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AQUIFER POTENTIAL IN ALLUVIUM LITOLOGY USING THE HORIZONTAL-TO-VERTICAL SPECTRAL RATIO (HVSR) METHOD, CASE STUDY: COASTAL DEMAK, INDONESIA

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Summary. The coastal area of Demak is composed of alluvial plains influenced by the presence of coastal deposits. The alluvial area has materials such as silt clay, grained clay, medium sand, silty sand, silt, clay, and sediment. Knowledge of soil structure and modulus of elasticity in the coastal area of the Demak Regency is essential to determine the potential of aquifers in an area. Research using the HVSR (horizontal to vertical spectral ratio) microtremor method was conducted to determine the potential for aquifers beneath the ground surface in the Demak Coastal area. Data collection was carried out at 89 points for 10 minutes using a 3-component TDS type 303S seismograph and a sampling rate of 20 Hz. Microtremor data were processed using Excel, Geopsy, and Dinver software to obtain the v_s and Poisson ratio parameters. The difference between aquicludes can be determined by combining the v_s value with the Poisson's ratio. The value of $v_s < 350$ m can describe the presence of soft clay, stiff clay and silt structures, while the Poisson's ratio describes the saturation of the material. Aquifers can be found with a combination of values ranging from $350 < v_s < 1500$ m and the Poisson's ratio > 0.3. Potential aquifers with saturated clay aquicludes are found at stations 5, 57 and 73, while unsaturated clay aquicludes are found at station 61. Potential aquifers with silt aquicludes are found at stations 14, 60, 71, 38 and 34.

Introduction

Demak is a regency in the Central Java Province located at coordinates 6°43'26" – 7°09'43" South Latitude and 110°27'58" – 110°48'47" East Longitude (BPS Demak Regency, 2020). It borders the Jepara Regency and the Java Sea to the north, Kudus and Grobogan Regencies to the east, Grobogan and Semarang Regencies to the south, and Semarang City to the west. Historically, the Demak Regency was originally a swampy area, resulting in unstable soil structure, particularly on the north coast. Flooding is common during the rainy season, and cracks in the soil are due to muddy structure during the dry season (Rahmawan et al., 2016).

Geologically, the coastal area of Demak consists of alluvial plains influenced by coastal and river sediments (Thanden et al., 1996). Alluvium and coastal deposits will form an unconfined aquifer (Santosa et al., 2021). Geoelectric data in the Demak area indicate the presence of an unconfined aquifer around this research area (Trihatmoko et al., 2020). According to Nurwidianto et al., (2024), most of the Demak area has low dominant frequency, indicating the presence of a very thick alluvium layer (> 30 m). Soil structure and elastic modulus are important parameters in interpreting aquifer potential. Therefore, to determine the soil structure and elastic modulus in the coastal area of the Demak Regency, geophysical methods are needed, one of which is the HVSR method. This method compares the spectrum of the horizontal component with the vertical component of microwaves by assuming that most microwaves are shear waves and ignoring surface waves (Rayleigh and Love waves).

The HVSR method is similar to the transfer function between sediment wave oscillations and bedrock. According to Nakamura (1989), this method is an analytical method based on observations of shear wave propagation for various geological conditions and can be used to determine the value of the amplification factor and the dominant period value in an area that can be estimated from the peak period of the H/V ratio of microtremors (Nakamura, 2000). Through inversion, a v_s value will be produced that can represent the presence of rock structures below the ground surface, as well as the S-wave velocity value (v_s) and the Poisson's ratio that can represent rock structures and the potential presence of groundwater below the ground surface.

Theory And Geology Research Area

The Demak Regency located on the north coast of Central Java has a significant potential for tidal flooding due to the relatively flat terrain and annual sea level rise. This impacts several villages in the Sayung District, such as Sriwulan, Tambakroto, Gemulak, Bedono, Tugu, Surodadi, Banjarsari, Sidorejo, and others. The coastal area of Demak consists of alluvial plains influenced by coastal and river sediments (Mulyono, 1996). Based on lithology, the area contains silt clay, grained clay, medium sand, silt sand, silt, clay, and so on. The excavated rocks in the area are sedimentary.

In general, the HVSR method is a passive seismic method that uses three components in its measurements: two horizontal components (East-West and North-South), and one vertical component. This method has been widely used to identify the fundamental frequency resonance of buildings and subsurface structures. Natural frequency and amplification are two important parameters resulting from the HVSR method, and its inversion can be used to determine the characteristics and structure of the subsurface, namely the v_s value and the Poisson's ratio related to the physical parameters of subsurface rocks (Herak, 2008). Equation 1 can be interpreted as the longitudinal wave equation. Based on this wave equation, the longitudinal seismic wave velocity or P-wave velocity (v_p) is obtained as:

$$v_p = \frac{(\lambda' + 2\mu)^{\frac{1}{2}}}{\rho} \tag{1}$$

The velocity of transverse waves (S waves) is a wave that comes after the primary wave (P wave) with transverse shear vibrations in a plane perpendicular to the direction of propagation, with a velocity of 60% of the P wave (Telford et al., 1990). The value of v_s in equation 2 can represent the rock structure and is written as follows:

$$v_S = \left(\frac{\mu}{\rho}\right)^{\frac{1}{2}} \tag{2}$$

where v_s is the S-wave velocity (m/s), λ' is Lame's constant, μ is the shear modulus (N/m^2), and ρ is the density (kg/m^3). S-waves can only propagate through solids, so they cannot penetrate liquids (Arintalofa et al., 2020). The v_s value can represent the rock structure.

The Poisson's ratio is the ratio of transverse contraction to longitudinal elongation when the rod is stretched. The Poisson's ratio can be used in the analysis of the presence of water in the soil by utilising transverse contraction to longitudinal strain or elongation as a result of changes in normal stress due to compression or dilation (Das Braja, 1993). In the form of the ratio of the longitudinal wave velocity v_p to the shear wave v_s, the Poisson's ratio can be written as equation 3 (Lay and Wallace, 1995), and classification is in Table 1:

$$\sigma = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)} \tag{3}$$

Table 1

Classification of Poisson Ratio

Value Range	Classification
0.15 – 0.3	Unsaturated clay, sand and gravel
0.3 – 0.35	Silt
0.35 – 0.45	Saturated Clay

Research methods

This research was conducted using a quantitative descriptive method by collecting data in the form of microtremor signal measurements in the form of time-domain seismic signals. Primary data measurement began with the creation of a microtremor measurement survey design of 89 points (Fig. 1) using Google Earth Pro software with a distance between measurement points of 1000-3000 m.

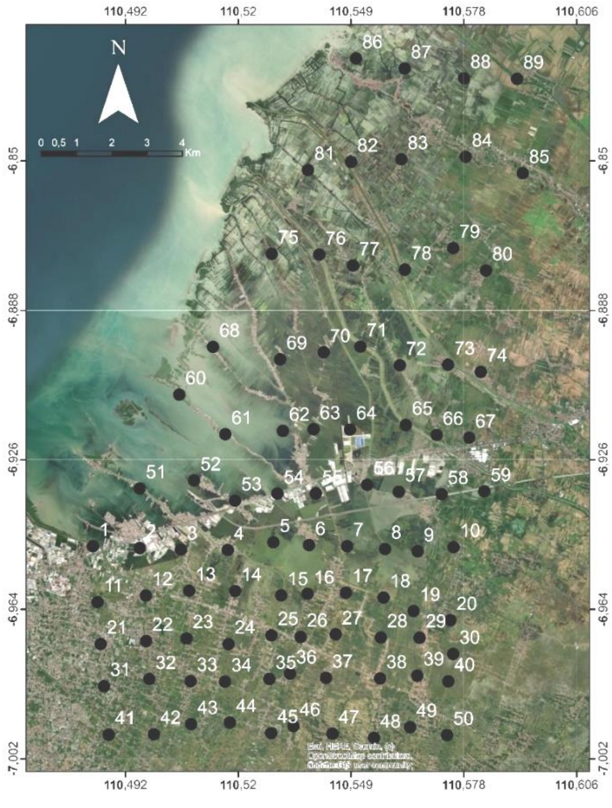

Fig. 1. Map of the location of data collection points in UTM coordinates

Microtremor signal measurements were carried out using a Triaxial Geophone VHL PS 2B and recorded with a GL 240 type data logger (Yulianto and Yuliyanto, 2023a). Seismograph installation requires a geological compass to indicate the north direction, and data collection for each point is carried out for 10 minutes with a sampling rate of 20 Hz (Yuliyanto et al., 2017 and Irham et al., 2021).

The obtained microtremor data was converted to .dat format using Notepad++ software and then converted to .txt format (Yuliyanto and Yulianto, 2023b). Once the data were in .txt format, it could be processed using Geopsy software to obtain the H/V curve (Yuliyanto et al., 2017; Nurwidyanto et al., 2023). Figure 2 shows the microtremor signals captured during the measurements and is the initial data. Then, inversion was performed using Dinver software to obtain the density, v_p and v_s values, and depth through the resulting H/V curve (Figure 3) (Yulianto, Yuliyanto 2023).

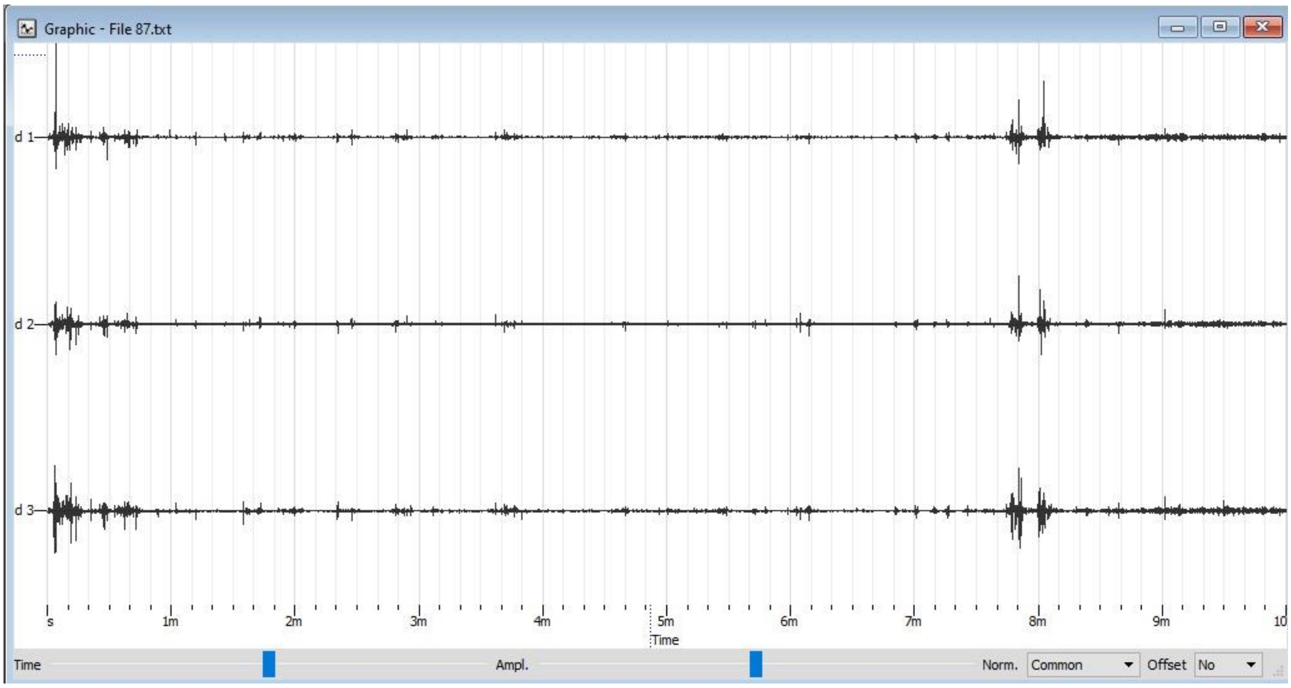

Fig. 2. Microtremor signal at station 87

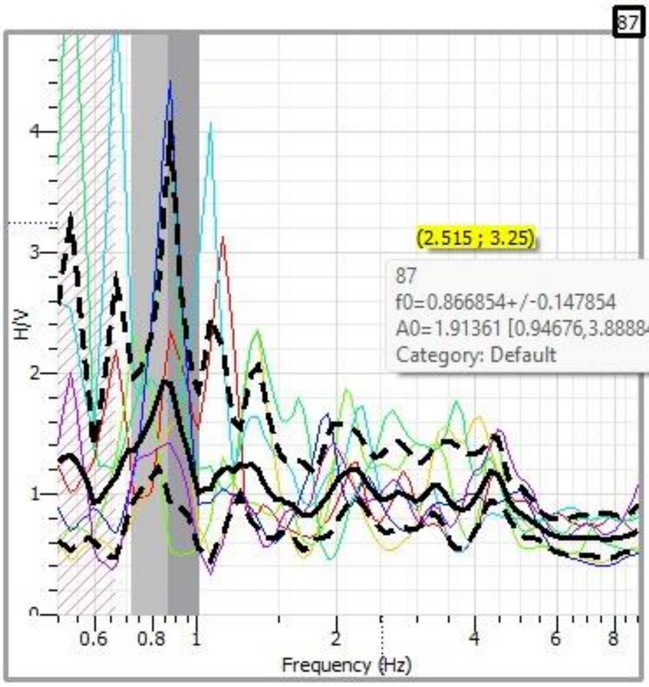

Fig. 3. HV curve at station 87

The results of the inversion have density, v_p, and v_s values at each specific depth according to the characteristics of each area (Yuliyanto et al., 2025). The Poisson's ratio value is obtained using the equation 3. The data is then sorted based on certain depths, namely 0, 10, 20, 30, 40, 50, 60, and 70 m. The selection of these depths is to make it easier to find out specific changes in soil structure within a range of 10 m. Data modeling was performed using ArcGIS software, a spatial analysis tool used in the interpolation process. Interpolation is used to create 2D patterns to estimate values at locations where data is unavailable or unmeasured based on the values of known sample points in the surrounding data.

Results and Discussion

Groundwater aquifers can be identified by observing the v_s value and Poisson's ratio. The v_s value can be used to determine the rock structure in an area. Based on the ASCE 7-16 classification regarding the v_s value, the v_s value can be classified into 5 sections. The first section is the classification of soft soils less than 175 m/s. The second section is the classification of medium soils with v_s values of 175 to 350 m/s. The third section is the classification of hard, very dense soils and soft rocks with v_s values of 350-750 m/s. The fourth section is the classification of bedrock with v_s 750-1500 m/s (Keçeli, 2012). The fifth section is the classification of hard rocks with v_s values of more than 1500 m/s. The Poisson's ratio can explain the fluid content contained in a rock.

Aquifers are located beneath impermeable layers. In this case, the impermeable layer is saturated with water but cannot transmit large amounts of water, or is impermeable (aquiclude). Aquifers in alluvial areas are usually found in gravel and sand, while aquicludes are found in silt and clay. Based on this, they can be classified into areas that are aquicludes/aquifugs and those that are aquifers. Figure 4 explains the v_s values at depths of (a) 0 m, (b) 10 m, (c) 20 m and (d) 30 m. Figure 5 explains the v_s values at depths of (a) 40 m, (b) 50 m, (c) 60 m, (d) 70 m. Figure 6 shows the Poisson's ratio values at depths of (a) 0 m, (b) 10 m, (c) 20 m and (d) 30 m. Figure 7 shows the Poisson's ratio values at depths of (a) 40 m, (b) 50 m, (c) 60 m and (d) 70 m.

Potential aquifers are found in several locations in the study area, with three types of aquicludes: saturated clay, unsaturated clay and silt. The differences between aquicludes can be identified by combining the v_s value <350 and the Poisson's ratio range in Table 1. A v_s value <350 (with soft and medium soil structures according to ASCE 7-16) can indicate the presence of soft clay, stiff clay, and silt structures, while the Poisson ratio reflects the saturation of the material. Aquifers can be found by the presence of a combination of values ranging from $350 < v_s < 1500$ and the Poisson's ratio > 0.3 (in alluvial areas) (Yuliyanto, Nurwidyanto, 2021).

The potential for aquifers with saturated clay aquicludes is found at stations 5, 57, and 73, while unsaturated clay aquicludes are found at station 61. Station 5 shows the presence of a 50 m thick aquiclude (0-50m) with saturated clay and sand as an aquifer at a depth of more than 60 m. Station 57 has an aquiclude at a depth of 0-30 m and an aquifer at a depth of 40-60 m. At a depth of 70 m there is no potential aquifer. Station 73 has a 30 m thick aquiclude with a depth of 0-30 m, and an aquifer was found at a depth of 40 m with a thickness of more than 30 m. Station 61 has an unsaturated clay aquiclude with a thickness of 40 m (0-40 m), and sand was found as an aquifer at a depth of 50 m with a thickness of more than 20 m.

The potential of aquifer with silt aquiclude is found at stations 14, 60, 71, 38 and 34. Station 14 shows the presence of a 40 m thick aquiclude (0-40 m) with silt and sand types as aquifers at depths of more than 50 m. Station 60 has an aquiclude at a depth of 30-40 m and an aquifer at a depth of 50 m with a thickness of more than 20 m. Stations 71 and 38 have a 60 m thick aquiclude with a depth of 0-60 m, and an aquifer was found at a depth of 70 m. Station 34 has an unsaturated clay aquiclude with a thickness of 10 m (40-50 m), and sand was found as an aquifer at a depth of 60 m with a thickness of more than 10 m.

Stations 1, 2, and 51 are areas with sand lithology, as evidenced by the presence of v_s values ranging from $350 < v_s < 1500$ and the Poisson's ratio < 3. Previous research by Trihatmoko et al. (2020) showed a similar interpretation using the geoelectric method. The results of the geoelectric (GL-04) from that study showed a resistivity value of 2.38 at a depth of 10 m, which can be classified as sand saturated with seawater. Depths of 20-60 m indicate a classification of a sand layer with clay inserts. This justifies the use of this microtremor method in determining subsurface potential.

Conclusion

The difference between aquicludes can be identified by combining the v_s value with the Poisson's ratio. A v_s value < 350 m can indicate the presence of soft clay, stiff clay, and silt structures, while the Poisson's ratio indicates the material's saturation. Aquifers can be identified by a combination of a range of $350 < v_s < 1500$ m and the Poisson's ratio >0.3. Potential aquifers with saturated clay aquicludes are found at stations 5, 57, and 73, while unsaturated clay aquicludes are found at station 61. Potential aquifers with silt aquicludes are found at stations 14, 60, 71, 38, and 34.

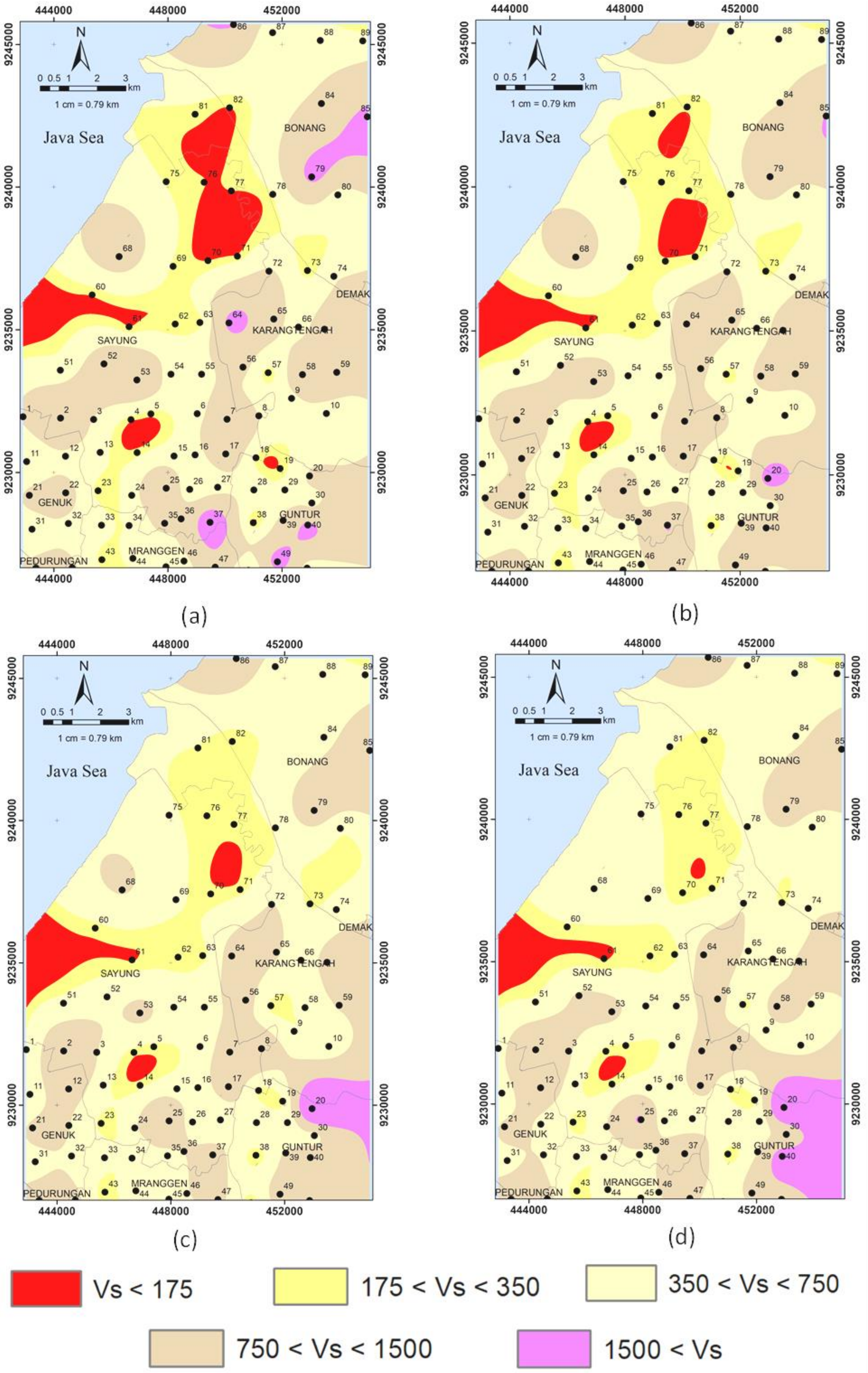

Fig. 4. Modeling v_s at depth (a) 0 m (b), 10 m (c), 20 m (d), 30 m

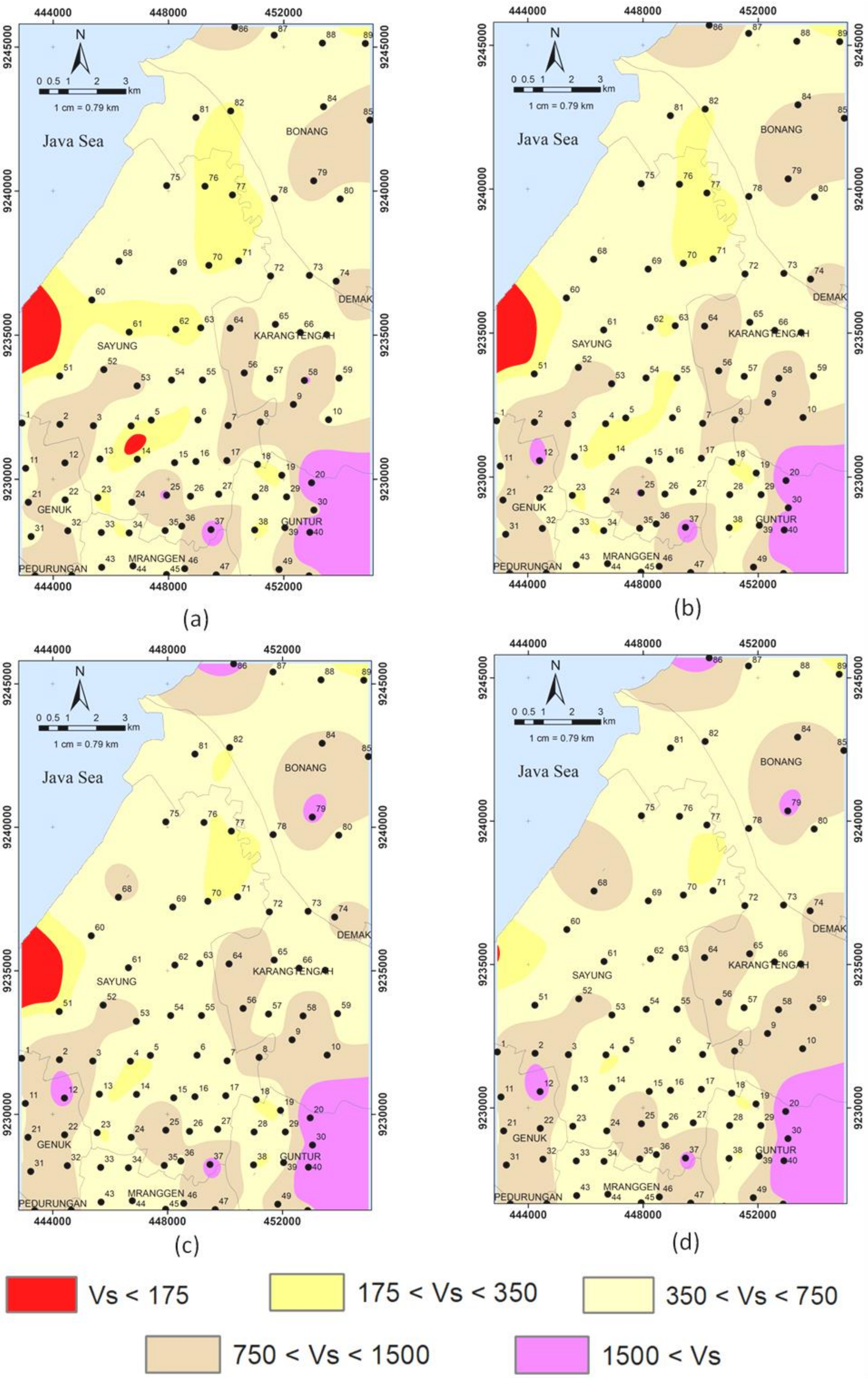

Fig. 5. Modeling v_s at depth (a) 40 m, (b) 50 m, (c) 60 m, (d) 70 m

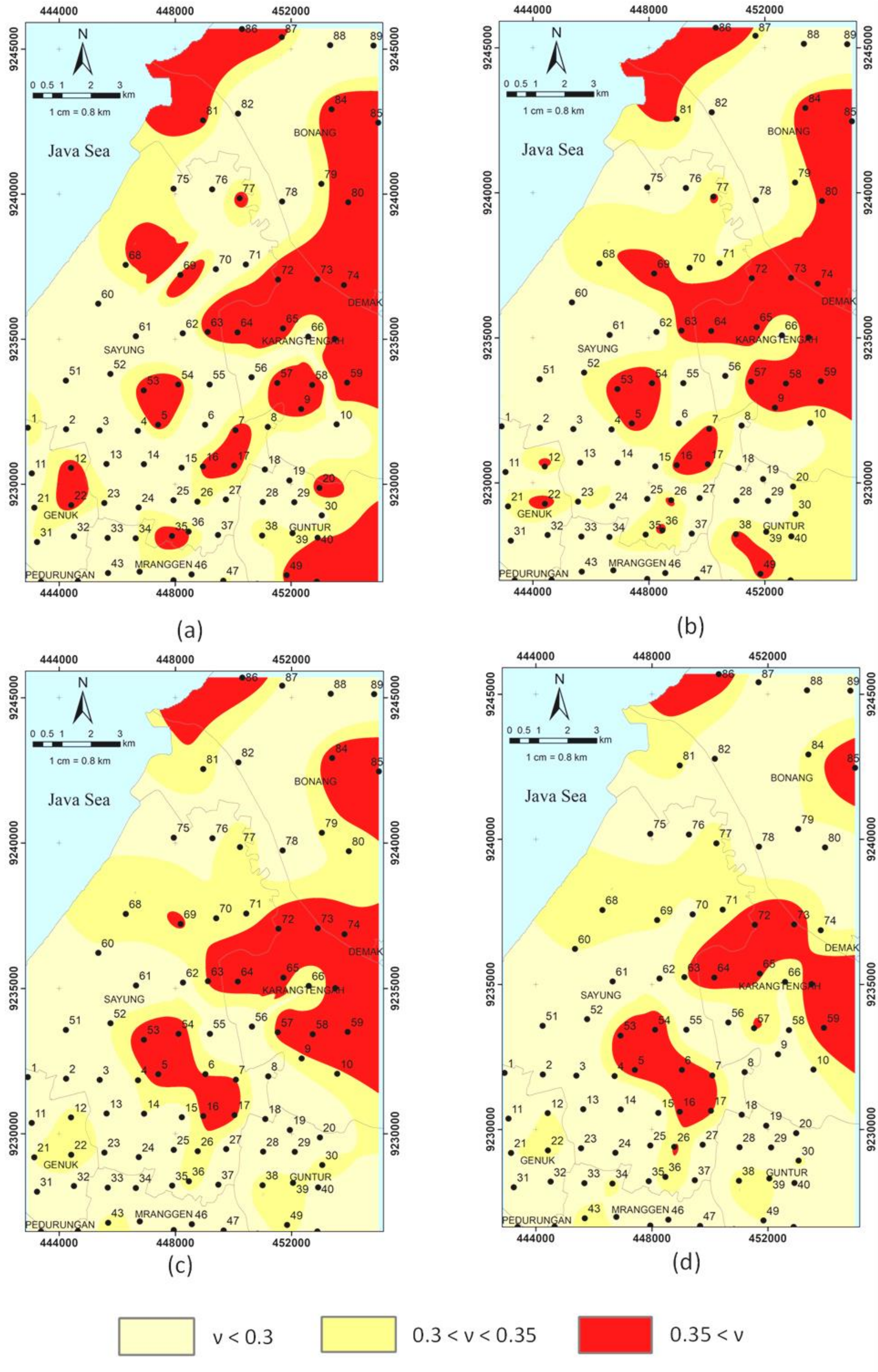

Fig. 6. The Poisson's ratio modeling at depth (a) 0 m, (b) 10 m, (c) 20 m, (d) 30 m

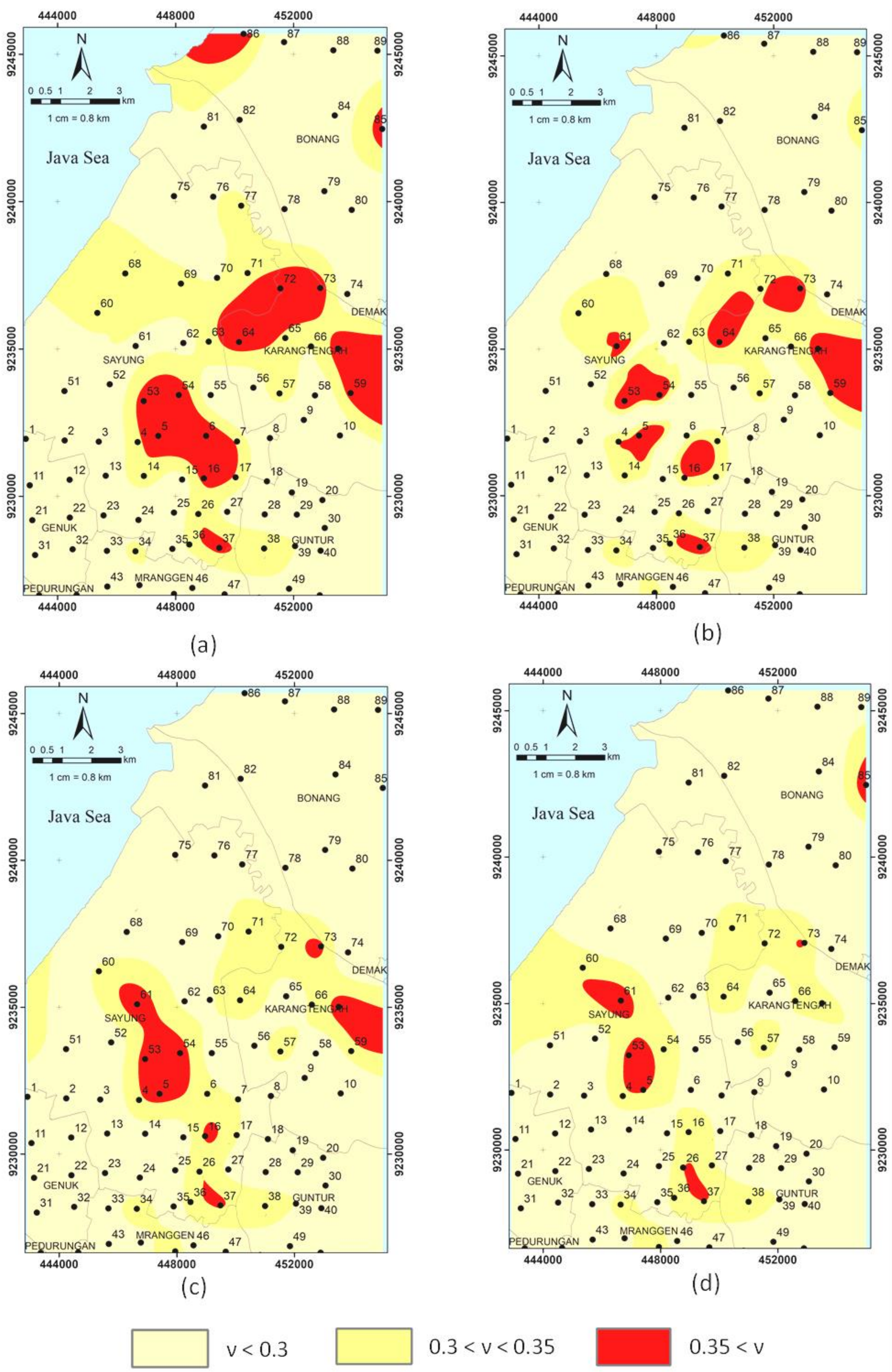

Fig. 7. Poisson ratio modeling at depth (a) 40 m, (b) 50 m, (c) 60 m, (d) 70 m

REFERENCES

American Society of Civil Engineers (2017) Minimum design loads and associated criteria for buildings and other structures (ASCE/SEI 7–16), ASCE. http://doi.org/10.1061/9780784414248

Arintalofa V, Yuliyanto G, Harmoko U (2020) Subsurface characterization of Diwak Derekan geothermal field by HVSR analysis method based on microtremor data. AIP Conference Proceedings, 2296(1). https://doi.org/10.1063/5.0030356

BPS Demak Regency (2020) Demak Regency in figures. BPS Demak Regency. Demak

Das BM (1993) Principles of geotechnical engineering. 3rd edn. PWS Publishing Company, Boston

Herak M (2008) Model HVSR-A matlabs tool to model horizontal to vertical spectral ratio of ambient noise. Journal Computer and Geosciences 34(11): 1514–1526. https://doi.org/10.1016/j.cageo.2007.07.009

Irham MN, Zainuri M, Yuliyanto G, Wirasatriya A (2021) Measurement of ground response of Semarang coastal region risk of earthquakes by Horizontal to Vertical Spectral Ratio (HVSR) microtremor method. IOP Publishing Journal of Physics: Conference Series, 1943(1):012033. http://doi.org/10.1088/1742-6596/1943/1/012033

Keçeli A (2012) Soil parameters which can be determined with seismik velocities. Jeofizik 16:17–29

Lay T, Wallace TC (1995) Modern global seismology. Academic Press, USA, p 521

Mulyono P (1996) Quaternary geological map of the Demak Plate, Java, Bandung. Center for Geological Research and Development

Nakamura Y (1989) a method for dynamic characteristics estimation of subsurface using mikrotremor on ground surface. Q. Rep. RTRI Railw Tech Res Inst 30(1):25-33

Nakamura Y (2000) Clear identification of fundamental idea of Nakamura's technique and its applications. The 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 30 January-4 February 2000, p 2656

Nurwidyanto MN, Harmoko U, Gernowo R et al (2024) Analysis of earthquake vulnerability of the Demak coastal area based on the HVSR (horizontal to vertical spectral ratio) method. Indonesian Journal of Applied Physics 14(2). https://doi.org/10.13057/ijap.v14i2.90703

Nurwidyanto MN, Zainuri M, Wirasatriya A, Yuliyanto G (2023) Microzonation for earthquake hazards with HVSR microtremor method in the coastal areas of Semarang, Indonesia. Geographia Technica 18(1):177–188. http://doi.org/10.21163/GT_2023.181.13

Rahmawan LE, Yuwono BD, Awaluddin M (2016) Monitoring survey of land surface deformation in coastal areas using GPS measurement method in Demak Regency in 2016. Jurnal Geodesi Undip 5(4):44–55 (in Indonesian)

Santosa DPP, Hadian MSD, Zakaria Z (2021) Hydrostratigraphy and aquifer geometry in Palu Groundwater Basin, Central Sulawesi Province after earthquake. Jurnal Sumber Daya Air 17(1):25–38. https://doi.org/10.32679/jsda.v17i.695 (in Indonesian)

Telford WM, Telford WM, Geldart LP (1990) Applied Geophysics. Cambridge University Press, Cambridge, p 792. https://doi.org/10.1017/CBO9781139167932

Thanden RE, Sumadiredja H, Richards PW et al (1996) Geological map of the Magelang and Semarang Sheets, Jawa. Geological Research and Development Centre. Bandung, Indonesia

Trihatmoko E, Wiguna HS, SanjotoTB et al (2020) Preliminary research on seawater intrusion in Sriwulan Village, Demak, Indonesia. Indonesian Journal of Oceanography 2(4):396-402. https://doi.org/10.14710/ijoce.v2i4.9304 (in Indonesian)

Yulianto T, Yuliyanto G (2023a) Microtremor data and HVSR method in the kaligarang fault zone Semarang, Indonesia. Data In Brief 49(109428). https://doi.org/10.1016/j.dib.2023.109428

Yuliyanto G, Yulianto T (2023b) Microtremor data and HVSR method of geothermal manifestation of Mt. Telomoyo, Central Java, Indonesia. Data In Brief 51:109721. https://doi.org/10.1016/j.dib.2023.109721

Yuliyanto G, Harmoko U, Widada S (2017) Identify the slip surface of land slide in Wirogomo Banyubiru Semarang Regency using HVSR method. Int J Appl Environ Sci 12:2069–2078

Yuliyanto G, Nurwidyanto MI (2021) Integrated survey to identify potential groundwater aquifers in Jabungan Semarang using geoelectric and microtremor methods. IOP Publishing Journal of Physics: Conference Series 1943(012026). http://doi.org/10.1088/1742-6596/1943/1/012026

Yuliyanto G, Nurwidyanto MIN, Harmoko U et al (2025) Aquifer zone delineation using correlation between microtremor methods and geoelectricity, ANAS Transactions 1:79–88. https://doi.org/10.33677/ggianas20250100143

ОПРЕДЕЛЕНИЕ ПОТЕНЦИАЛА ВОДОНОСНОГО СЛОЯ АЛЛЮВИАЛЬНЫХ ОТЛОЖЕНИЙ С ИСПОЛЬЗОВАНИЕМ МЕТОДА ГОРИЗОНТАЛЬНОГО И ВЕРТИКАЛЬНОГО СПЕКТРАЛЬНЫХ ОТНОШЕНИЙ (HVSR) НА ПРИМЕРЕ ПРИБРЕЖНОЙ ЗОНЫ ДЕМАКА, ИНДОНЕЗИЯ

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Резюме. Прибрежная зона Демак состоит из аллювиальных равнин, на которые повлияло наличие прибрежных отложений. Аллювиальная зона содержит такие материалы, как иловая глина, зернистая глина, средний песок, илистый песок, ил, глина и осадок. Знание структуры почвы и модуля упругости в прибрежной зоне округа Демак необходимо для определения потенциала водоносных горизонтов в этом районе. Исследования с использованием метода микросейсм HVSR (горизонтально-вертикальное спектральное отношение) были проведены для определения потенциала водоносных горизонтов под поверхностью земли в прибрежной зоне Демак. Сбор данных проводился в 89 точках в течение 10 минут с использованием 3-компонентного сейсмографа TDS типа 303S и частотой дискретизации 20 Гц. Данные микросейсм обрабатывались с помощью программного обеспечения Excel, Geopsy и Dinver для получения параметров v_s и коэффициента Пуассона. Разницу между водоупорами можно определить, объединив значение v_s с коэффициентом Пуассона. Значение v_s < 350 м может характеризовать наличие мягких глинистых, плотных глинистых и иловых структур, в то время как коэффициент Пуассона характеризует водонасыщенность материала. Водоносные горизонты могут быть обнаружены при сочетании значений от 350 < v_s < 1500 м и коэффициенте Пуассона > 0.3. Потенциальные водоносные горизонты с насыщенными глинистыми водоупорами обнаружены на станциях 5, 57 и 73, в то время как ненасыщенные глинистые водоупоры – на станции 61. Потенциальные водоносные горизонты с иловыми водоупорами обнаружены на станциях 14, 60, 71, 38 и 34.

Ключевые слова: *микротремор, HVSR, водоносный слой, коэффициент Пуассона, v_s, прибрежная зона Демак, грунтовые воды*

İNDONEZİYANIN DEMAK SAHİL ZONASI NÜMUNƏSİNDƏ ÜFÜQİ ŞAQULİ SPEKTRAL ƏLAQƏLƏR (HVSR) METODUNDAN İSTİFADƏ EDƏRƏK ALLÜVİAL ÇÖKÜNTÜLƏRİN SULU QATININ POTENSİALININ TƏYİNİ

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Xülasə. Demak sahil zonası. Sahil çöküntülərinin təsirinə məruz qalmış allüvial düzənliklərdən ibarətdir. Allüvial zonada lil, gil, dənəvər gil, orta qum, lilli qum, lil, gil və çöküntü kimi materiallar var. Demak sahil bölgəsindəki torpağın strukturu və elastiklik modulu haqqında məlumat bölgədəki sulu təbəqələrin potensialını təyin etmək üçün lazımdır. Demak sahil zonasında Yer səthinin altındakı sulu təbəqələrin potensialını təyin etmək üçün HVSR mikroseysm metodundan (üfüqi şaquli spektral nisbət) istifadə edərək tədqiqatlar aparılmışdır. Məlumatların toplanması 89 nöqtədə 10 dəqiqə ərzində 3 komponentli TDS tipli 303S seysmoqraf və 20 Hz nümunə dərəcəsi ilə aparılmışdır. Mikroseism məlumatları vs parametrləri və Poisson əmsalı əldə etmək üçün Excel, Geopsy və Dinver proqramı ilə işlənmişdir. Su müqaviməti arasındakı fərqi vs dəyərini Poisson əmsalı ilə birləşdirərək müəyyən edilə bilər. Vs dəyəri < 350 m yumşaq gil, sıx gil və lil quruluşlarının mövcudluğunu xarakterizə edə bilər, Poisson əmsalı isə materialın Su doymasını xarakterizə edir. Akiferlər 350 < vs < 1500 m və Poisson əmsalı > 0.3 arasındakı dəyərlərin birləşməsi ilə aşkar edilə bilər. Doymuş gil su keçirməyən potensial sulu təbəqələr 5, 57 və 73 stansiyalarında, doymamış gil su keçiriciləri isə 61-ci stansiyada tapılır. 14, 60, 71, 38 və 34-cü stansiyalarda lil su keçirməyən potensial sulu təbəqələr aşkar edilmişdir.

Açar sözlər: *mikrotremor, HVSR, sulu təbəqə, Poisson əmsalı, vs, Demak sahil zonası, yeraltı sular*