

Delineation Of Potential Groundwater Aquifers Using Microtremor HVSR And Two And Three-Dimensional Subsurface Modelling In Gejayan, Banyusidi, Magelang, Central Java, Indonesia

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Abstract: Groundwater availability is strongly controlled by subsurface lithology, porosity, permeability, and groundwater saturation. Delineating potential aquifer zones is therefore important for identifying suitable locations for groundwater development, particularly where direct subsurface information is limited. This study investigates the distribution and depth of potential groundwater aquifers in Gejayan, Banyusidi, Pakis, Magelang, Central Java, Indonesia, using the microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) method. Thirty microtremor observation stations were distributed across the study area, with surface elevations ranging from 979 to 1010 m above sea level. HVSR-derived subsurface parameters were interpreted using two-dimensional profiles and three-dimensional models of shear-wave velocity and Poisson's ratio. The three-dimensional model indicates two principal potential aquifer trends along stations 6–10 and 26–30. Two-dimensional analysis provides a more detailed delineation of these zones. The first potential aquifer occurs beneath station 9 at an estimated depth of approximately 40 m and can be traced downward to approximately 60 m, whereas the second potential aquifer occurs beneath station 27 at approximately 30–40 m depth. Both zones are interpreted as potential unconfined aquifers. The results demonstrate that integrating microtremor-derived elastic parameters with two- and three-dimensional modelling can provide an efficient preliminary approach for groundwater exploration. However, the inferred aquifer zones should be validated using geoelectrical, well, drilling, or hydrogeological data before groundwater development.

Keywords: aquifer; groundwater; microtremor; HVSR; inversion; shear wave velocity; Poisson's ratio; Magelang

1. Background

Groundwater is an important freshwater resource for domestic, agricultural, and economic activities. Its occurrence is controlled by lithology, porosity, permeability, fracturing, compaction, and groundwater saturation. Because drilling provides information only at discrete locations and may be expensive, geophysical methods are widely used for preliminary groundwater exploration.

The Horizontal-to-Vertical Spectral Ratio (HVSR) method is a passive seismic technique that characterizes the subsurface response from ambient vibrations. The method has been widely applied to estimate resonance characteristics and subsurface impedance contrasts [1–3]. Inversion of microtremor data can further provide estimates of shear-wave velocity (V_s), compressional-wave velocity (V_p), layer thickness, and related elastic parameters [4,5].

Poisson's ratio is particularly useful as a complementary parameter in groundwater interpretation. It is calculated from the V_p/V_s ratio as $\nu = [(V_p/V_s)^2 - 2] / \{2[(V_p/V_s)^2 - 1]\}$. Previous studies have demonstrated that the combination of Poisson's ratio and V_s

can be used to delineate groundwater aquifer zones [6–10]. A recent IJPSAT study, for example, used microtremor inversion to obtain Vs, Vp and Poisson's ratio for groundwater-aquifer identification [11].

The present study was conducted in Dusun Gejayan, Banyusidi, Pakis, Magelang, Central Java. Thirty observation stations were distributed over the investigated area. The three-dimensional model obtained from the field study indicates potential aquifer zones along stations 6–10 and 26–30. The original interpretation further identifies a target beneath station 9 at approximately 40 m depth and another beneath station 27 at approximately 30–40 m depth. The objective of this study is to delineate the geometry and depth of these potential aquifer zones by integrating microtremor-derived Vs and Poisson's ratio with two- and three-dimensional subsurface modelling.

2. Materials and Methods

2.1 Study area and observation stations

The study area is located in Dusun Gejayan, Banyusidi, Kecamatan Pakis, Kabupaten Magelang, Central Java, Indonesia. Thirty microtremor stations were measured. The coordinates range from approximately 428559–428811 m Easting and 9174921–9175101 m Northing, with elevations between 979 and 1010 m above sea level.

The stations form several measurement corridors. Two corridors are particularly important for aquifer interpretation: stations 6–10 in the eastern part of the study area and stations 26–30 in the western part. The complete station coordinates are retained from the field report and should be inserted as Table 1.

Table 1. Coordinates and elevations of the 30 microtremor observation stations.

Station	Easting (m)	Northing (m)	Elevation (m)
1	428798	9175068	1009
2	428803	9175057	1010
3	428805	9175053	1010
4	428807	9175048	1010
5	428811	9175042	1010
6	428732	9175051	1005
7	428733	9175044	1006
8	428735	9175036	1006
9	428737	9175023	1007
10	428739	9175009	1006
11	428689	9175072	997
12	428689	9175045	1000
13	428695	9175022	1002
14	428699	9174995	1000
15	428703	9174964	993
16	428639	9175078	989

17	428640	9175058	992
18	428644	9175015	998
19	428649	9174970	995
20	428655	9174926	990
21	428590	9175101	979
22	428596	9175055	986
23	428602	9175012	993
24	428614	9174975	993
25	428616	9174930	991
26	428559	9175074	980
27	428560	9175034	983
28	428561	9174999	987
29	428562	9174962	987
30	428564	9174921	986

2.2 Microtremor acquisition and HVSR processing

Microtremor data were analysed using the three-component ambient-vibration records. The processing workflow consisted of signal quality control, spectral analysis of the horizontal and vertical components, construction of the HVSR curve, identification of the dominant resonance response, and inversion/gridding to obtain subsurface elastic-property models. Following the standard HVSR formulation, $H(f)$ was calculated from the two horizontal components and divided by the vertical spectral amplitude [2,3].

2.3 Shear-wave velocity and Poisson's ratio

Microtremor inversion was used to estimate the vertical distribution of subsurface shear-wave velocity (V_s) and compressional-wave velocity (V_p). Poisson's ratio was calculated from the V_p/V_s ratio using:

$$\nu = [(V_p/V_s)^2 - 2] / \{2[(V_p/V_s)^2 - 1]\} \quad 1$$

In this revised manuscript, the parameter previously labelled 'porosity' in the original presentation is corrected to Poisson's ratio. This correction is essential because the values shown by contours of approximately 0.26–0.40 represent a dimensionless elastic ratio and should not be described as volumetric porosity unless an independent porosity calculation is available.

2.4 Two- and three-dimensional modelling

The inverted point models were interpolated to construct three-dimensional representations of the subsurface. Potential aquifer zones were first identified from spatially coherent anomalies and subsequently examined using two-dimensional slicing along stations 6–10 and 26–30. This procedure was adopted because a 3D isosurface alone does not adequately constrain the vertical depth of a potential aquifer.

3. Results

3.1 Three-dimensional distribution of potential aquifer zones

The three-dimensional model shows two principal spatially coherent potential aquifer zones. The first follows stations 6–7–8–9–10, while the second follows stations 26–27–28–29–30. The continuity of these anomalies suggests that the interpreted targets may represent subsurface geological units rather than isolated point anomalies.

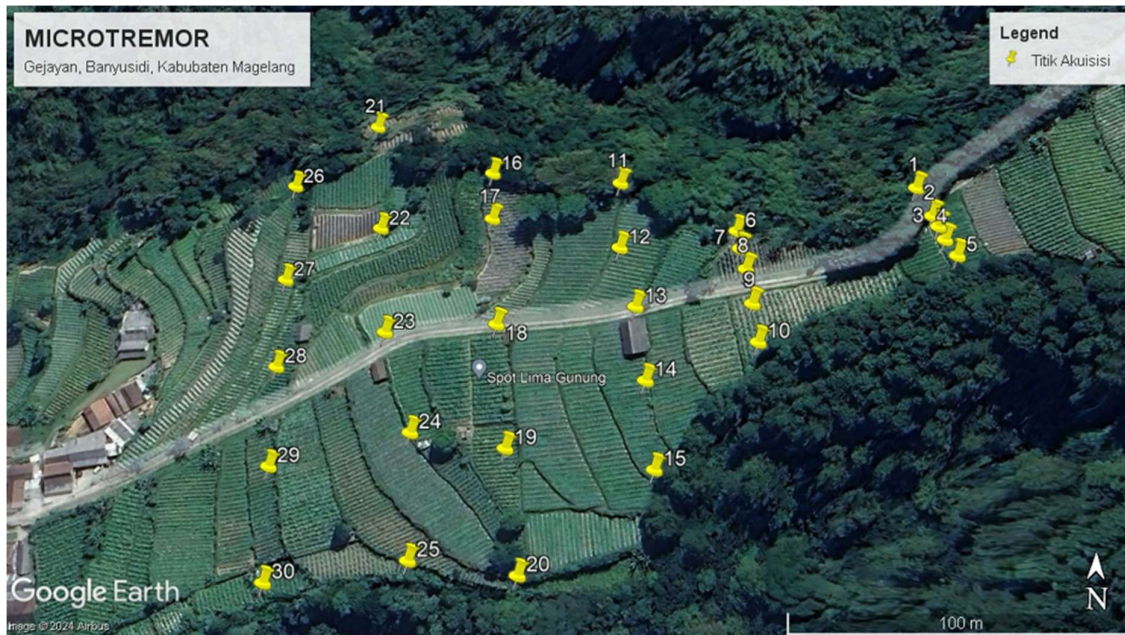


Figure 1. Location of the 30 microtremor stations in Gejayan, Banyusidi, Pakis, Magelang.

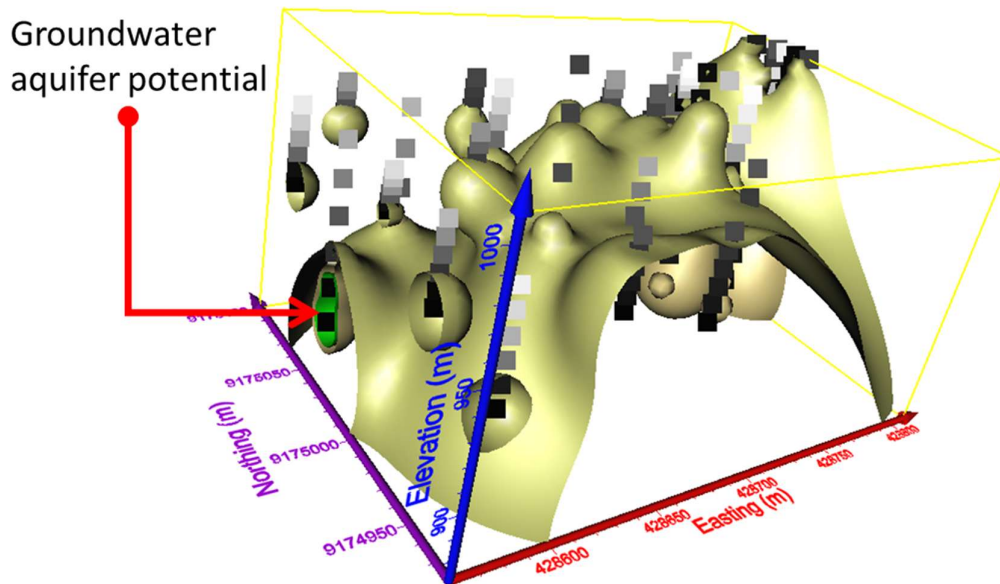


Figure 2. Three-dimensional model showing the potential aquifer isosurfaces and observation stations.

3.2 Profile along stations 6–10

The 2D section along stations 6–10 indicates a distinct subsurface anomaly beneath the central part of the profile. The most prominent target is located near station 9. The interpreted potential aquifer begins at approximately 40 m depth and can be traced downward to about 60 m. The lower part of the section is characterized by progressively higher stiffness, suggesting a transition toward a more competent subsurface unit.

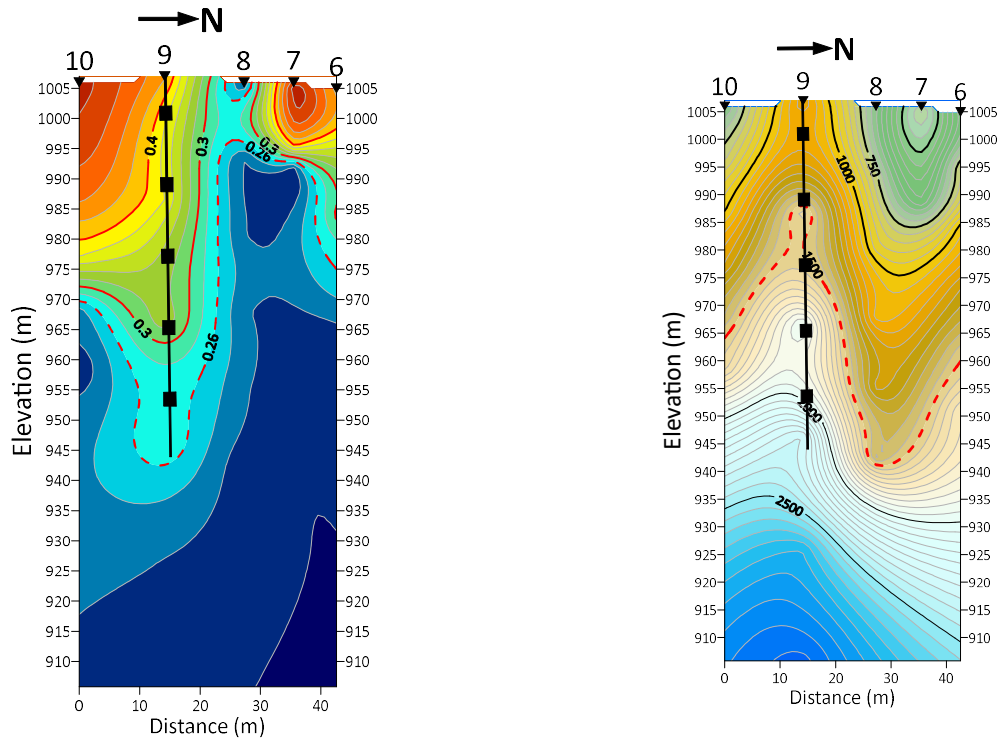


Figure 3. Two-dimensional Poisson's ratio (left) and shear-wave-velocity-related profile along stations 6–10 (right)

3.3 Profile along stations 26–30

The 2D section along stations 26–30 identifies another coherent anomaly centred near station 27. The potential aquifer is interpreted at approximately 30–40 m depth and appears to continue laterally toward adjacent stations. The spatial continuity of the anomaly supports interpretation of a laterally persistent groundwater-bearing formation.

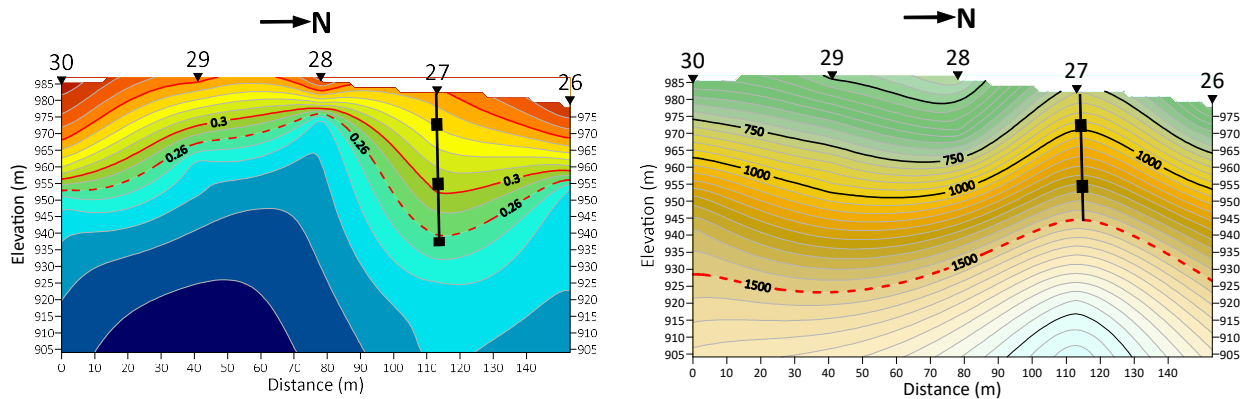


Figure 4. Two-dimensional Poisson's ratio and shear-wave-velocity-related profile along stations 26–30.

4. Discussion

4.1 Significance of Poisson's ratio for aquifer interpretation

Poisson's ratio is not a direct measurement of groundwater content. It is an elastic property that responds to the relationship between compressional and shear-wave velocities. Consequently, groundwater interpretation should use Poisson's ratio together with V_s , geological setting, layer continuity, and other independent evidence [6–10]. In the present study, the interpretation is strengthened by the spatial continuity of the anomalies and their persistence in the 2D sections.

4.2 Potential aquifer beneath station 9

The station-9 target is the principal groundwater exploration target in the study area. It occurs at approximately 40 m depth and continues downward to about 60 m. The progressively stiffer material beneath the target may represent a lower boundary or a more competent formation. The result is consistent with the source interpretation that the first potential aquifer is located beneath station 9 and is interpreted as an unconfined aquifer.

4.3 Potential aquifer beneath station 27

The second target occurs beneath station 27 at approximately 30–40 m depth. Its continuity toward stations 26, 28, 29 and 30 indicates that the target may extend laterally. Because the target is shallower than the station-9 target, it may be a practical priority for follow-up investigation, although drilling feasibility and groundwater yield cannot be established from the present data alone.

4.4 Hydrogeological interpretation and validation

The two targets are interpreted as potential unconfined aquifers, consistent with the original field interpretation. However, the term 'potential' is retained because HVSR is an indirect geophysical method and does not by itself establish hydraulic conductivity, transmissivity, groundwater level, or sustainable yield. Geoelectrical resistivity, existing well logs, drilling, and pumping tests are recommended for validation. Previous studies have shown that combining microtremor and geoelectrical data can strengthen aquifer interpretation [7,10,11].

4.5 Implications for groundwater exploration

The 3D model suggests that the interpreted aquifer system may continue toward the western or settlement direction. Additional stations should therefore be added in this direction before a production well is designed. The most efficient follow-up strategy is to use the present microtremor model to position 2D electrical-resistivity profiles and then validate the preferred target by drilling or an existing well.

5. Conclusions

Microtremor measurements at 30 stations in Gejayan, Banyusidi, Pakis, Magelang, delineate two principal zones interpreted as potential groundwater aquifers. The first zone follows stations 6–10 and is most prominent beneath station 9 at approximately 40 m depth, extending to about 60 m. The second zone follows stations 26–30 and is centred near station 27 at approximately 30–40 m depth. The corrected interpretation uses Poisson's ratio rather than porosity for the dimensionless elastic parameter derived from V_p/V_s . Integration of Poisson's ratio, shear-wave velocity, and 2D–3D spatial continuity provides a useful preliminary framework for groundwater exploration. Because the aquifer interpretation is indirect, the targets should be validated using geoelectrical, well, drilling, or hydrogeological data before groundwater development.

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