ANAS Transactions **Earth Sciences** **1 / 2025**

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AQUIFER ZONE DELINEATION USING CORRELATION BETWEEN MICROTREMOR METHODS AND GEOELECTRICITY

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Keywords: *microtremor, geoelectric, resistivity, HVSR, aquifer zone, Poisson's ratio, Grabang Magelang*

Summary. Geoelectric and microtremor are geophysical methods that can be used to determine subsurface conditions, especially in determining the presence of aquifer zones. This study aims to determine the potential and presence of aquifer rocks in the Grabag District area through microtremor and geoelectric methods and to compare the results of the two methods. The area of the Grabag District is very limited in conducting geoelectrical research because it is related to narrow topographical contours, so a microtremor method is needed to determine the condition of the aquifer below the ground surface. Measurements in this study resulted in 3 geoelectric trajectories and 20 microtremor measurement stations. The results of microtremor and geoelectric measurements have a good correlation between the two. The geoelectrical method uses resistivity parameters while the HVSR method uses v_s and Poisson's ratio parameters. There are several anomalies that can be suspected as the presence of aquifer zones such as surface water found at station 2, unpressured aquifers at stations 16 and 19, depressed aquifers at stations 1, 10 and 20 and water loss zones at stations 4, 2 and 13. Based on the advantages of the two methods in collecting data in the field, microtremor is more flexible and better used in narrower conditions like in this study and the depth of microtremor does not depend on how long the stretch is like geoelectric.

Introduction

Groundwater is very necessary and increasing population will lead to a reduction in available groundwater reserves. The increasing number of people requires a sufficient amount of water. An area that has limited water is difficult to meet the needs of a high population, especially during the dry season. According to Sadjab et al. (2012) groundwater is stored in an aquifer, which is a water-saturated geological formation that has the ability to store and release water economically and in sufficient quantities. Investigation of water catchment areas in an area is inseparable from its geological conditions, which include rock composition, rock properties and geological structure. The subsurface geological conditions of an area can be determined through geophysical measurements.

Geophysics is a branch of geology that applies physical principles in understanding and finding solutions to geological problems (Alile, Amadasun, 2008). Some examples of methods from geophysics that can be used for groundwater exploration are electrical resistivity, seismic refraction and electromagnetic methods. The resistivity method is carried out using an artificial current source, which is transmitted below the ground surface (Sheriff, Geldart, 1995). Geoelectricity can provide information about the structure of groundwater and can determine vertical variations in subsurface electrical properties that can be related to the geology of the area (Omada, Obayomi, 2012). Based on research by Kasidi (2017), the geoelectric method can be used to determine groundwater potential, namely by using the VES method, so that groundwater potential is obtained which includes VES 1, 5, 7, 9, 11, 12, 16, 17, and 18 at depths ranging from 40 – 80 m.

The microtremor method is used to support the analysis of groundwater aquifers, which is carried out using the geoelectric method. The 1D profile from the geoelectric method will be correlated with the 2D profile from the microtremor method on the same line. Yuliyanto and Nurwidyanto (2021) introduced a geophysical method that can be used to identify potential groundwater aquifers by utilizing microwaves using the microtremor method. The parameters used to determine the existence of an aquifer are v_s and Poisson's ratio. Based on his research, the potential for subsurface water sources is below microtremor point 9 with a v_s value of 840 m/s with a Poisson's ratio value > 0.3 at a depth of 70 m.

This research will provide an overview of the potential and existence of aquifer rocks in the Grabag

District area using geophysical methods, namely microtremors using v_s parameters and Poisson's ratio. Apart from that, this research will also provide a comparison of the results of microtremor and geoelectric survey methods to determine the aquifer.

Theory

Geological structure

Based on the Magelang-Semarang geological map sheet (Thanden et al., 1996) it can be explained that Grabag's geological conditions are composed of Merbabu volcanic rock (Qme) composed of igneous rock composed of olivine and andesite augite, Andong and Kendil (Qak) volcanic rock composed of hornblende-augit andesite breccias and Gilipetung volcanic rocks (Qg) which are composed of hollow lava flows, the three rock units are the result of volcanic activity while the sedimentary rocks that compose this area are the Kaligetas Formation (Qpkg) which is composed of volcanic breccias, lava flows, tuff, tuffaceous sandstone and claystone.

Groundwater can be found in permeable soil known as aquifers which are water-binding formations that allow large enough amounts of water to move through them. Glacial sand and gravel deposits, floodplain alluvial fans and sand delta deposits are all excellent water sources. The aquifer system is controlled by several aspects which can be lithology, stratigraphy, and geological structure of geological sedimentary materials and formations (Kodoatie, 1996). These hydrogeological boundaries determine three important elements in the anatomy of a hydrogeological basin, namely recharge area, flowing area, and discharge area. The various types of aquifers that will determine the distribution of groundwater in hydrogeological mapping can be divided into 4 parts, namely:

1. Unconfined aquifer
2. Confined Aquifer
3. Semi Confined Aquifer
4. Semi Unconfined Aquifer

Microtremor

Microtremor is a low amplitude vibration of around 0.1-1 microns and a speed amplitude of 0.0001-0.01 cm/second at the ground surface caused by various natural factors such as wind, sea waves, vehicle noise, and others (Mirzaoglu, Dykmen, 2003). Microtremor, also called background seismic (ambient vibration), is a ground vibration caused by natural or artificial events that has relatively low energy and low amplitude which is always present in every seismic recording and can describe geological conditions near the surface (Tokimatsu, 1995). In the study of seismic engineering, softer lithology has a higher risk of being shaken by earthquake waves, this is because it experiences greater wave amplification compared to more compact rocks (Kanai, 1983).

The HVSR (Horizontal to vertical spectrum ratio) transfer function of microtremors introduced by Nakamura (1989) can be expressed by equation 1.

$$\mathbf{SE}\ (\boldsymbol{\omega}) = \frac{\mathbf{HS}\ (\boldsymbol{\omega})}{\mathbf{HB}\ (\boldsymbol{\omega})} \tag{1}$$

where $\mathbf{H}_{\mathbf{S}(\omega)}$ is the horizontal component microtremor spectrum on the surface while $\mathbf{H}_{\mathbf{B}(\omega)}$ is the horizontal component microtremor spectrum found in the bedrock. The wave amplification contained in the vertical component can be referred to as the spectrum ratio of the vertical component at the surface and in the bedrock which can be written in equation 2.

$$\mathbf{AS}\ (\boldsymbol{\omega}) = \frac{\mathbf{VS}\ (\boldsymbol{\omega})}{\mathbf{VB}\ (\boldsymbol{\omega})} \tag{2}$$

where VS (ω) is the vertical component microtremor spectrum on the surface, and VB (ω) is the vertical component microtremor spectrum in the bedrock. Normalization is carried out to reduce the source effect contained in the horizontal gain spectrum SE (w) on the source spectrum As (w) to obtain equation 3. SM (ω) is the transfer function for the soil layer.

$$\boldsymbol{SM\ (\omega)} = \frac{\boldsymbol{SE\ (\omega)}}{\boldsymbol{AS\ (\omega)}} \tag{3}$$

Poisson's ratio (σ) can be interpreted as a ratio of transverse strain or contraction to longitudinal strain or extension due to changes in normal stress due to compression or dilation. The form of comparison related to the propagation speed of the longitudinal wave v_p to the shear wave v_s can be written as (Lay, Wallace, 1995).

$$\boldsymbol{\sigma} = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)} \tag{4}$$

Geoelectric

Geoelectric is one of the geophysical methods to determine the resistivity value of the rock layers below the soil surface. Measurements are made by flowing an electric current into the ground using 2 metal electrodes (current electrodes) commonly known as current electrodes A and B. If the ground is dry, water should be sprinkled around the electrodes to improve the current relationship. The electric voltage that occurs between the two electrodes is also measured with 2 metal electrodes (potential electrodes) known as potential electrodes M and N. The value of rock resistivity is a representation of variations in the physical and chemical characteristics of the rock.

Apparent resistivity can be interpreted as the resistivity measured over a layered medium which has a difference in resistivity and layer thickness which is considered to be isotropically homogeneous. The earth consists of layers with different ρ at each depth, so that the measured potential is the influence of these depth layers. This will mean that the measured resistivity is not the resistivity value for just one layer. This apparent resistivity is formulated by equation 5 (Sharma, 1997; Telford et.al., 1990):

$$\rho_{(a)} = K \frac{\Delta V}{I} \quad \textbf{(5)}$$

$\rho_{(a)}$ is the apparent resistivity with units of Ωm (ohmmeter), K is the geometry factor of the electrode configuration, ΔV is the measured potential between potential electrodes with units of V (volts), and I is the measured electric current between current electrodes with units of A (amperage). Geometry factors vary depending on the type of configuration used during the data collection process in the field. For the resistivity geoelectric method used, the Schlumberger configuration aims to identify vertical resistivity continuity (Telford et.al., 1990). The geometric factor of the Schlumberger configuration is shown by equation 6 (Sharma, 1997; Telford et.al., 1990):

$$K = \frac{\pi}{4}\left[\frac{(AB)^2 - (MN)^2}{MN}\right] \quad \textbf{(6)}$$

where K is the configuration geometric factor, π is a constant (3.14), AB is the distance from current source A to current source B (m), and MN is the distance from potential source M to potential source N (m). The inversion method is a method that can obtain actual resistivity values where the earth has heterogeneous resistivity. According to Jupp and Vozoff (1976), inversion is generally described by a model or point with a layered earth structure.

Research methods

Research on estimating the aquifer zone at the study site was carried out using several tools. Microtremor data collection uses 3 sets of data loggers, 3-component digital seismograph VHL PS 2B, global positioning system (GPS), and compass to determine the North - South direction from data collection. Software that can be used later for data processing in microtremor (HVSR) method is Microsoft Excel, Notepad, Notepad++, Geopsy, and Dinver (Irham et al., 2021) (Arintalofa et al., 2022). Raw microtremor data will be obtained in the form of a file in CSV format which can be opened in Microsoft Excel. This data shows the response of microtremors in showing subsurface images with several components, namely horizontal East-West component, horizontal North-South component, and then vertical component. These three components will then be processed using Geopsy software to produce an HV curve, dominant frequency and amplification factor (Yuliyanto, Yulianto, 2023). These results can be processed again using dinver software to produce v_p, v_s, density and depth values (Yulianto, Yuliyanto, 2023). The results of v_p and v_s will later be used in determining the Poisson's ratio value.

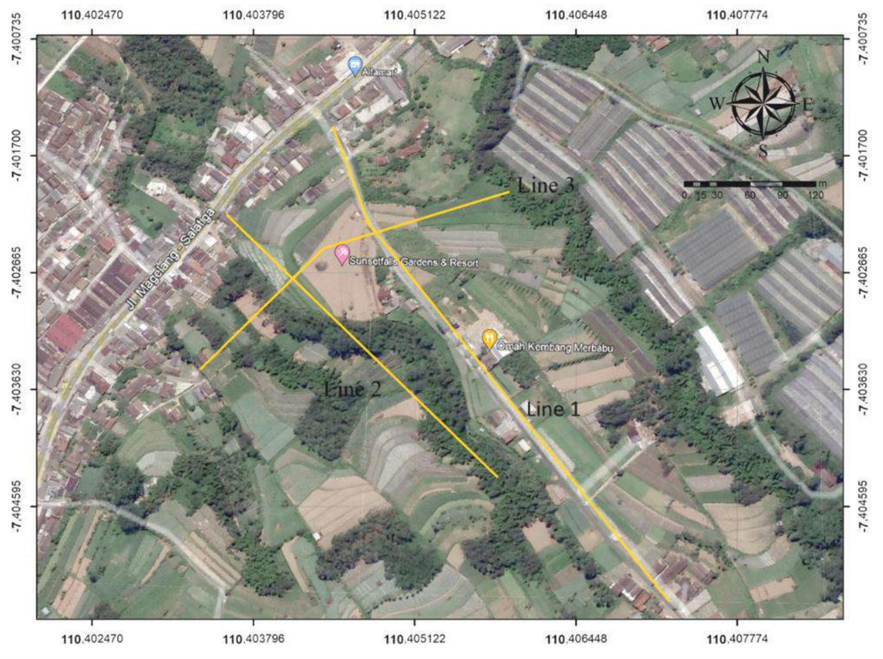
Table 1

2D trajectories of microtremor measurements

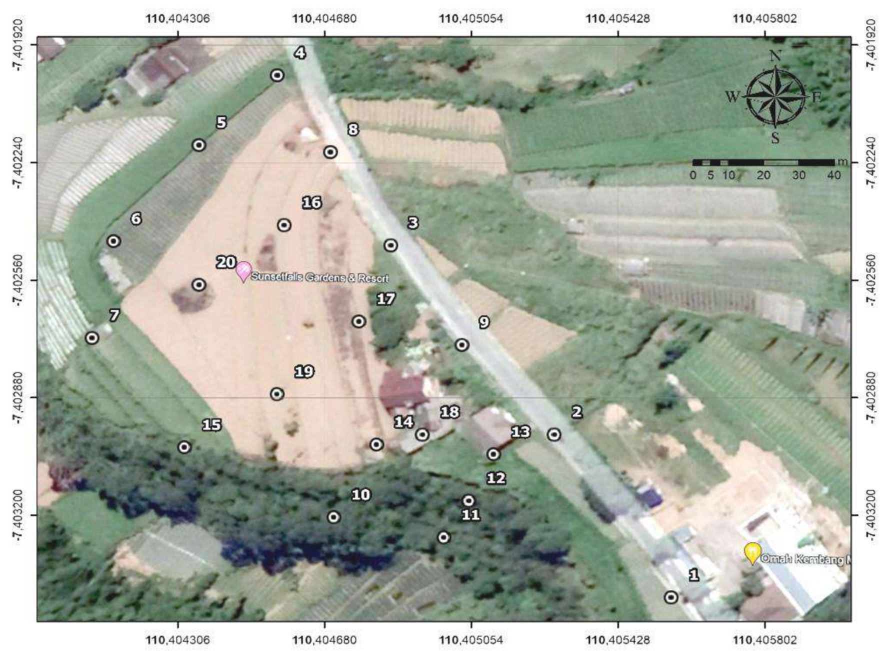
Trajectory	Microtremor measurement station
A – A'	4, 8, 3, 9, 2, 1
B – B'	5, 16, 17, 18, 13
C – C'	6, 20, 19, 14, 12
D – D'	7, 15, 10, 11
E – E'	7, 6, 5, 4
F – F'	7, 20, 16, 8
G – G'	15, 19, 17, 3
H – H'	10, 14, 18, 9
I – I'	11, 12, 13, 2

Table 1 explains the 2D trajectories used in microtremor data analysis. The microtremor measurement stations in Table 1 show the name and sequence of the track used, while the trajectory shows the name of the track. Data modeling uses Golden Software: Surfer which is used for 2D modeling.

Retrieving geoelectrical data using Naniura NRD-300. Software that can be used to process geoelectrical data is Res1DInv. The configuration method used in this research uses the Schlumberger configuration. In this study, the path length AB/2m from each line 1, 2, and 3 from geoelectric measurements is 250 m, 180 m, and 180 m. Figure 1(a): 3 geoelectrical path measurements were carried out together with (b) 20 microtremor measurement stations due to the limitations of the field area (length and width) of the study location on the length of the geoelectric cable stretch at the site location. Both locations use a geographic coordinate system (decimal degree system) with S 7.405560° to S 7.400735° and E 110.40247° to E 110.407774°. The microtremor method uses 3 sets of tools, each microtremor requiring 10 minutes of recording at each station location. Meanwhile, the geoelectric method uses 1 set of tools and takes around 90 minutes for a path length (AB/2) 80 m (depending on the length of the track).



(a)



(b)

Fig. 1. Measurement trajectory for (a) Geoelectric, (b) Microtremor

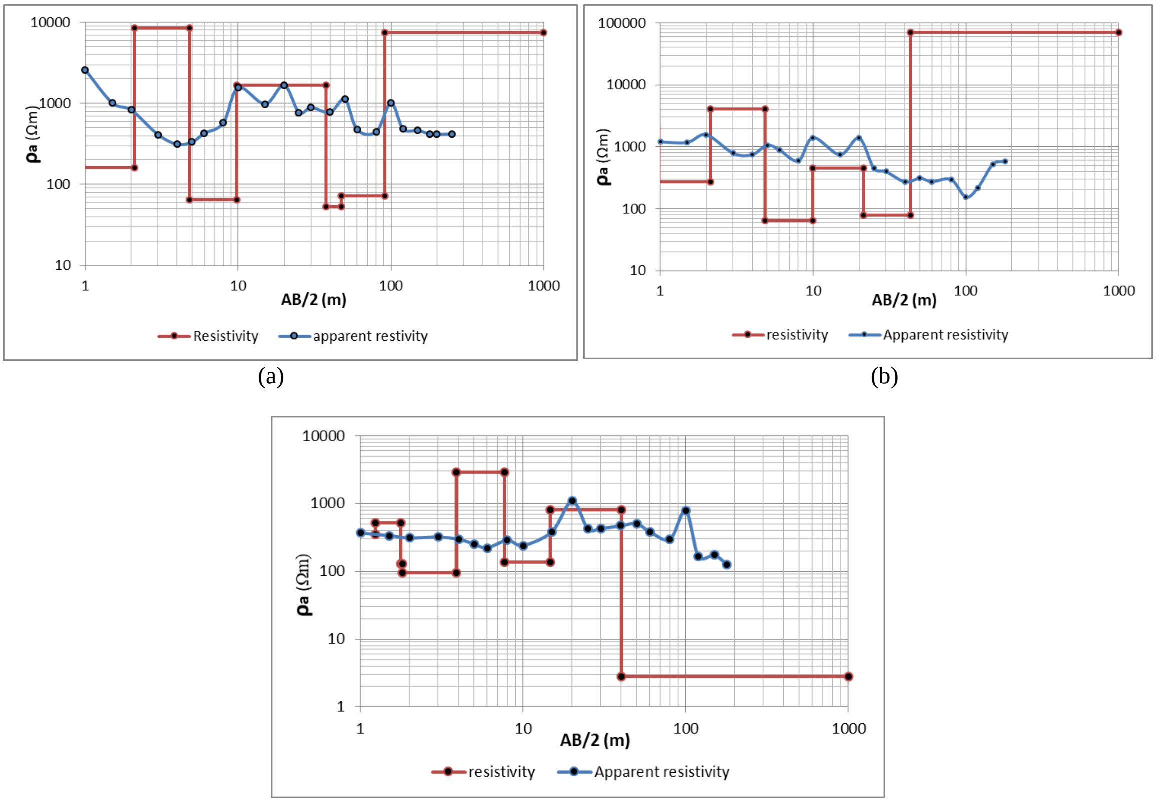
Results and discussion

2D modeling was carried out by adjusting the straight trajectory of each microtremor station according to Figure 1 (b) and Table 1. The results of 1D microtremor data processing (v_p, v_s, and density) will be imaged in 2D using modeling with kriging as a geostatistical analysis. The concept of kriging itself is estimating a value at a point that is not sampled based on surrounding sample points by paying attention to spatial correlation using spatial weighting whose correlation is shown through a variogram (Bahtiyar et al., 2014). The results of modeling using kriging are in the form of 2D images on each trajectory in Figure 1 (b), which is explained in detail in Table 1, imaged as in Figures 4 and 5. These images show that the modeling was carried out using kriging so that 2D contours were obtained from cross-correlation data in the research area.

The results of the field data processing that has been carried out and the cross-sectional resistivity obtained can then be correlated with local geological conditions. Figure 2 is the result of geoelectric processing with the x-axis as AB/2 and the y-axis as the apparent resistivity and actual resistivity values. Figure 2 (a) shows the measurement results on Line 1, Figure 2 (b) shows the measurement results on Line 2 and Figure 2 (c) shows the measurement results on Line 3. Figure 3 is a cross-section of the 3 lines with the x-axis as the distance between them, line and y-axis as depth based on geoelectrical measurements.

Interpretation of aquifer potential is obtained through the presence of a value in Geoelectric measurements (Yuliyanto, Nurwidyanto, 2021). Referring to Wahyono et al. (2023) and Telford et al. (1990) research, water soil has a resistivity of around 0.5-300 Ωm, clay has a resistivity range of 10-45 Ωm, and sandstone has a resistivity of 45-333 Ωm. The results are in Figure 2 (a). There is an aquifer potential at a depth of 38 to 81 m from the ground surface with resistivity values of 53 and 71.5 Ωm (Sandstone lithology). Figure 2 (b) shows the potential for an aquifer at a depth of 24 to 44 m from the ground surface for geoelectric measurements with a resistivity value of 78.6 Ωm (Sandstone lithology). Figure 2 (c) shows that there is an aquifer potential at a depth of 40 m below the ground surface for geoelectric measurements with a resistivity value of 2.78 Ωm. This can be influenced by the surrounding geological conditions, namely the presence of several rocks that have good porosity and permeability as water carriers.

Based on Figure 4 and Figure 5 the results of microtremor modeling and processing obtained 20 measurement stations and from these 20 stations, there can be 9 microtremor modeling paths. One indication of the presence of water can be known by using the Poisson's ratio parameter (Equation 4.). The Poisson's ratio used in determining groundwater has a value of > 2.5 (Yuliyanto, Nurwidyanto, 2021). Track 1 in Figures 4 (a) and 5 (a) shows a Poisson's ratio contour with a value of 0.3 below station 2 in the form of surface water and confined aquifers at station 1 at a depth of 40-120 m below the ground surface. Track 2 in Figures 4 (b) and 5 (b) has a Poisson's ratio contour of 0.3 below station 16 with a depth of 70 m in the form of an unconfined aquifer. Track 3 in Figures 4 (c) and 5 (c) shows a Poisson's ratio contour of 0.3 below station 20 with a depth of 105-190 m in the form of a confined aquifer and below station 19 in the form of an unconfined aquifer to a depth of 90 m. Track 4 in Figures 4 (d) and 5 (d) has an anomaly in the form of a water loss zone at a depth of 90-140 m at station 4. Track 5 in Figures 4 (e) and 5 (e) at station 10 has an aquifer potential at a depth of 60-125 m with a Poisson's ratio > 0.25. Track 6 in Figures 4 (f) and 5 (f) found a Poisson's ratio contour with a value of 0.3 below station 20 with a depth of 105-190 m in the form of a confined aquifer and below station 16 in the form of an aquifer that is not depressed to depth 70 m.



(a) (b) (c)

Fig. 2. Geoelectric processing results (a) Line 1 (b) Line 2 (c) Line 3

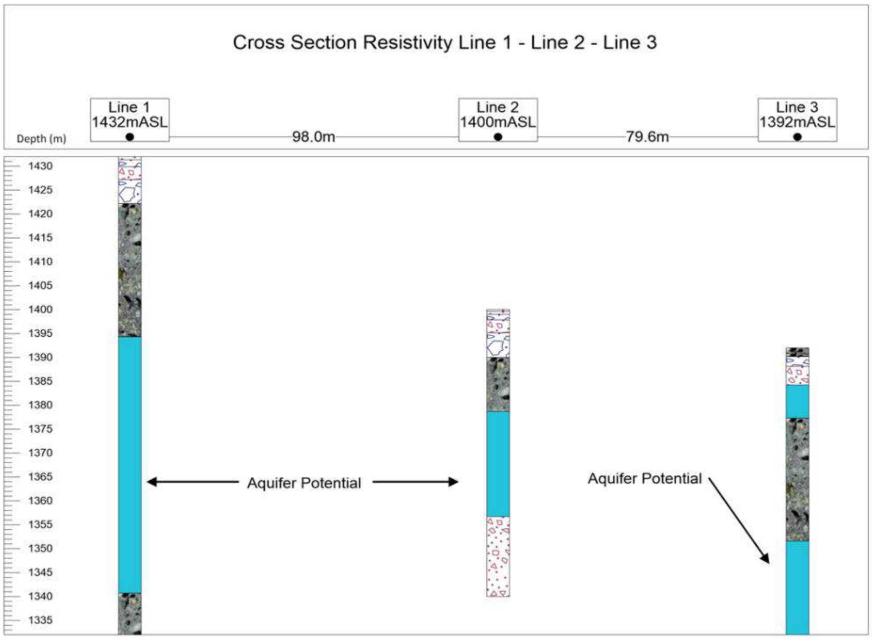


Fig. 3. Cross section of the soil layer resistivity

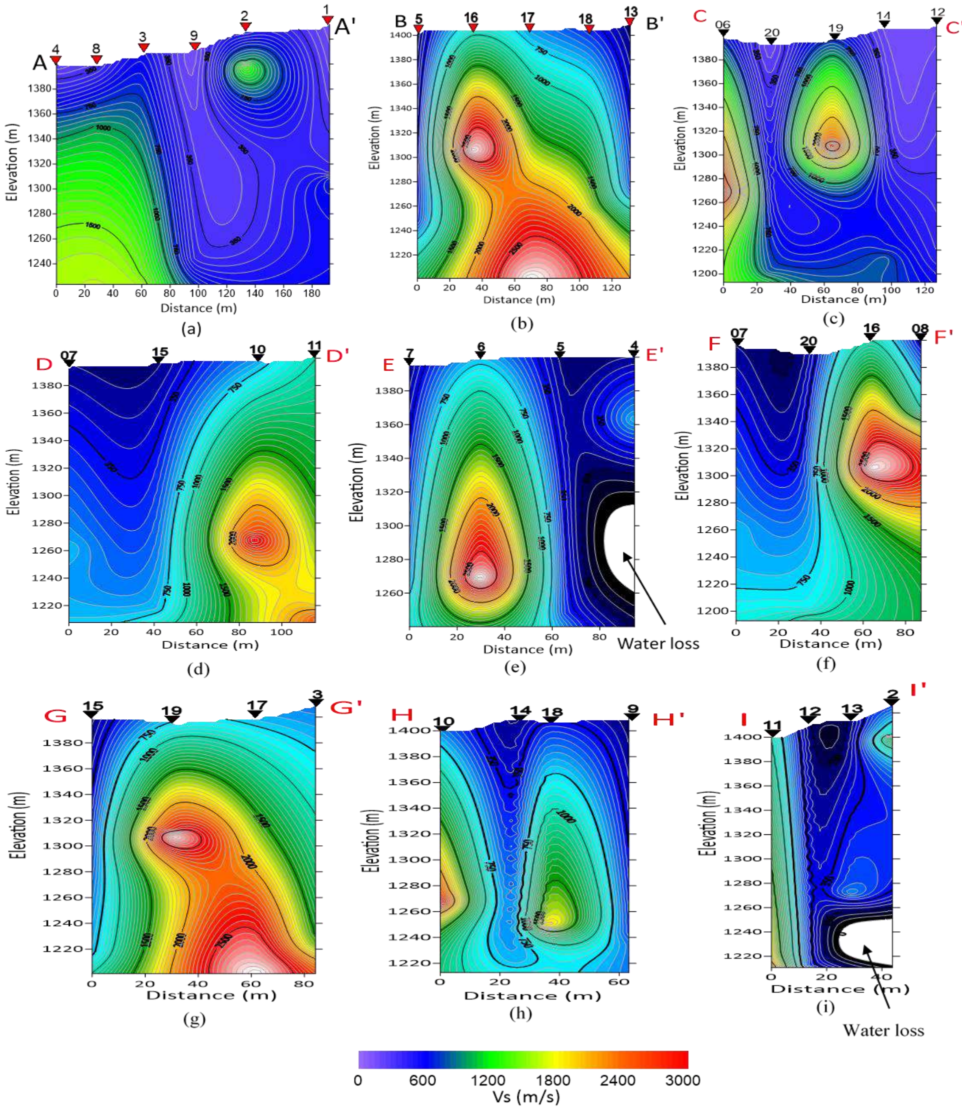


Fig. 4. Modeling v_s on each path: (a) A-A', (b) B-B', (c) C-C', (d) D-D', (e) E-E', (f) F-F', (g) G-G', (h) H-H', (i) I-I'

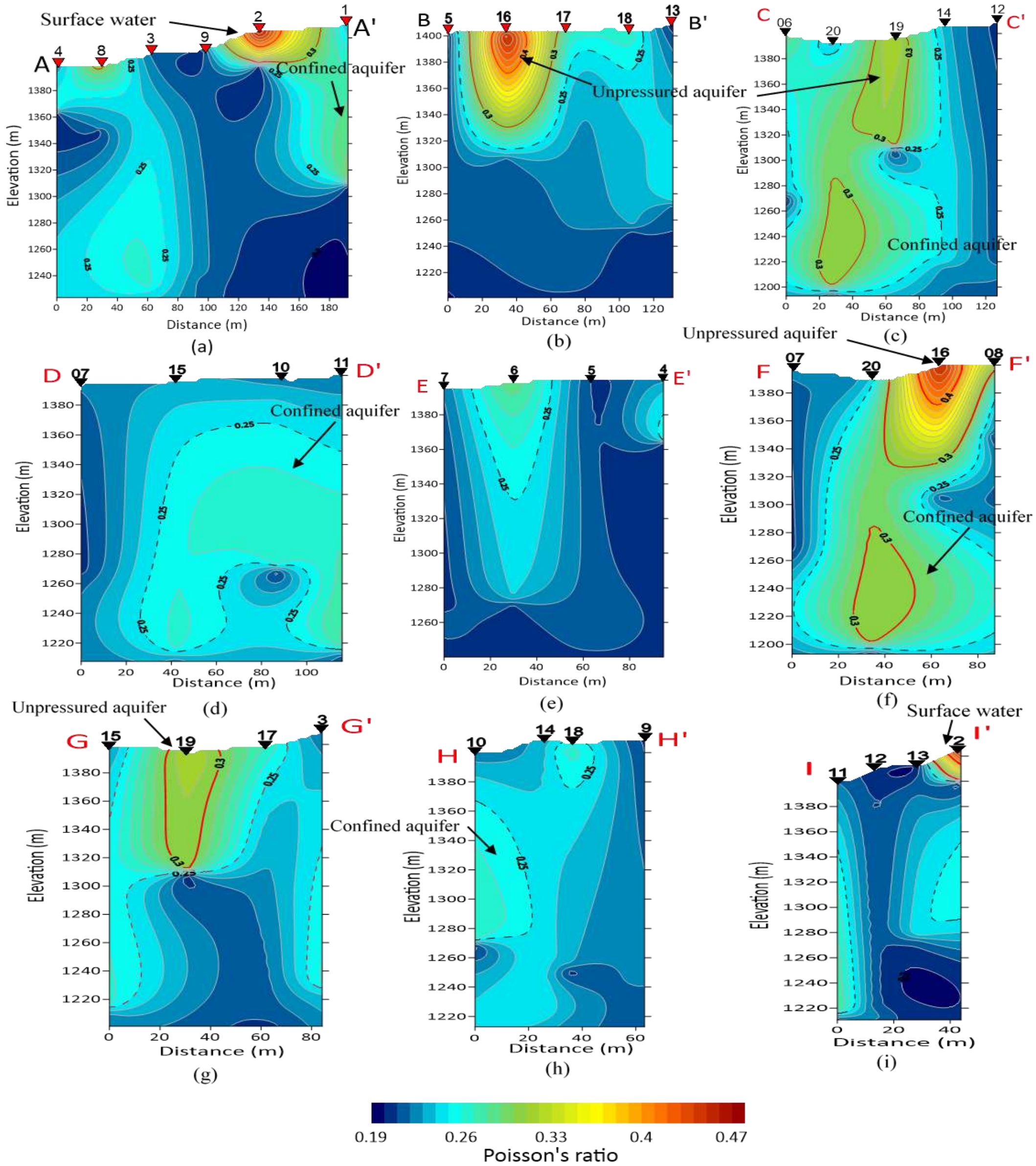


Fig. 5. Poisson's Ratio modeling on each path (a) A-A', (b) B-B', (c) C-C', (d) D-D', (e) E-E', (f) F-F', (g) G-G', (h) H-H', (i) I-I'

Track 7 in Figures 4 (g) and 5 (g) found a Poisson's contour ratio of 0.3 below station 19 in the form of an unconfined aquifer to a depth of 80 m. On track 8 in Figures 4 (h) and 5 (h), there is station 10 which has an aquifer potential at a depth of 60-125 m with a Poisson's ratio value > 0.25. Track 9 in Figures 4 (i) and 5 (i) has an anomaly in the form of a water loss zone at a depth of 180-230 m at stations 2 and 13.

Figure 6 (a) is a correlation between microtremor measurements at station 20 and geoelectricity at line 1, while Figure 6 (b) is a correlation between microtremor measurements at station 10 and geoelectricity at line 2. The imaged correlation is the correlation of the hv curve of the microtremor which has frequency value as the x-axis and the average value of the horizontal to vertical mean values which are weighted as the y-axis. The correlation of geoelectricity in images (a) and (b) has depth values as the x-axis and weighted resistivity values as the y-axis. Weighting is carried out to obtain a correlation regarding the response of microtremor values from the HV curve and geoelectricity form resistivity.

According to Yuliyanto et al. (2017) one of the methods to determine the condition and physical properties of the soil using a geophysical approach is the microtremor method which has a fairly good correlation between data and measurement data using the geoelectric resistivity method. Based on the two analyzes regarding the search for aquifer zones, the two methods (microtremor and resistivity) provide a compatible solution (Yulianto et al., 2021) and shows a suitable response in showing the response of subsurface imagery to search for groundwater by using corelation hv curve and resistivity (Figure 6).

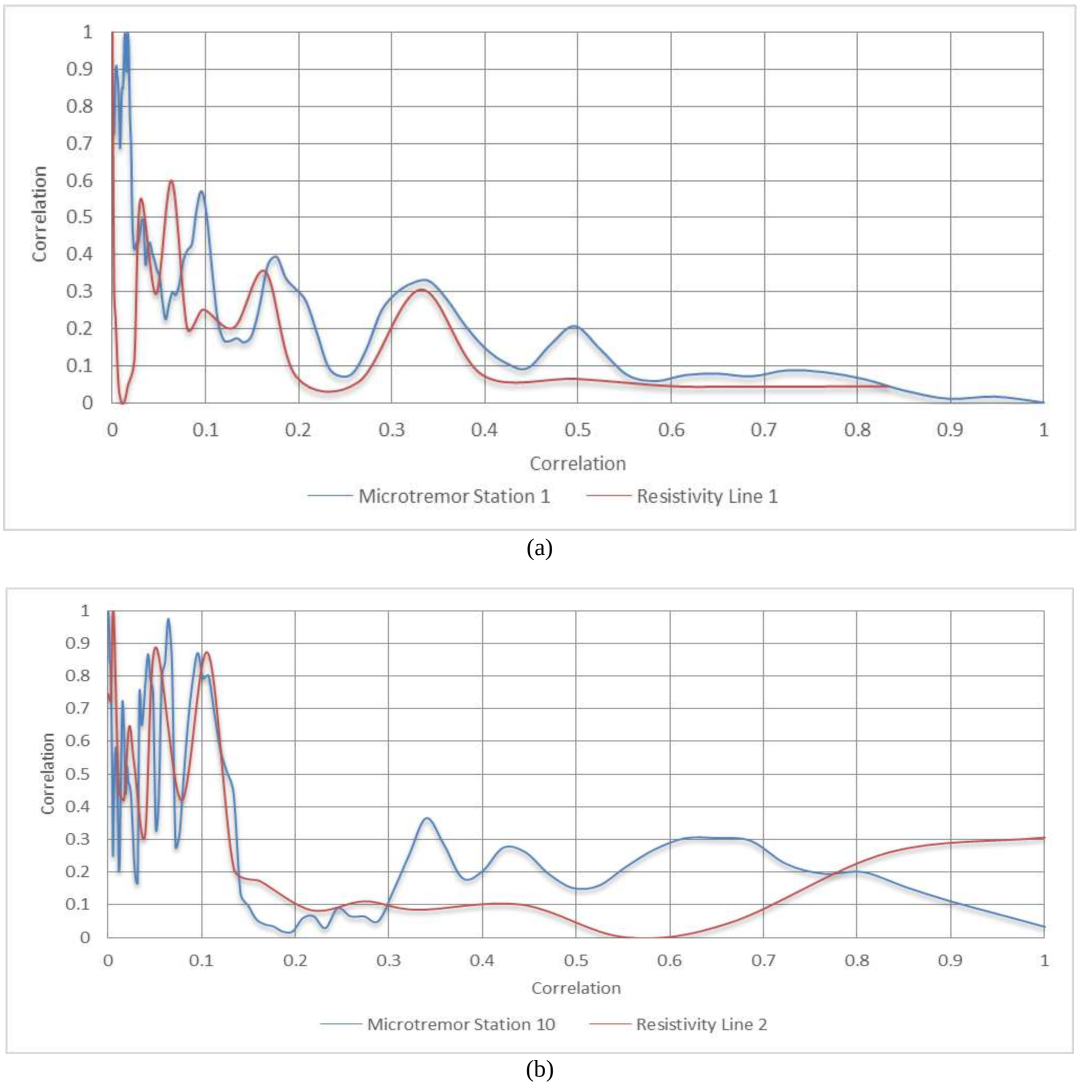


Fig. 6. Correlation between Geoelectricity and Microtremor: (a) measurement 1 (b) measurement 2

The geoelectrical resistivity and the Poisson's ratio on microtremor indicate an accuracy in knowing the aquifer zone. However, when viewed from the amount of data obtained and the flexibility in data collection, microtremor has more advantages than geoelectric. Retrieval of data on the Geoelectric method requires a long enough path length to determine subsurface conditions that are deep enough, while data collection on microtremor can easily be used in narrower conditions and the depth of microtremor does not depend on how long the stretch is like geoelectric.

Conclusion

The results of research that has been carried out using geoelectric and microtremor with the HVSR method can identify the potential presence of aquifer layers. Based on the research results, it was found:

1. The results of microtremor and geoelectric measurements have a good correlation between the two. There are several anomalies that can be suspected as the presence of aquifer zones such as surface water found at station 2, unpressured aquifers at stations 16 and 19, confined aquifers at stations 1, 10 and 20 and water loss zones at stations 4, 2 and 13.
2. Based on The advantages of both methods in collecting data in the field, microtremor is more flexible and better used in narrower conditions such as in this study and the depth of microtremor does not depend on how long the stretch is like geoelectric.

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ВЫДЕЛЕНИЕ ЗОН ВОДОНОСНЫХ ГОРИЗОНТОВ С ИСПОЛЬЗОВАНИЕМ КОРРЕЛЯЦИОННОГО АНАЛИЗА РЕЗУЛЬТАТОВ МИКРОТРЕМОРНОГО И ГЕОЭЛЕКТРИЧЕСКОГО МЕТОДОВ

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Резюме. Геоэлектрический и микротреморный методы – это геофизические методы, которые можно использовать для определения подземных условий, особенно при определении наличия зон водоносных горизонтов. Это исследование направлено на определение потенциала и наличия водоносных пород в районе Грабагского района с помощью микротреморного и геоэлектрического методов, а также на сравнение результатов этих двух методов. Территория Грабагского района очень ограничена для проведения геоэлектрических исследований, так как связана с узкими топографическими контурами, поэтому для определения состояния водоносного горизонта под поверхностью Земли необходимо использование микротреморного метода. В рамках данного исследования были определены три геоэлектрических профиля и выполнены измерения на 20 станциях микротреморных наблюдений. Результаты микротреморных исследований и геоэлектрических измерений показывают их хорошую согласованность между собой. В геоэлектрическом методе используются параметры удельного сопротивления, в то время как в методе HVSR (горизонтально-вертикальные спектральные отношения) используются параметры v_s и коэффициент Пуассона. Есть несколько аномалий, в которых можно предположить наличие зон водоносных горизонтов, таких как поверхностные воды, обнаруженные на станции 2, безнапорные водоносные горизонты на станциях 16 и 19, депрессивные водоносные горизонты на станциях 1, 10 и 20 и зоны потери воды на станциях 4, 2 и 13. Основываясь на преимуществах двух методов сбора данных в полевых условиях, микротреморный метод обладает большей гибкостью и лучше подходит для работы в сложных условиях, как и показано в данном исследовании. В отличие от геоэлектрического метода, глубина микротреморных исследований не зависит от длины профиля.

Ключевые слова*: микротремор, геоэлектрический, удельное сопротивление, HVSR, водоносный горизонт, коэффициент Пуассона, Grabang Magelang*

MİKROTREMOR VƏ GEOELEKTRİK ÜSULLARDAN ƏLDƏ EDİLƏN NƏTİCƏLƏRİN KORRELYASİYA ANALİZİ İSTİFADƏ EDİLMƏKLƏ SUSAXLAYAN HORİZONTLARIN AYRILMASI

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Xülasə. Mikrotremor və geoelektrik, yeraltı şəraiti müəyyən etmək üçün, xüsusən də sulu təbəqə zonalarının mövcudluğunu müəyyən etmək üçün istifadə edilə bilən geofiziki üsullardır. Bu tədqiqat mikrotremor və geoelektrik üsullarla Qrabaq rayonu ərazisində sulu təbəqə süxurlarının potensialını və mövcudluğunu müəyyən etmək və iki metodun nəticələrini müqayisə etmək məqsədi daşıyır. Qrabaq rayonunun ərazisi geoelektrik tədqiqatların aparılmasında çox məhduddur, çünki o, dar topoqrafik konturlarla bağlıdır, ona görə də yer səthinin altındakı su qatının vəziyyətini müəyyən etmək üçün mikrotremor metoduna ehtiyac var. Bu tədqiqatda ölçmələr 3 geoelektrik trayektoriya və 20 mikrotremor ölçmə stansiyası ilə nəticələndi. Mikrotremor və geoelektrik ölçmələrin nəticələri ikisi arasında yaxşı korrelyasiyaya malikdir. Geoelektrik üsul müqavimət parametrlərindən istifadə edir, HVSR metodu isə VS və Poisson nisbəti parametrlərindən istifadə edir. 2-ci stansiyada aşkar edilmiş səth suları, 16 və 19-cu stansiyalarda təzyiqsiz sulu laylar, 1, 10 və 20-ci stansiyalarda çökək sulu laylar və 4, 2 və stansiyalarda su itkisi zonaları kimi sulu təbəqə zonalarının olması kimi bir neçə anomaliyadan şübhələnmək olar. 13-cü sahədə məlumatların toplanmasında iki metodun üstünlüklərinə əsaslanaraq, mikrotremor daha çevikdir və bu tədqiqatda olduğu kimi daha dar şəraitdə daha yaxşı istifadə olunur və mikrotremorun dərinliyi uzanmanın geoelektrik kimi nə qədər uzun olmasından asılı deyil.

Açar sözlər*: Mikrotremor, Geoelektrik, Rezistivlik, HVSR, Aquifer zonası, Puasson nisbəti, Grabang Magelang*