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GROUNDWATER AQUIFER DELINEATION USING POISSON'S RATIO ANALYSIS FROM MICROTREMOR DATA INVERSION

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ABSTRACT

To develop new potential wells, in this research study identification and delineation of groundwater aquifer used Poisson's ratio extracted from microtremor inversion data in an area of 240 x 174 m^2 with 22 microtremor measurement stations. As a referred station is the former drilled well that is used to determine the location of the well using the geoelectric method. Based on the 2D and 3D modeling of the Poisson's ratio value, it can be delineated the subsurface aquifer and the possible direction of developing new drilling locations.

Keywords: aquifer, delineation, poison's ratio, microtremor, inversion.

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INTRODUCTION

In searching for aquifers or deep groundwater sources, the most widely used geophysical method is the geoelectric method. Several studies on delineation of groundwater aquifers using geoelectric methods [1, 2, 3, 4, 5, 6, 7]. Another alternative geophysical method that is being developed for the search for groundwater aquifers is the microtremor method [8, 9]. The concept under development uses this passive seismic method is that shear waves cannot propagate in a fluid and the presence of a fluid phase can be identified based on the relatively large Poisson ratio value to a maximum value (>0.3). The use of this microtremor method is very efficient because it does not require long cable stretches, and the equipment is simple and compact, easy to operate, and mobile [9].

One of the efforts to address the increasing need for groundwater is to improve or develop the capacity of groundwater wells and the number of wells to be drilled. For this reason, we used Poisson's ratio approach extracted from microtremor inversion data. In Terong Village, Dlingo District, Bantul Regency, Yogyakarta Special Region, Indonesia, there is a former bore well that has been operating for a long time, which used to be obtained using the geolectric resistivity method (Figure-1). In this study, we used this well as forward modeling data. The location of this well is -7.888720S, 110.456287E.

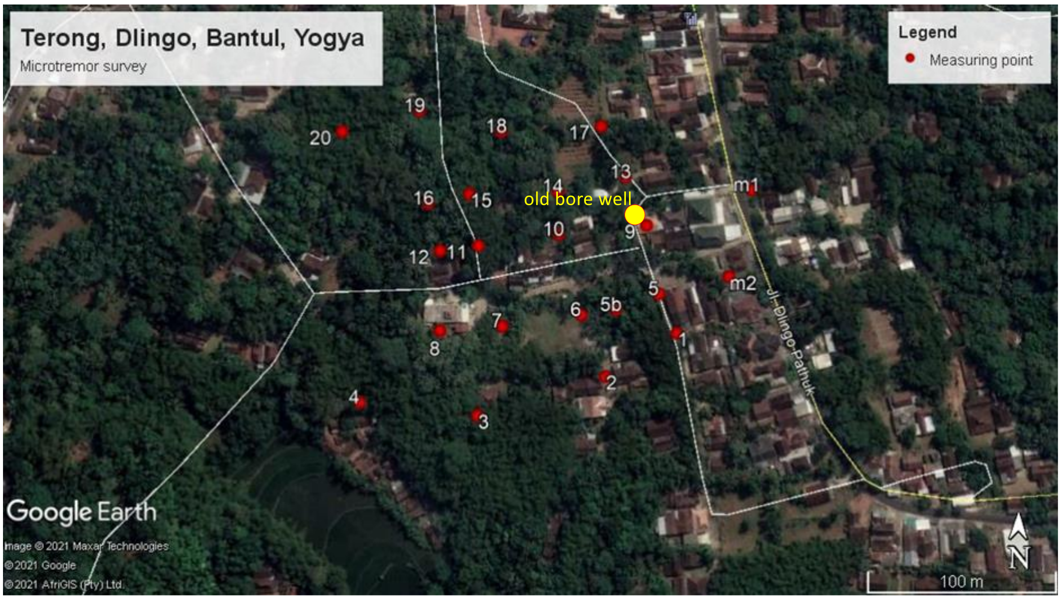

Figure-1. Location of measurement stations (red circle). The old bore well is located near the station 9 (yellow circle). The map is taken from Google map in 2021.

Microtremor

The microtremor was acquired by Omori in 1908, then developed by Kanai and Tanaka in 1961 and then in 1970 Nogoshi and Igarashi introduced a technique that uses the horizontal to the vertical spectral ratio of the microtremor [10], which was then used by Nakamura [11]

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to estimate the resonant frequency and local geological amplification factors from microseismic data. Microtremor is low amplitude vibration around 0.1-1 microns and velocity amplitude of 0.0001-0.01 cm/sec at the ground surface caused by various natural factors such as wind, sea waves, vehicle noise, and others [12]. One of the microtremor methods, namely the HVSR method or Horizontal to vertical Spectral ratio, is also known as the single station method because the compared spectra are measured from a measurement station. The use of this method then developed a lot in geotechnics and the environment with early publications on the estimation of soil vulnerability index [11], then also developed for estimation of building vulnerability index [13, 14], estimation of vulnerable areas building damage due to local effects [15, 16], local geological characterization, natural frequency and amplification related to physical subsurface parameters and until now there have been many applications of this method such as identification of landslide zones [17, 18, 19, 20, 21], vibration vulnerability identification [22], and identification of ground layer structures of land subsidence sensitive areas [23].

Poisson's Ratio

One of the elastic parameters of the rock that can be extracted from microtremor inversion data is the Poisson Ratio (σ), which is the ratio of transversal strains or contractions to longitudinal strains or extensions resulting from changes in normal stress due to compression or dilation. In the form of the ratio of the velocity of the longitudinal wave V_p to the shear wave V_s, Poisson's ratio can be written as [24:

$$\sigma = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \quad (1)$$

In general, the elastic parameters of rocks largely depend on their lithological properties, one of which is water saturation. In a fluid medium that has zero rigidity, there is no shear wave that propagates and the magnitude σ in the fluid is 0.5. The porous sediment liquid saturation causes an increase in P-wave velocity which results in value σ will increase. It is generally known that seismic wave propagation from unsaturated sediments to saturated sediments will increase the P-wave velocity and consequently, the Poisson ratio tends to increase in magnitude. At constant pressure, σ increases with increasing water saturation and with increasing porosity.

METHOD

In this study, data acquisition was carried out at 22 measurement stations in an area of 240 m x 75 m with the duration of data acquisition at each measurement station was 20 minutes. Data acquisition was carried out using 4 portable seismometers using a VHL PS 2B triaxial geophone sensor, 2 units of DI710 dataloggers with a sampling rate 400, and 2 units of GL 240 dataloggers with a sampling of 50 ms. By using geopsy software, the data in the time domain is processed and HVSR curves are generated with information on the magnitude of the amplification value and the dominant frequency. Then using the Dinver software the data is inverted and the data of compression wave velocity and shear wave velocity are obtained. Using Excel software, the Poisson ratio value for a certain thickness or depth is calculated,. Voxler software models the Poisson's ratio in 3D. Then using the Surfer software, the contours of the shear wave velocity and Poisson ratio on the surface and 2D depth profile were modeled.

RESULTS AND DISCUSSIONS

The contours of the Poisson's ratio research area on the surface are given in Figure-2. There are 5 zones that have a fairly high Poisson ratio value compared to other areas, namely below dots 5, 5B, 8, and 18. To see zones with high Poisson ratios in the subsurface efficiently, 3D modeling is used as shown in Figure-3.

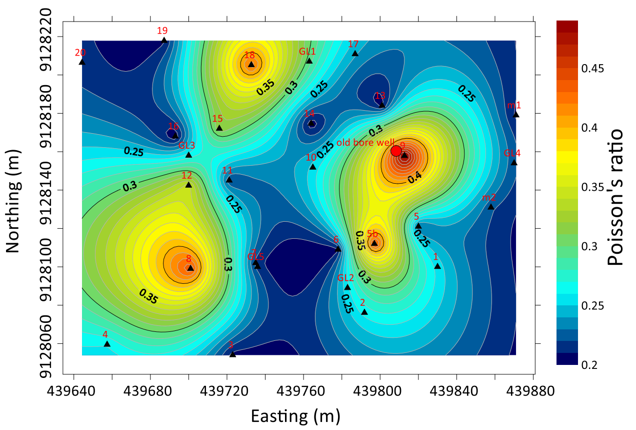

Figure-2. Poisson's ratio contour of the research area. The red circle mark is an old bore well.

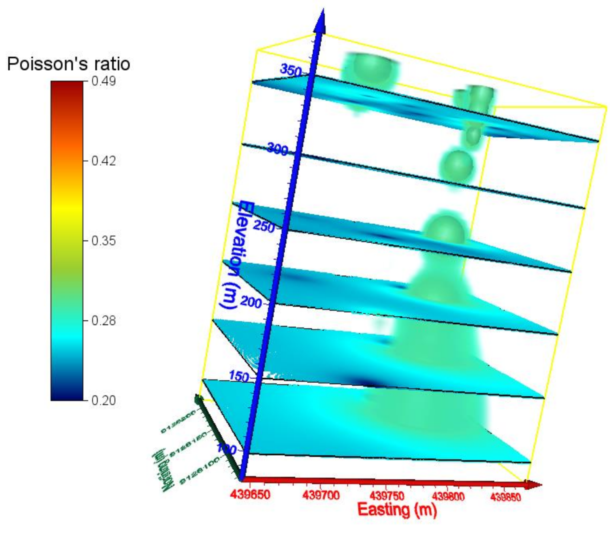

Figure-3. Poisson ratio 3D model of the research area. It can be seen below station 9 near the old drilled well, there is a high Poisson ratio value starting at a depth of 70 m which is getting further down the shape of the distribution is more divergent.

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In Figure-3, it is clearly seen that there is an aquifer body below station 9 which spreads around it with an increasingly larger area. To emphasize the direction of delineation, a 2D Poisson-to-depth profile is made with a path that passes through station 9, namely from station 12 to station m1, from station 19 to station m2, and station 17 to station 1 as shown in Figure-4.

Based on Figure-4, it can be seen that below station 12 to station m1 and station 19 to station m2, drilling can be carried out with a depth approaching station 9 which is getting shallower. For the trajectory of station 17 to station 1, it is seen below station 17 and station 13, there is no groundwater aquifer potential. Below station 9 to station 1 there is a Poisson ratio with a maximum value indicating the greatest potential for the presence of deep groundwater aquifers.

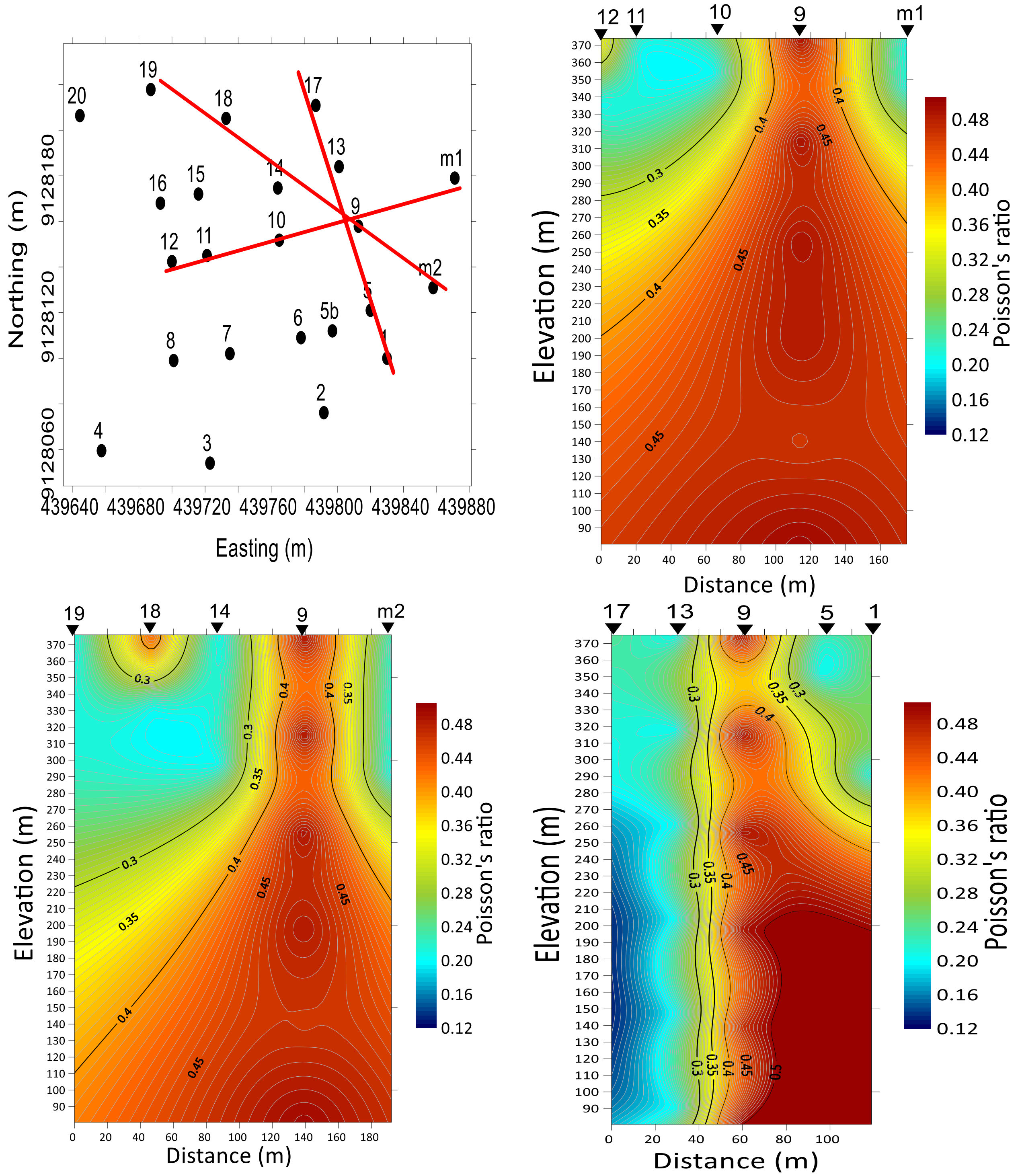

Figure-4. Poisson's ratio 2D profile for the path of station 12 to station m1 (top right), 2D profile of Poisson's ratio for path of station 19 to station m2 (bottom left), and 2D Poisson's ratio profile for path of station 17 to station 1.

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CONCLUSIONS

Based on 2D and 3D analysis of the Poisson's ratio model in the research area, deep groundwater aquifers can be delineated and can be developed for new drilling below station 9 which is close to the old well drilled towards station 5 which has a maximum Poisson’s ratio value (0.5) with the greatest potential at depths from 170 m.

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REFERENCES

[1] Aluko KO, Raji WO, and Ayolabi EA. 2016. Application of 2-D resistivity survey to groundwater aquifer delineation in a sedimentary terrain: A case study of south-western Nigeria. Water Utility Journal 17: 71-79.

[2] Riwayat AA, Nazri MAA, and Abidin MHZ. 2017. Application of Electrical Resistivity Method (ERM) in Groundwater Exploration, IOP Conf. Series: Journal of Physics: Conf. Series 995 (2018) 012094.

[3] Shantharam Y. and Elangovan K. 2018. Groundwater potential zone delineation using geo-electrical resistivity method and GIS for Coimbatore, India. Indian Journal of Geomarine Sciences. 47(05): 1088-1095.

[4] Elubid BA, Huang T, Peng DP, Ekhlas H. Ahmed EH, Babiker MM. 2020. Delineation of groundwater potential zones using integrated remote sensing, GIS and multi-criteria decision making (MCDM). Desalination and Water Treatment. 192: 248-258.

[5] Fajana AO. 2020. Groundwater aquifer potential using electrical resistivity method and porosity calculation: a case study. NRIAG Journal of Astronomy and Geophysics, 9(1): 168-175, DOI: 10.1080/20909977.2020.1728955

[6] Irwan, Ilham, Susilo A. 2020. Three-Dimensional Resistivity Model for Ground Water Exploration in Volcanic Zone of Tidar Pleteau, Malang, East Jawa. Indonesian Physical Review. 3(1).

[7] Raji WO and Abdulkadir KA. 2020. Geo-resistivity data set for groundwater aquifer exploration in the basement complex terrain of Nigeria, West Africa. Data in Brief 31- 105975.

[8] Zuhri AS, Yuliyanto G, and Harmoko U. 2020. Modeling of 3D Aquifer Layers using Poisson’s Ratio Analysis HVSR Method in Tembelang Village, Candimulyo District, Magelang Regency. Journal of Physics and Its Applications. 3(1): 124-128.

[9] Yuliyanto G and MI Nurwidyanto. 2021. Integrated survey to identify potential groundwater aquifers in Jabungan Semarang using geoelectric and microtremor methods. Journal of Physics: Conference Series 1943 (2021) 012026.

[10] Nakamura Y. 1989. A Method for Dynamic Characteristics Estimations of Subsurface Using Microtremors on the ground Surface, QR RTRI, 30, pp. 25-33.

[11] Nakamura Y. 1997. Seismic Vulnerability Indices for Ground and Structures using Microtremor. World Congress on Railway Research, Florence, Nov.

[12] Mirzaoglu M and Dykmen U. 2003. Application of microtremors to seismic microzoning procedure Jurnal of the Balkan Geophysical Society. 6(3): 143-153, Greece.

[13] Sato T., Nakamura Y. and Saita J. 2004. Evaluation of The Amplification Characteristics of Subsurface Using Microtremor and Strong Motion: The Studies at Mexico City. 13th World Conference on Earthquake Engineering, Paper No. 862, Vancouver, B.C., Canada.

[14] Sato T., Nakamura Y., Saita J. 2008. The Change of The Dynamic Characteristics u sing Microtremor. The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China.

[15] Panou A. A., N. Theodulidis, P. Hatzidimitriou, K. Stylianidis, C. B. Papazachos. 2005. Ambient noise horizontal-to-vertical spectral ratio in site effects estimation and correlation with seismic damage distribution in urban environment: the case of the city of Thessaloniki (Northern Greece). Soil Dynamics and Earthquake Engineering. 25: 261-274.

[16] Panou A. A. 2007. Use of Ambient Noise for Microzonation Studies in Urban Environment: The City Of Thessa Loniki (N. Greece), 4th International Conference on Earthquake Geotechni Cal Engineering June 25-28, 2007 Paper No. 1580.

[17] Sasongko DP., Yuliyanto G. and Arifin Z. 2020. Karakterisasi Daerah Rawan Gerakan Tanah di Lapangan Pandanmurti Desa Candigaron Kecamatan

ARPN Journal of Engineering and Applied Sciences

Sumowono Kabupaten Semarang dengan Metode Mikrotremor. Jurnal Pembangunan Wilayah dan Kota. 16(2).

[18] Yuliyanto G, Harmoko U, and Widada S. 2016. Identification of Potential Ground Motion Using the HVSR Ground Shear Strain Approach in Wirogomo Area, Banyubiru Subdistrict, Semarang Regency. International Journal of Applied Environmental Sciences. 11(6): 1497-1507.

[19] Yuliyanto G, Harmoko U, and Widada S. 2017. Identify the slip surface of land slide in Wirogomo Banyubiru Semarang Regency using HVSR method. International Journal of Applied Environmental Sciences. 12(12): 2069-2078.

[20] Yuliyanto G, Harmoko U, and Rina DI. 2018. Identification of landslide area in Jabungan Village, Banyumanik, Semarang by using microtremor method. International Journal of Recent Trends in Engineering & Research (IJRTER). 06, Issue 03 pp 38-46. Volume 04, Issue 05.

[21] Afriyanti N, Yuliyanto G, and Irham MN. 2020. Identification of landslides arround Old Gombel in Tinjomoyo Village Semarang using HVSR method. International Journal of Recent Trends in Engineering & Research (IJRTER). 06(03): 8-46.

[22] Sasongko DP., Yuliyanto G. and Arifin Z. 2019. Vibration Vulnerability Identification in Kota Lama Semarang using Microtremor Method. Indonesian Journal of Applied Physics. 9(2): 105-111.

[23] Widada S., Zainuri M., Yuliyanto G., Yulianto T. and Deny NS. 2019. Identification ground layer structure of land subsidence sensitive area in Semarang city with horizontal to vertical spectral ratio method. IOP Conf. Series: Earth and Environmental Science 246 -012023.

[24] Lay T and Wallace TC. 1995. Modern Global Seismology. Academic Press. California. United States.