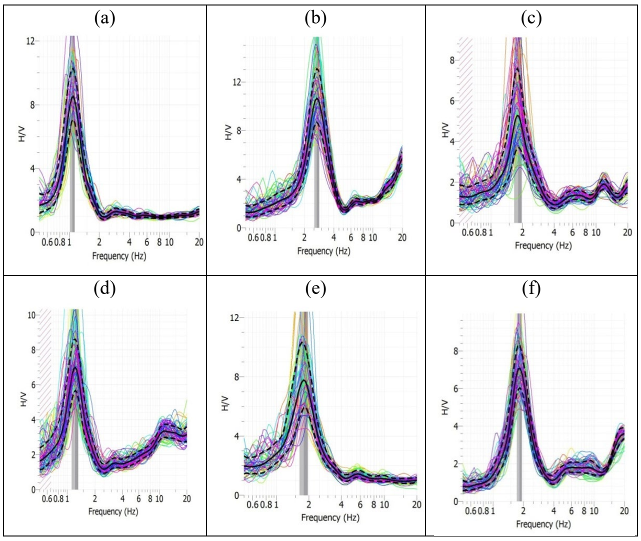

Figure 8. HVSR spectrum at points (a) B-10, (b) B-15, (c) C-06, (d) C-09, (e) D-08, and (f) E-15.

The HVSR curve results were used to determine the dominant frequency value, which was subsequently used to create a contour map of the dominant frequency distribution in Kebumen City and its surroundings, as shown in Figure 9. Between 0.62 and 5.26 Hz is the dominating frequency in the study area. Low dominant frequency values, which span the frequency range of 0.62 to 1.51 Hz, predominate in the frequency distribution of Kebumen City District. Adimulyo District, Alian District, Bulus Pesantren District, Klirong District, and Sruweng District; these districts were also scattered with low dominant frequencies, as shown in green in Figure 9.

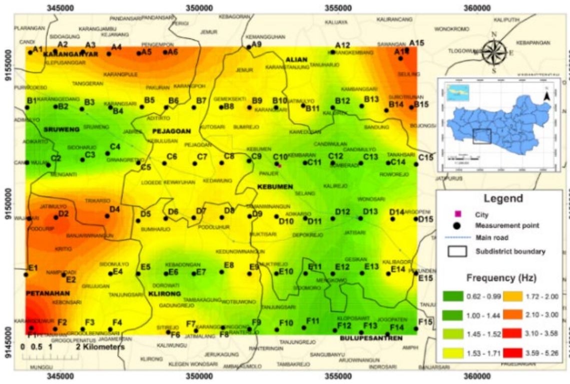

Figure 9. Distribution map of dominant frequency (fo) overlaid with administrative map of Kebumen Regency

Low dominant frequency values are found at measurement points A12, B01, B02, B03, B04, B05, B10, B12, B13, C01, C02, C03, C04, C05, C09, C10, C11, C12, C13, C14, C15, D11, D12, D13, E05, E06, E07, E08, E09, E10, E11, E12, E13, F08, F10, F11, F12, F13, F14, and F15. Areas with moderate frequency values of 1.52 Hz to 1.74 Hz are spread across Kota Kebumen District, Alian District, Kutowinangun District, Klirong District, Pejagoan District, and Petanahan District which are shown in yellow in Figure 9.

Moderate frequency values are at measurement points B06, B07, B08, C06, C07, C08, B11, D05, D06, D07, D08, D09, D10, D14, D15, E01, E04, E09, E14, E15, F03, F04, and F06. Areas with moderate frequency were mostly found in the alluvial formation in the central part of the study area, with some entering the Halang Formation in the northern and eastern parts of the study area. Areas with high frequency values of 1.75 Hz to 5.26 Hz are scattered in Kota Kebumen District, Alian District, Karanganyar District, Sruweng District, and Petanahan District as shown in red in Figure 9. High-frequency values were observed at measurement points A01, A02, A03, A04, A05, A06, A14, A15, B09, B14, B15, D01, D02, E02, F01, and F02. The Halang Formation, composed of andesitic sandstones, tuffaceous conglomerates, and marl mixed with sandstones, has the majority of prominent high-frequency values. Due to the thinner sediment layer in the southwest of the study area than in the south, high frequencies were also discovered in the alluvial formations. If the dominant frequency value is adapted to the topography of the study area based on the processing results, it is appropriate. Low dominant frequency values were found in regions with low altitudes compared with other measurement locations.

DOI:https//doi.org/10.22452/mjs.vol43no4.5
Malaysian Journal of Science 43(4): 38-43 (December 2024)

The amplification value is the strengthening of shaking during an earthquake, which was obtained from the results of the HVSR analysis and was then used to create a contour map of the distribution of amplification values in Kebumen City and its surroundings, as shown in Figure 10. This amplification is caused by the impedance contrast, that is a considerable change in rock compactness between the sedimentary and bedrock layers (Kyaw et al., 2015). The amplification value is related to the rock density level; a lower rock density can increase the amplification value. A low dominant frequency value results in a high amplification value (amplification) for earthquake waves, and vice versa. If an earthquake occurs in an area, there will be amplification (strengthening) according to the amplification value for that area. This can lead to an even greater potential earthquake risk.

The amplification value in the study area ranged from 1.16 to 10.61 shown in Figure 10. Based on Figure 10 the low amplification value are shown in green with a range of values from 1.16 to 4.30 which are spread across Sruweng District, Kecamatan Pejagoan, the northern part of Kebumen City District, Petanahan District, Klirong District, Buluspesantren District, and Alian District. Low amplification value are at measurement points A12, A14, B04, B05, B06, B07, B08, C06, C07, C13, C15, D01, D02, E05, E06, E07, E08, E09, E10, F01, F02, F03, F04, F06, F07, F08, F09, F10, F11, F12, F13, F14, and F15. Low amplification values were observed in the alluvial formation to the south of the study area and Halang Formation to the north of the study area. Moderate amplification values with a range from 4.31 to 5.50, are shown in yellow and spread over Alian, Klirong, Pejagoan, and Petanahan sub-districts. Moderate amplification values were obtained at the measurement points A01, A03, A09, A15, C14, D05, D06, D07, E02, E04, E11, F13, F14, and F15.

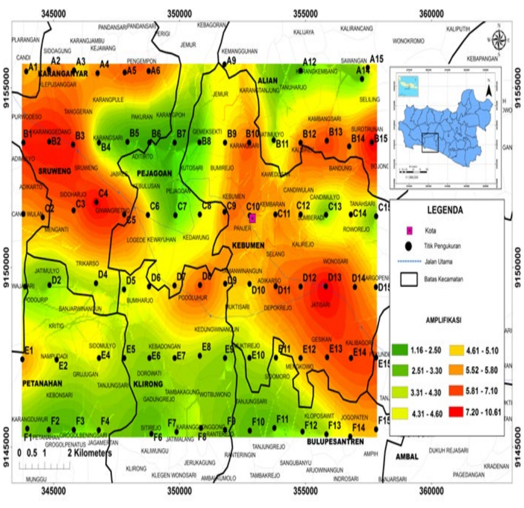

Figure 10. Map of the amplification value (A0) distribution overlaid with the administrative map of Kebumen Regency

The dominant frequency and shear wave velocity at a depth of 30 m (Vs30) were used to calculate the sediment layer thickness. Equation 1 can be used to express the sediment layer thickness and dominant frequency (Wulandari et al., 2018). A contour map of the distribution of the sediment layer thickness values was then created, as shown in Figure 11. The sediment layer thickness values were interconnected with the dominant frequency values in the area.

Very low dominant frequency values affect long-period vibration hazards and low dominant frequency values produce thick layers of sediment (Thamarux et al., 2019). An area with a thick layer of sediment over a long period can threaten high-rise buildings if earthquakes occur in the area. Areas with high dominant period values have thick layers of sediment (Edison, 2022). A thick layer of sediment causes sufficiently high damage when an earthquake occurs because the value of the dominant period is directly proportional to the amplification value (Edison, 2022). A thick layer of sediment causes significant damage when an earthquake occurs.

$$h = \frac{V_s}{4f_0} \qquad (1)$$

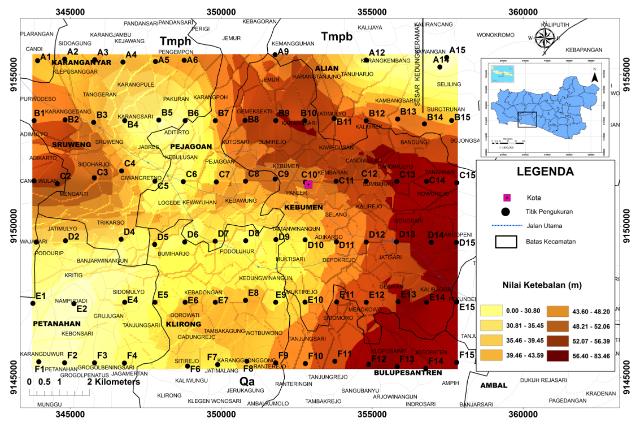

Figure 11. Distribution map of sediment layer thickness values (h) overlaid with the administrative map of Kebumen Regency

From Figure 11, the distribution of moderate sediment thickness values was found to be at measurement points A01, A02, A03, A04, A05, A06, A,15, B01, B02, B03, B04, B05, B06, B09, B11, B14, B15, C01, C02, C03, C04, C05, C06, C07, C08, C09, C10, C11, C12, C14, D04, D05, D06, D07, D08, D09, D10, D11, D12, D13, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14, E15, F03, F04, F06, F07, F08, F09, F10, F13, and F11. Areas that have thick sediment layer with thickness between 60 and 120 m are shown in dark brown, which are spread in the eastern part of Kota Kebumen District, Alian District, and Buluspesantren District. These sediment thickness values were distributed at measurement points A09, A12, A14, B10, B12, C15, D14, F12, F14, and F15.

4. Conclusion

Microtremor readings taken in Kebumen and its vicinity were used to produce the findings of this study. Eighty-two measurement points were obtained and an accurate HVSR curve was constructed by analyzing the HVSR curve. Twenty-four measurement points were obtained from the HVSR curve analysis results, in accordance with the requirements for a clear HVSR curve (clear peak). The amplification value (Ao) ranged from 1.16 to 10.61, and the dominating frequency (fo) ranged from 0.62 to 5.26 Hz based on the processing of microtremor data. The seismic map was merged with maps of social vulnerability, infrastructure, and economics. The risk of earthquakes in the Kebumen area can be classified into three categories. A few places in Petanahan District, Klirong District, Bulus Pesantren District, and Pejagoan District have low levels of seismic danger. There are a few places in Pejagoan District, Sruweng District, Petanahan District, Kebumen City District, Buluspesantren District, and Alian District that are moderately dangerous. Sruweng, Adimulyo, Kota Kebumen, Alian, and Buluspesantren Districts contain several high-risk zones.

5. References

Abdel-Rahman, K., Abd El-Aal, A. K., El-Hady, S. M., Mohamed, A. A., & Abdel-Moniem, E. (2012). Fundamental site frequency estimation at new domiat city, Egypt. Arabian Journal of Geosciences, 5(4), 653–661. https://doi.org/10.1007/s12517-010-0222-2

Alamri, A. M., Bankher, A., Abdelrahman, K., El-Hadidy, M., & Zahran, H. (2020). Soil site characterization of Rabigh city, western Saudi Arabia coastal plain, using HVSR and HVSR inversion techniques. Arabian Journal of Geosciences, 13(2). https://doi.org/10.1007/s12517-019-5027-3

Ansori, C., & A Wardhani, F. (2019). Tipe Magmatik Batuan Beku Formasi Gabon di Tinggian Karangbolong, Kebumen. Jurnal Geologi Dan Sumberdaya Mineral, 20(2), 63. https://doi.org/10.33332/jgsm.v20i2.406

Ashadi, A. L., & Kaka, S. L. I. (2019). Ground-Motion Relations for Subduction-Zone Earthquakes in Java Island, Indonesia. Arabian Journal for Science and Engineering, 44(1), 449–465. https://doi.org/10.1007/s13369-018-3563-x

Devi Riskianingrum. (2013). Penanganan Bencana Dan Transformasi Pengetahuan Tentang Kegempaan Di Masa Kolonial. Paramita: Historical Studies Journal, 23(1), 1–13. https://journal.unnes.ac.id/nju/index.php/paramita/article/view/2492/2545

Edison, R. (2022). Pemetaan Vs30 Dengan Menggunakan Korelasi Zhao Di Pesisir Cilacap. Jurnal Geosaintek, 8(1), 181. https://doi.org/10.12962/j25023659.v8i1.12601

Griffin, J., Nguyen, N., Cummins, P., & Cipta, A. (2019). Historical earthquakes of the eastern sunda arc: Source mechanisms and intensity-based testing of Indonesia's national seismic hazard assessment. Bulletin of the Seismological Society of America, 109(1), 43–65. https://doi.org/10.1785/0120180085

Harun, A. (2018). Subvolcanic Hydrocarbon Prospectivity of Java: Oppotunities and Challenges. October, 13–16. https://doi.org/10.29118/ipa.0.15.g.105

Kyaw, Z. L., Pramumijoyo, S., Husein, S., Fathani, T. F., & Kiyono, J. (2015). Seismic Behaviors Estimation of the Shallow and Deep Soil Layers Using Microtremor Recording and EGF Technique in Yogyakarta City, Central Java Island. Procedia Earth and Planetary Science, 12, 31–46. https://doi.org/10.1016/j.proeps.2015.03.024

Sili, P. D. (2013). Penentuan Seismisitas dan Tingkat Risiko Gempa Bumi. In Gempa Bumi. Universitas Brawijaya Press.

Tanjung, N. A. F., Permatasari, I., & Yuniarto, A. H. P. (2021). Mapping of weathered layer thickness and Seismic Vulnerability in Tegal using HVSR method. Journal of Physics: Conference Series, 1951(1). https://doi.org/10.1088/1742-6596/1951/1/012053

Thamarux, P., Matsuoka, M., Poovarodom, N., & Iwahashi, J. (2019). VS30 seismic microzoning based on a geomorphology map: Experimental case study of Chiang mai, Chiang rai, and Lamphun, Thailand. ISPRS International Journal of Geo-Information, 8(7), 1–18. https://doi.org/10.3390/ijgi8070309

Wulandari, A., Suharno, Rustadi, & Robiana, R. (2018). Pemetaan Mikrozonasi Daerah Rawan Gempabumi Menggunakan Metode HVSR Daerah Painan Sumatera Barat. Jurnal Geofisika Eksplorasi Vol., 4(1).

DOI:https//doi.org/10.22452/mjs.vol43no4.5
Malaysian Journal of Science 43(4): 38-43 (December 2024)