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FLUID ACTIVITY DETECTION IN THE KENDALISODO GEOTHERMAL MANIFESTATION, SEMARANG, INDONESIA, USING MICROTREMOR ANALYSIS OF THE VP/VS RATIO

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ABSTRACT

Experimental methods using microtremor recordings can identify site effects in moderate seismic activity areas with many ground motion records and high noise levels in urban or industrial contexts. Using observation data from several sites makes this survey easy to get consistent results. This study uses microtremors, Vp/Vs ratio, Poisson's ratio, and Vs30 analysis to identify thermal aquifer sources and recharge sites around the Kendalisodo geothermal manifestation. Vp/Vs ratios were calculated at 24 noise measurement locations. The Vp/Vs ratio and its alterations are examined. This study also examined the distribution of VS30, the predominant single-value metric that most accurately characterises seismic soil. Poisson's ratio varies from 0.20 to 0.49, with a 0.45 anomaly associated with the geothermal spring signifying fluid-saturated regions. The Vs30 values are approximately 1300 m/s near the geothermal manifestation, indicating the presence of stiff to strongly consolidated igneous rock, as per geological evaluations. Moreover, reduced values of the Vp/Vs ratio indicate the presence of high-porosity regions that enable the movement of geothermal fluids. The study's results become clearer after looking at the Poisson ratio distribution, which shows a value of 0.45 near the manifestation. Multiplying the compressional and shear wave velocities shows an area with a lot of holes in the rock. The bedrock type, based on geological data, matches the shear wave velocity value around the manifestation, which means that hard rock, specifically igneous rock, is pushing through.

Keywords: Kendalisodo manifestation; Vp/Vs ratio; Poisson ratio; porosity; thermal fluid

INTRODUCTION

Geothermal energy is the most reliable and stable renewable resource because it is always available, even during weather or climate changes. Indonesia has been among the top five Asian countries in terms of installed geothermal power capacity for the past few years. In 2015, Indonesia moved up two places from 2010 to the top spot [1]. Energy use is a crucial environmental concern because of how various forms are utilised and harnessed, since their origin, production, transmission, and consumption frequently have an impact on ecosystems. Geothermal energy also has the added benefit of being environmentally friendly. Under normal conditions, not all countries can produce geothermal energy; only countries in the Ring of Fire can. Indonesia has geothermal potential due to its location along the global Ring of Fire [2].

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The geological processes in a localised area subject to micro-earthquake events that divide the regime into smaller zones are known as seismic microzonation. This reaction depends on the underlying structure. The condition of the rocks in the subsurface structure determines the nature and significance of this response [3]. Soil amplification of harmonic horizontal motion of bedrock is a function of soil-layer depth and shear-wave propagation velocity, and was used to predict a uniform, linearly elastic, isotropic soil layer enclosing hard bedrock [4]. Understanding the geothermal composition of a region is critical to confirming the magnitude of potential geothermal resources in an area. When evaluating a reservoir's potential for electricity production and the sustainable utilisation of geothermal resources, it is crucial to consider its temperature, water-to-steam ratio, chemical composition, and flow system of thermal fluids. However, due to the absence of Cl-rich fluids in geothermal manifestations, these parameters are challenging to evaluate in geothermal environments. Estimating the factors that produce geothermal systems requires developing a method that incorporates several types of geological and geophysical data [5].

The Vp/Vs ratio is a well-known way to tell if there is fluid in subsurface formations because changes in elastic properties are strongly affected by pore fluid conditions and lithology [6], [7]. Fluid-saturated zones are often linked to high Vp/Vs values, while lower values may mean that gas is present or that pore pressure has dropped. This parameter is especially helpful for finding fluid pathways and reservoir characteristics in geothermal systems. A multidisciplinary approach was used to explore the fluid activity in several low-enthalpy thermal springs. It integrated geophysical observations, time-lapse evaluations of hydrogeological variables, and detailed hydrochemical assessments, with the goals of locating the origin aquifer of the thermal surface water, characterising the circulating systems, and evaluating the possibility of more thorough, higher-temperature circulation trends for future geothermal exploitation. Effective rainfall statistics are displayed with continuous temperature and electrical conductivity (EC) values. The actual rainfall was estimated using daily rainfall and possible evapotranspiration. Observations of the water level were also documented [8].

Understanding the movement of geothermal fluids and enhancing the use of geothermal energy rely heavily on heat-distribution phenomena, fractures, and the three-dimensional characteristics of porosity in the geothermal field. The relationship between rock characteristics and seismic velocity and attenuation can reveal temperature rise, fracturing, and partial melting based on the increase in the Vp/Vs ratio [9]. Generally, as the temperature rises, the velocities of Vp and Vs decrease, even if gradually, at which point their characteristics change rapidly. [7]. As a physical parameter of fluid presence, based on Poisson's Ratio values in the interval 0.25 to 0.46 (typically greater than 0.25 for the Earth's crust and upper mantle), it can be a valuable predictor of pore fluid pressure and lithology [7].

For fluid identification, the combination of the shear and compressional waves may be highly helpful. Studies have found that, in porous rocks, light petroleum saturation increases the velocity of shear waves and reduces the velocity of compressional waves (compared to water-of-formation saturation). Rock elasticity and density have a conjugate effect on both compressional and shear waves. When gas or light hydrocarbons are used in place of water, the density decreases gradually. But elasticity is not the same [6]. Because shear waves are more sensitive to fluid change than P-waves, Vp/Vs crossplots may be more sensitive to fluid change than either Vp or Vs. This is the basis for using Vp/Vs crossplots to detect fluid type.

It is commonly acknowledged that a site's shear-wave velocity (Vs) profile offers a vital parameter in determining the liquefaction level, site-specific amplification factor, or medium capacity for bearing. Here, we may investigate the physical relationship between structures in

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soil according to the association between shear-wave velocity and physical properties of the soil using a number of empirical equations and soil indices. The calculation of shear wave velocity (Vs) profiles using the dispersive characteristics of Rayleigh waves propagating through a layered material is the foundation of surface wave approaches. The two most well-known approaches are refraction microtremor (ReMi) [10] and multichannel analysis of surface waves (MASW) [11]. These methods can provide the best information on near-surface soil dynamic elastic variables because they are quicker, less expensive, and produce more precise data than other surface seismic methods [12].

A digital topographic model is a three-dimensional representation of the land that contains a wealth of information in digital format, allowing the extraction of various hydrological and topographical features from the region [13]. Digital terrain modelling was successfully carried out to determine slope, elements, flow accumulation, and flow networks within the Kendalisodo geothermal manifestation catchment. The Analytic Hierarchy Process (AHP) resolves inconsistent judgments and offers ways to improve accuracy [14].

Kendalisodo hot spring manifestation is located on the southeast slope of Mount Ungaran. The manifestation at this location is in the form of altered rocks, the product of hot fluid flow and the intrusion of magmatic rocks to the surface, which is one indicator of geothermal potential in a place. Another manifestation at this location is the presence of hot springs at several points, each of which residents use as a bathing pool and for religious rituals. The temperature of these hot springs ranges from 34 °C to 36 °C. The study area has a hot, humid climate with year-round highs of between 26 and 30 degrees Celsius. It is located on the northwest slope of the Ungaran volcano and is officially part of the Semarang region of Central Java Province.

The emergence of hot water manifestations in the Kendalisodo Geothermal Field remains a great mystery, and no one has investigated the whereabouts of the hot water in these manifestations, whether the present hot water is the manifestation of the Ungaran Geothermal system outflow or of a separate system. The problems in the Kendalisodo field present multiple issues that need to be resolved: Where does the fluid that fills the rock pores and emerges to the surface as hot springs come from? Is there a rock structure that indicates a hot spring source below the manifestation spot? The research with the object of manifestation in Kendalisodo Field aims to study the mechanism of the emergence of hot springs around Kendalisodo Mountain. The stages in this research are microtremor measurements to obtain several physical parameters, including primary wave velocity Vp, secondary wave velocity Vs, Poisson ratio, and density. These parameters analyse the fluid flow pattern and its distribution in the subsurface around the Kendalisodo manifestation site. Based on the product of compressional and shear-wave distribution patterns indicating a stiff rock type, drainage pathways in the Kendalisodo geothermal manifestation catchment control the changing patterns of surface runoff produced by the catchment. Flow accumulation plays a significant role in the formation of specific river channels originating from the high volcanic hill of Ungaran.

GEOLOGY OF THE STUDY AREA

Southeast of the Sundaland continental core of Southeast Asia lies the geologically diverse Indonesian archipelago. It lies between the Eurasian, Indian–Australian, and Pacific plates and is encircled by a tectonically dynamic zone characterised by strong seismicity and volcanism, driven by plate subduction behaviour that began at 45 Ma [15,16]. A late Tertiary to Quaternary eruption belt with numerous active volcanoes has formed along the coastline of Java as a result of the convergence of the Indian–Australian plate beneath the Eurasian plate [5].

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A sequence of andesitic to basaltic lavas and breccia with sporadic tuff interbedding makes Ungaran a stratovolcano. According to Budiardjo et al. (1997), the product of the Ungaran stratovolcano covers the Tertiary marine sedimentary rock formation. Van Bemmelen et al. (1970) state that the Middle Damar Beds, the oldest of the Ungaran, are a representative sample of the Lower Pleistocene, when volcanism first began. The older Ungaran and Younger Ungaran were created as the volcano grew. The Quaternary andesitic volcanic complex of Ungaran Mountain is the focal point of the Ungaran prospect's geothermal resources, which are concentrated near Gedongsongo. It is assumed that nearly impermeable Upper Quaternary volcanic rocks of the post-caldera cap the upper portion of the reservoir. The reservoir fluid is high-temperature sodium chloride water, which is most commonly found in fractured Tertiary and lower Quaternary pre-caldera igneous rocks. The intrusive body of amorphous and dioritic materials at Ungaran Volcano is the primary heat source. By measuring the gases extracted from the Gedongsongo fumaroles using a geothermometer, this body grows warmer, the system temperature to a storage vessel temperature of roughly 220°C [17].

The Kendalisodo region is geologically significant. The type of slope, wavy relief with a 50 m height difference between contours, is based on morphological specifications derived from geological cross-sectional relief and is connected to the van Zuidam classification. Figure 1 provides a more detailed view by overlaying the geological mapping findings onto Magelang's basic geological sheet map [18]. The andesite breccia units, tuffaceous sandstone units, and andesite intrusion units are the lithological conditions or rock types that characterise the Kendalisodo and surrounding areas.

Northeast (NE) – southwest (SW) is the direction of the major stress, according to the geological structure discovered as a joint fold. The emphasis on describing the path of the thermal manifestations in the Kendalisodo region and its environs is crucial to the direction of this interest. Furthermore, the existence of these joints suggests the possibility of the typical northeast-southwest-oriented juvenile Ungaran faults. The lithological evidence obtained in the field, and its linkage with the territorial geology of the Magelang – Semarang sheet provided the stratigraphy of the investigation area [19]. The andesite intrusion unit is thought to correspond to the andesite penetration rock type (Tma), which is suggested to be Miocene in age, based on the rock lithology. In the meantime, it is believed that the andesite breccia units and tuffaceous sandstone form part of the Kaligetas Formation (Qpkg). The outcomes of field observations demonstrate that andesite breccia units are primarily located over the tuffaceous sandstone unit, making them highly reflective of the formation. The Kaligetas Formation is suggested to be of Pleistocene age [20]. The results obtained indicate that andesite intrusion parts, tuffaceous sandstone parts, and andesite breccia parts are the oldest to the youngest linked rock layers.

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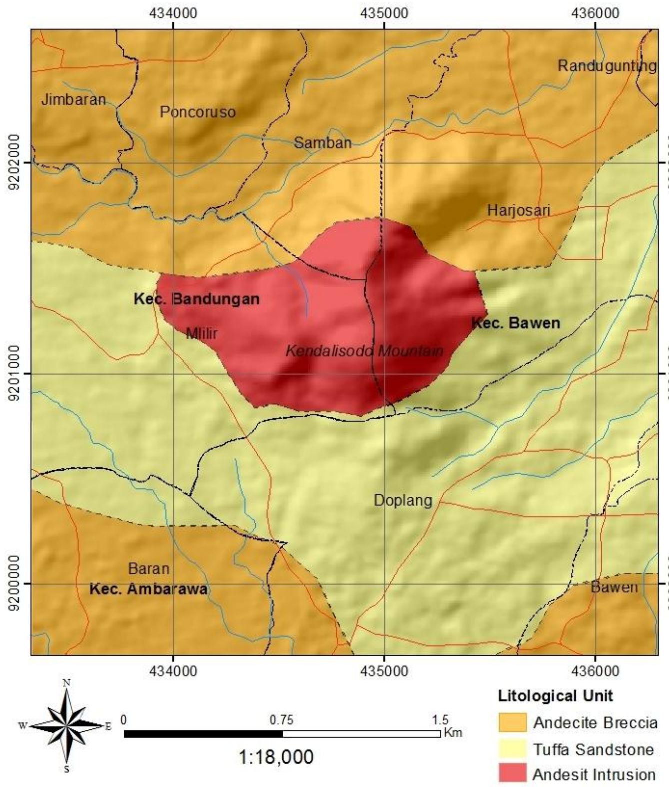

Figure 1. Geological map of the Kendalisodo Geothermal Area [20]

The following is an additional explanation of a few lithological units identified in the geological mapping results: a unit of andesite breccia. The appearance in the field tends to be reddish brown or orange in hue, with the matrix consisting of tuffaceous sand and the pieces composed of andesite. Weathering and oxidation processes that are thought to cause the rock's colour to change to an orange or reddish hue can frequently occur in the field at moderate levels. Unit of tuffaceous sandstone: The sand material has a grey-brown appearance due to its lithology. The sand material has moderate to significant weathering, is medium in sand size, and is carbonate-free. Andesite intrusion unit: This section exhibits an orange or reddish-brown colour due to oxidation and low weathering. This unit can only be found on Mount Kendalisodo, which is thought to be the intrusion's central point.

METHOD

The microtremor approach involves measuring the vertical and horizontal components of the ground-motion spectrum at each investigated frequency, computing the Fourier transform, and recording the vertical and horizontal components of the background seismic noise wavefield. Different interference effects are produced on the horizontal and vertical components of seismic waves by the subsurface's varying composition as energy (from both organic and human-made sources) flows through the earth in the form of microtremors. A microtremor peak should be seen in the most basic scenario, which involves a single discontinuity within strata horizontally homogeneous strata and isotropic seismic noise [21]. Microtremor analysis not only helps us find geothermal resources, but it also helps protect the environment during exploration. Researchers can look at the subsurface without altering the geological formations by using non-invasive technologies like the spatial autocorrelation approach that extracts Rayleigh wave dispersion curves [22]. This method also makes it easier to find geothermal

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reservoirs and cap layers more accurately, which is important for drilling and managing resources efficiently. The use of microtremor analysis in geothermal exploration could greatly lower the hazards of existing drilling methods as the need for sustainable energy sources develops. This would lead to better and more ecologically friendly energy alternatives[23]. Adding vp/vs fluid detection methods makes microtremor analysis even more useful in geothermal exploration by letting researchers tell the difference between the different types of fluid in the reservoir. This difference is very important because certain fluids can have a big effect on the thermal properties and total output of geothermal systems. Geoscientists can make better choices about where to drill and how to do it by using advanced techniques like the three-term frequency dependence AVO inversion, which has shown promise in accurately identifying fluid properties[24]. Microtremor measurements were applied at 24 stations around the Kendalisodo hot spring manifestation. The measurement points are at the coordinate range of 433613 to 434290 in latitude and 9201034 to 9202191 in longitude. The basis for determining the measurement points is the feasibility of human access to the hot spring manifestation site. Four sets of recording devices, each consisting of a VHL PS 2B triaxial geophone sensor, a GL240 datalogger recording at 50 ms for a measurement period of 20 minutes at each measurement station, and a battery power source, were used. The specific recording model device is a triaxial geophone VHL3 PS 2B. The geophone's general synchronous frequency is between 2 Hz and 40 Hz. The sensitivity is 22 ± 20% V/m/s, the Coil resistance is 3600 Ω, and the natural frequency is 2 ± 20% Hz. The measurement points were spaced at 280 m to 300 m. The measurement point layout is shown in Figure 2. Transient signals were avoided by using anti-trigger software. Furthermore, Geopsy, a free program, was used to process and analyse the data. The software was first presented in 2005 as a widespread data processing package for analysing environmental vibration data. There were two stages to the Geopsy software's examination of HVSR data [25]: A calculation of the seismic signal's ratio between its vertical and horizontal components (HVSR curve) and The HVSR curve's inversion. Combining Vs30 site characterisation with microtremor analysis helps us better understand how seismic waves affect things, which makes geothermal drilling safer and more efficient. This all-encompassing method not only makes seismic evaluations more accurate, but it also helps improve drilling tactics, which in turn makes geothermal energy production safer and more efficient. Also, combining real-time monitoring tools with microtremor analysis can make geothermal projects even more efficient. Operators can keep an eye on subsurface conditions and fluid dynamics all the time by using modern sensors and IoT devices. This lets them change their drilling plans right away based on real-time data. This proactive strategy not only reduces the hazards that come with sudden changes in the geology, but it also makes resource extraction more efficient by making sure that operations are in line with the current status of the geothermal reservoir[26].

First, the program split the signal into time windows of a chosen length. Next, it detrended and selected the segments with a stationary signal, removing intense transitory noises that could cause spurious HVSR peaks and lower the signal-to-noise ratio. The Fourier transform was used in each window to calculate the smoothed spectral amplitude of the three seismic signal components. The vertical component (Up-Down) and the average of the two orthogonal components in the horizontal plane (N-S and E-W components) were considered when extracting the HVSR. An HVSR (ellipticity) curve was generated through the process of averaging the spectral ratios obtained from each designated time interval, encompassing a frequency spectrum of 0.5–100 Hz.

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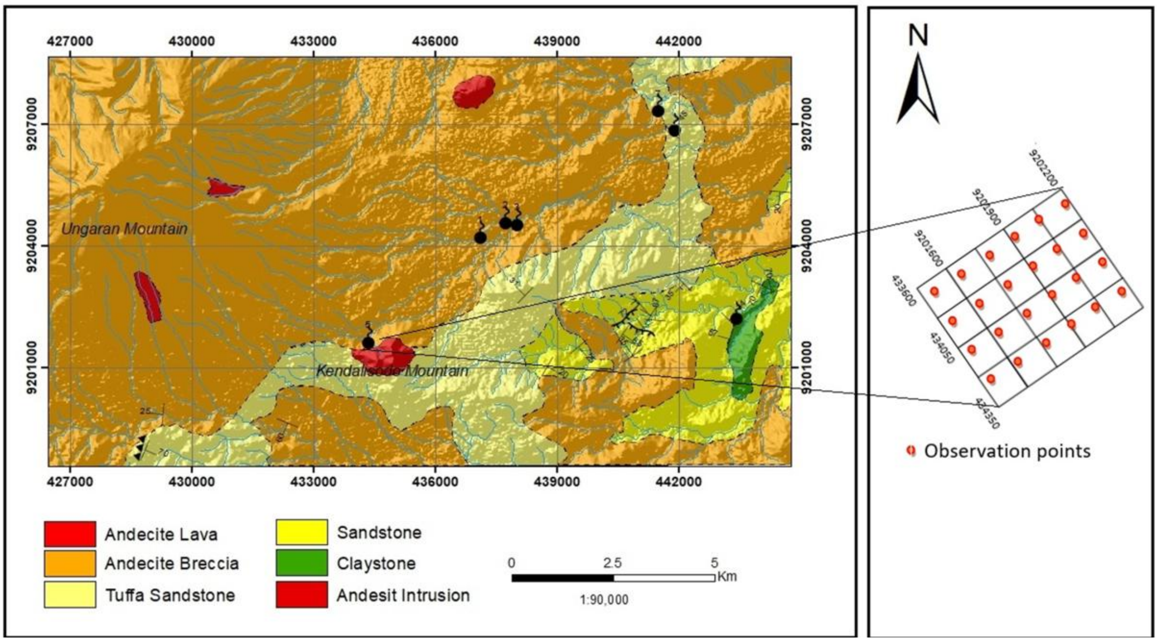

Figure 2. Microtremor measurement in the east of Mount Ungaran in the area of andesite intrusion

The second step involved using the Geopsy package's DINVER module to invert the previously extracted ellipticity curves to obtain a set of seismic models (Vp, Poisson ratio, Vs, and density versus depth) for each measurement station for which the synthetic ellipticity curve and the measured one are similar. The reference values for Vs were incorporated into a first-guess, two-layer model to perform data inversion. The Konno-Ohmachi function is then used to process the spectrum over a bandwidth. Dinver software performed the inversion, with parameters modified to suit the study area. Using equation (1), the Poisson's ratio value at each measurement location can be determined by extracting the inversion result data in the form of compression wave velocity Vp and shear wave velocity Vs [7]. Inversion calculations were performed using the Dinver software, and Poisson's ratio values were obtained at each measurement point as a function of depth. Poisson's ratio, σ, which is connected to r (=Vp/Vs) by, is a useful indicator of steam water conditions and subsurface fluid saturation [8]:

$$\sigma = \frac{r^2 - 2}{2(r^2 - 1)} \tag{1}$$

There is a relationship between the Vp/Vs ratio and the rock's physical parameters; temperature increases, fracture, and particularly partial melt are associated with increases in the Vp/Vs ratio. Drops may be related to the presence of supercritical fluids or gases. Generally speaking, as the temperature rises, Vp and Vs velocities fall, though they do so gradually until they approach the melting point, at which point their characteristics change quickly. In this work, we carry out the analysis initiated by Lees & Wu (2000) and consider both the product VpVs and the Vp/Vs variants. These combinations respond differently to physical factors and offer distinct perspectives on subsurface changes.

Vs_{30} is frequently used to analyse soil properties, and there are various approaches to carrying out VS30 field observations. The subsoil beneath the sensor is represented by the Vs_{30} data from the field survey. The data were then converted using the geomorphological basis map to

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seismic microzoning. The National Earthquake Hazards Reduction Program (NEHRP) provisions of the United States were cited regarding the relationship between VS30 and the amplification factor. Using the geomorphological units, a polygon feature representing soil properties was created from the Vs_{30} point feature [22]. Geomorphology maps are recommended for Vs_{30} mapping [27]. The results of the investigation were applied to the web-based strong ground motion immediate estimation technique and used for site assessment across Japan. The association among geomorphologic units and site amplification levels in Japan was later also shown [28]. The following formula should be used to calculate the upper 30 m's average shear wave velocity:

$$V_{s30} = \frac{30}{\sum_{i=1}^{n} \frac{H_i}{V_{si}}} \tag{2}$$

whereby H_i and V_i represent the formation's or layer's thickness (measured in meters) and shear-wave velocity (at an average shear strain scale of 10−5 or less), respectively, in the total amount of N that exists in the upper 30 m.

A digital terrain model is a three-dimensional model of the land that contains a wealth of digital data, allowing for the extraction of various hydrological and topographical features from the region [14]. In order to determine the slope, element, flow accumulation, and stream pathways within the Kendalisodo geothermal manifestation catchment, digital terrain modeling was carried out for this study. The understanding of water's movement dynamics from the outside into the subsurface is the main goal of this study area, and these terrain features offer vital information about it. Digital Elevation Model (DEM) derivatives furnish comprehensive spatial data, delineating the topographic distribution in relation to a designated reference point, thereby facilitating the analysis of supplementary variables such as groundwater elevations and the chemical characteristics of water. The Shuttle Radar Topography Mission (SRTM) provided the DEM for the region.

The lineament densities, gradient, elevation, terrestrial use/cover, discharge network (flow accumulation), magnetic susceptibility, and soil varieties were the spatial data used to produce the specific maps for the Ungaran Volcanic area. The assessment criteria that Thomas[14] created are used to give each parameter weight. In this study, factors were ranked by their significance in promoting groundwater recharge. This weighing method essentially compares variables based on the goal and intended result. The weight of every parameter in the last column was determined by comparing the variables (e.g., lineaments in the initial row) in Table 1 against other variables (columns 2–8) using an ordinal scale. Since data on land cover categories and soil types cannot be continuous, they were assigned discrete values based on their relative influence on groundwater replenishment when incorporated into hydrologically optimised datasets [29].

RESULTS AND DISCUSSION

The microtremor data were analysed using several parameters, including the velocity of the compression wave Vp and the shear wave Vs, and the Vp/Vs ratio, to obtain a reference for rock type in the study area, as shown in Table 2. Poisson's ratio, typically 0.25 to 0.45 for the

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Table 2. Variation of Vp/Vs parameters with respect to soil and rock types [7]

Soil and rock-type	Vp	Vs
Hard and massif rocks	6000 - 4200	4000 - 4200
Very stiff	4200 - 3000	2700 - 3000
Stiff	3000 - 2000	1500 - 700
Moderate stiff but altered	2000 - 1500	700 - 400
Loose and Soft	1500 - 600	400 - 100
Soft and saturated	> 1300	> 100

Earth's crust and upper mantle, can be a valuable indicator of lithology and pore-fluid pressure [30]. The porosity of sedimentary rocks, however, has been identified using the product of shear wave and compressional velocities, or Vp Vs [31]. The primary single-value measure that captures the behaviour of seismic soil is Vs_{30} [4].

In this study, microtremor depth penetration reaches 160 m to investigate hydrothermal fluid conditions in the subsurface of the manifestation area. Groundwater fluids can be readily identified from the Poisson-ratio distribution derived from microtremor data analysis [9]. As shown in Figure 3, the distribution of Poisson ratio values varies from 0.20 to 0.49, and there is an anomaly around the hot spring manifestation. On the three-dimensional map, an anomaly is evident in the area around the Kendalisodo hot spring manifestation. This indicates the presence of fluid that appears on the surface as a hot spring manifestation. However, localised tectonics and faulting patterns are crucial to fluid flow, as they strongly influence the active field's permeability, porosity, and temperature.

Physically, fluid flow in rocks can be analysed by looking at the porosity of rocks. The stability of rock porosity distribution in sedimentary rocks can be qualitatively assessed from the product of Vp and Vs velocities [31]. VpVs decreases with increasing porosity in sedimentary rocks by confirming the analytical results of the Poisson ratio parameter with the rock porosity, which is indicated qualitatively as presented in Figure 4. This indicates that the low value of VpVs of this product is a good state of rock porosity in the manifestation area. From a physical perspective, fluid flow in rocks can be analysed based on porosity characteristics. The stability of rock porosity distribution in sedimentary rocks can be qualitatively determined based on the multiplication of Vp and Vs velocities [31].

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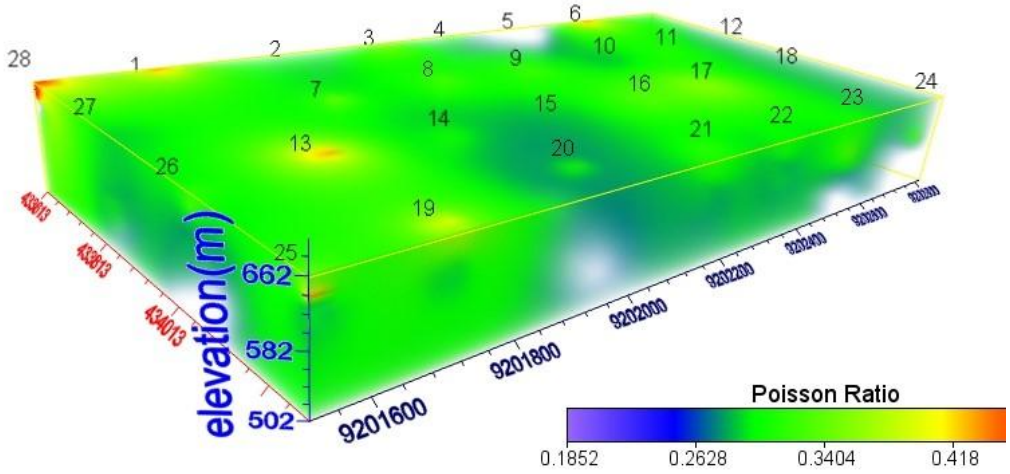

Figure 3. Poisson ratio distribution in the study area as indicated by the anomaly around the hot spring manifestation.

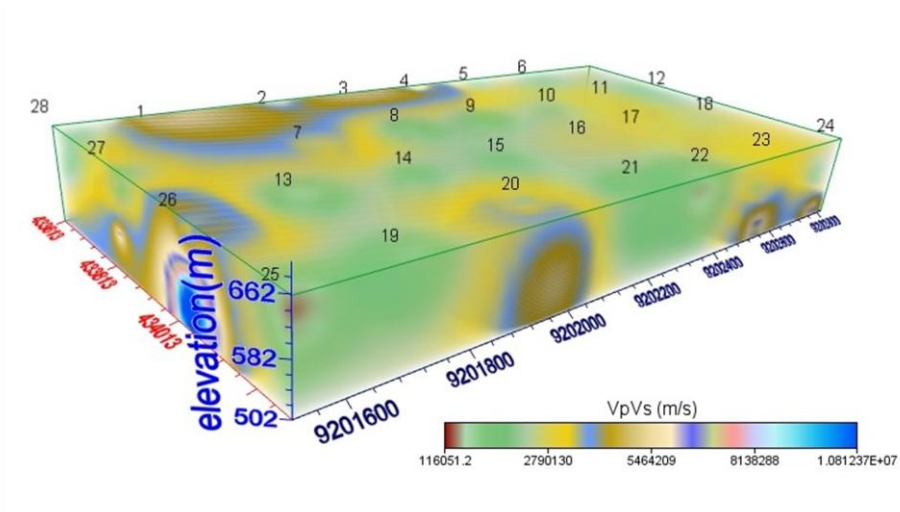

Figure 4. The product of compressional and shear waves as a qualitative indicator of the porosity of rocks at the Sedimentary Surface.

Site impacts are often represented by site terms in ground motion prediction problems, typically expressed as the average shear-wave velocity in the upper 30 m (Vs_{30}) [6]. The relationship between bedrock type and shear wave velocity parameter supports a better understanding of the morphology of the Kendalisodo hot spring manifestation and shear wave velocity parameter based on Keceli's (2012) research. Based on Figure 5, the shear wave velocity, Vs, around the manifestation is 1300 m/s. This result is in agreement with the type of stiff rock (Table 2). This result is in accordance with the conditions in the field where there is an igneous intrusion around the manifestation.

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The process was followed by clarifying the broader surface-water source, and the local microtremor measurements were assessed using elevational-difference modelling in a GIS application using satellite data (Figure 6). Abundant cracks resulting from building disturbance and geological phenomena can contribute to weak structural interfaces and dominating flow pathways in naturally occurring masses of rock. A more precise calculation of fracture permeability forecasting may assist in a better understanding of fluid flow properties by permitting precise characterisation of surface influence and fracturing morphology and measurement of their influence on fluid flow [32].

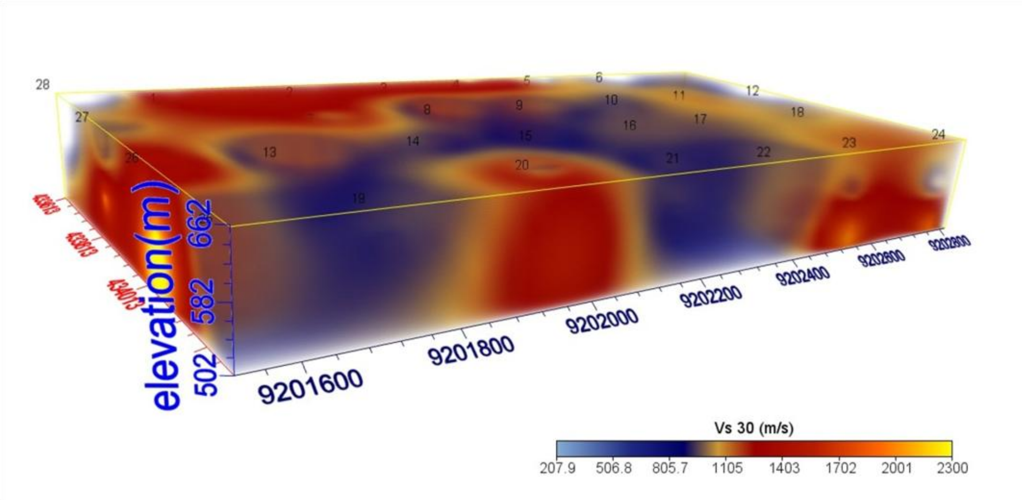

Figure 5. The Vs_{30} as a qualitative indicator of the soil properties of the Sedimentary Surface.

Natural processes have typically recharged groundwater, and as outflow has increased, so too has groundwater. Using groundwater-level sensitivity derived from observations, the environmental level of the groundwater phase could be determined. When precipitation is the primary source of groundwater replenishment, the pressure exerted on the groundwater affects whether the water table is rising naturally or artificially, or falling due to excessive water abstraction. Rainfall, together with induced and natural recharge methods that are precisely located in a zoned area of potential replenishment, is the primary source of refreshment of groundwater. The feasibility of particular sites will be determined using geospatial data and several thematic layers superimposed in a GIS environment [29]. Drainage pathways for the Kendalisodo geothermal manifestation catchment, which control the changing patterns of surface runoff, were derived from Figure 6 using SRTM data. Flow accumulation plays a significant role in certain river channels that originate from the high volcanic hill of Ungaran. The topography of the Kendalisodo catchment region varies, with higher mountains bordering the area on the western side. In the eastern part of the region, where the majority of the ground slopes less than two degrees, the shift in elevation is quite mild. This is a good surface for rainwater to seep naturally, without releasing most of the water as runoff. By combining and cross-correlating these disparate data, the geothermal field has been better understood, and a comprehensive hydrogeological conceptual model has been proposed.

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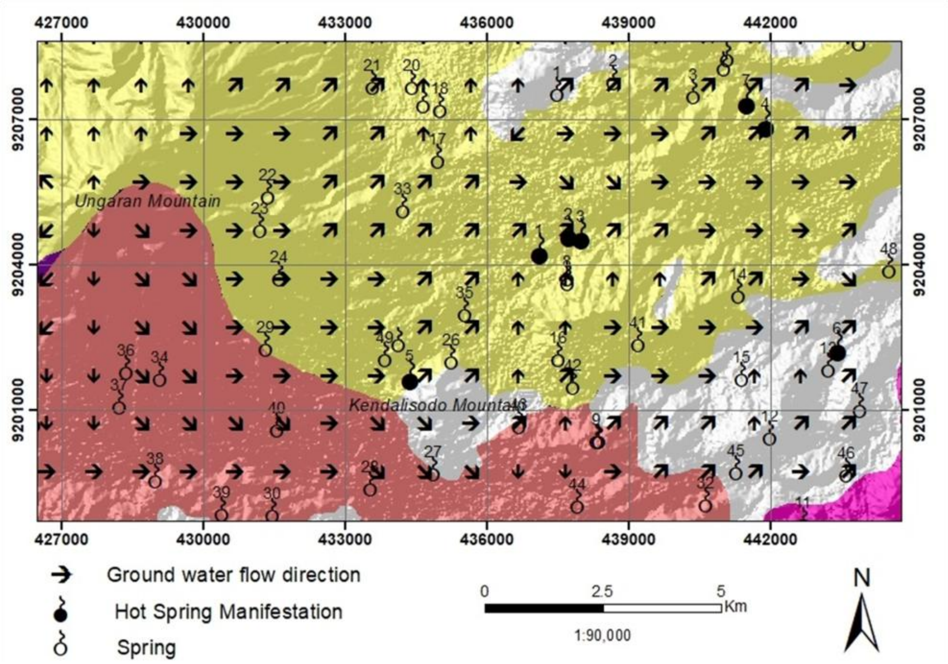

Figure 6. Surface fluid flow direction based on the topographical difference among two points block on the surface gravitationally to obtain the fluid flow direction of the surface.

CONCLUSION

Most active geothermal fields in Central Java Province, including the Dieng field, were found by recognising hot springs and hydrothermally altered topography. Even if the Kendalisodo field systems have no valid geothermal potential estimates, a paradigm for locating and defining geothermal reservoirs with business potential would be great. The work detailed here examined hot spring emergence around Kendalisodo Mountain. To see the hydrothermal fluid flow pattern up until its manifestation, consider the modelling results, particularly the distributions of Poisson ratio, VpVs, and Vs_{30} parameters. The Poisson-ratio distribution map (0.45), indicating fluid, was used to identify the manifestation's fluid-flow channel. Low VpVs indicate porosity, confirming the fluid distribution map. Based on geological information and shear-wave velocity readings around the manifestation, the bedrock is igneous rock, and the compressive and shear-wave velocities of the porosity zone are multiplied.

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