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Temperature and conductivity variation in the Ungaran geothermal area, Central Java, Indonesia

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Abstract. This study aims to examine variations in groundwater temperature and conductivity in the Ungaran geothermal area, which has unique geothermal characteristics. This area is known to have significant geothermal activity, which can affect the physical and chemical characteristics of groundwater. Temperature and electrical conductivity measurements were conducted at several spring locations. Data obtained from these groundwater temperature and conductivity measurements were analyzed to determine the relationship between the two parameters and for geological interpretation purposes. The results show significant variations in both temperature and groundwater conductivity in the Ungaran area. This finding indicates that temperature does not determine the value of groundwater electrical conductivity. This is evidenced by the very low correlation (1.4%) across all springs or 20.9% for geothermally controlled springs. Thus, these temperature and conductivity variations can be caused by various local geological conditions.

1 Introduction

Hydrogeological research in geothermal areas focusing on the physical/chemical properties of groundwater has been extensively developed, but the integration of these parameters has not been widely explored. One physical parameter that needs to be studied is groundwater temperature (T) and electrical conductivity (EC). To assess their relationship to local geology, these properties need to be identified directly in the field and laboratory.

Studies on groundwater in Indonesia have been developed by several previous researchers using various methods [1-3]. Hydrochemical methods have been widely used to address groundwater problems, as well as problems with its physical properties. Physically, groundwater can be seen from its color, turbidity, and EC values. EC measurements have been developed to assess water quality, both surface water [4] and groundwater. Studies on groundwater hydrochemistry have also been carried out by many researchers in an effort to understand the genetics and evolution of groundwater hydrochemistry [5]. This study of groundwater quality significantly supports groundwater exploration and can aid in

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groundwater genetic interpretation. By conducting groundwater exploration, we can ensure the availability of good-quality water.

The research area is located in the Ungaran geothermal prospect area, Central Java (Figure 1). Geologically, Mt. Ungaran still active, but it has begun to enter a post-volcanic phase. This condition is characterized by more dissected peak morphology.

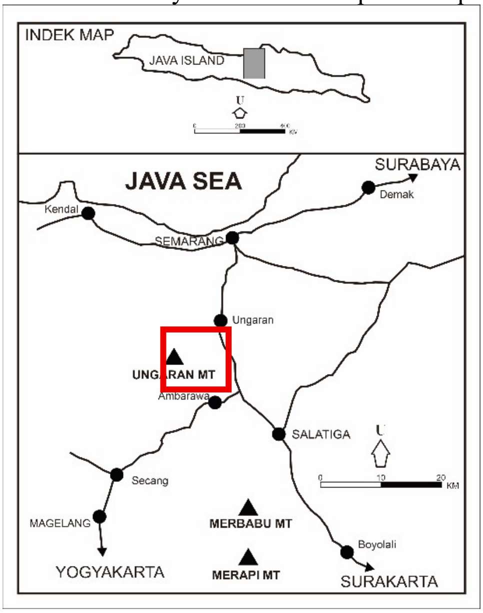

Fig. 1. The research area is in Mount Ungaran and its surroundings, Central Java.

Groundwater studies require data on the rocks and local geological characteristics specific to each region. The Ungaran area is a volcanic region with geothermal potential. This area has a many geothermal manifestations, including hot springs and altered rocks. This alteration process has changed several minerals and may influence groundwater EC.

Several researchers have conducted studies on the physical/chemical properties of groundwater in geothermal areas [6]. The chemical characteristics of geothermal groundwater have been discussed, including EC as an indicator of dissolved minerals [7].

In the study area, springs vary in temperature, from cold to normal to hot. This research in the Ungaran geothermal area aims to determine temperature variations and groundwater EC, along with their geological interpretation. This research aims to conceptually develop existing theories across a range of geological conditions. This research will complement previous groundwater studies, particularly in examining temperature and EC variations. In practice, groundwater conductivity can be measured to understand water quality and the hydrogeological characteristics of an area.

2 Method

The method used in this research was a field hydrogeological survey. This survey was conducted to locate several springs with cold, normal, and hot temperatures in the Ungaran area. Springs are one manifestation of groundwater, so that this groundwater research can collect data from springs. Eight springs were selected for research, ranging in temperature from cold to hot (Table 1).

The T and EC measurements of groundwater were conducted directly in the field (Figure 2). These measurements used an Eutech EC-meter calibrated with an HI7033 Hanna instrument standard solution. Furthermore, groundwater sampling was carried out using plastic bottles and taken to the accredited BTKLPP water laboratory. The T and EC measurements were conducted at least 10 times in each spring, to obtain representative data. Six springs were selected for further laboratory testing. The results of these field and laboratory measurements were then analyzed using statistical methods to determine their correlation between T and EC as well as their relationship to local geology.

Table 1. Location of the springs.

Code	Spring	Temperature	Location		
			Area	Village	Sub District
S1	Nglimut	Hot	Gonoharjo	Nglimut	Boja
S2	Gds 1	Hot	Gedongsongo	Candi	Ambarawa
S3	Gds 2	Normal	Gedongsongo	Candi	Ambarawa
S4	Gds 3	Hot	Gedongsongo	Candi	Ambarawa
S5	Sidomukti	Cold	Manggung	Sidomukti	Bandungan
S6	Diwak	Warm	Ngempon	Diwak	Bergas
S7	Kaliulo	Warm	Kaliulo	Klepu	Pringapus
S8	Sendang Kramat	Warm	Klotok	Doplang	Bawen

Fig. 2. Measurement and sampling of groundwater at the Gedongsongo and Kaliulo springs.

3 Literature review

3.1 Geological overview

The research area is included in the Quaternary volcanic complex of Ungaran Mt. The morphology on the lower slopes shows undulating to hilly topography. This area is located on the north side of the western part of the Kendeng Anticlinorium, composed of rock formations from old to young, namely the Pelang, Kerek, Banyak, Kalibeng, Damar, and Notopuro Formations [6].

Gedongsongo is the main manifestation of the geothermal system of Mount Ungaran. This andesitic stratovolcano activity produces rocks such as andesitic-basaltic lava and pyroclastic rocks (breccia/tuff). Around geothermal manifestations, these volcanic rocks often show alteration conditions and sulfur deposits. The Nglimut area is on the northern slope of Mount Ungaran with geothermal manifestations in the form of hot springs.

Gedongsongo has several hot springs the main geothermal manifestation located in the upflow section, composed of volcanic material. Sidomukti is located on the upper slopes of Mount Ungaran which is composed of volcanic material. Diwak, Kaliulo, and Sendangkramat are located on the lower slopes/foot of Mount Ungaran, with volcanic breccia as the rock. Limestone is also found in the Kaliulo area.

3.2 Geological overview

In general, temperature affects EC due to two factors, namely: (i) increased ion mobility (the temperature coefficient of EC is usually compensated to 25 °C), and (ii) increased mineral dissolution in hydrothermal environments, which increases TDS [8]. On the other hand, boiling tends to lower the EC through the removal of steam and degassing of CO_2/H_2S, which can trigger mineral precipitation and reduce the total dissolved ions in the remaining liquid phase; conversely, evaporation without the removal of dissolved mass will increase the EC.

Meanwhile, EC is a measure of the ability of water to conduct an electric current, which directly reflects the dissolved ion content (TDS), ion activity, and temperature [9]. In geothermal systems, EC is a key parameter for assessing the degree of rock-water interaction, mixing between hydrothermal fluids and shallow groundwater, and boiling and dilution processes. Because EC is fast and easy to measure in the field, this variable is often used as an initial indicator in mapping heat flow zones and to identify hydrothermal plumes under structural control.

EC values generally increase with the concentration and mobility of ions in groundwater formed through leaching reactions of silicate, carbonate, and sulfide minerals at high temperatures. Neutral-chloride systems generally show high EC due to the dominance of Na–K–Cl, while acid-sulfate systems can show very high EC due to sulfate and dissolved metal ions resulting from the oxidation of acid gases (H_2S to SO_4^{2-}) and mineral leaching by acidic fluids. The dissolution-precipitation balance of silica and carbonate compounds, as well as changes in pH and eH, also modulate EC [10].

4 Results and discussion

The results of the T and EC measurements of the groundwater studied are presented in Table 2 below. Eight springs showed varying T and EC values. The field data presented in the table are the average values from at least 10 field measurements.

Table 2. Results of groundwater T and EC value tests in the field and laboratory.

Code	Field Data		Laboratory Results	
	T (°C)	EC (μS/cm)	T (°C)	EC (μS/cm)
S1	40.4	1,669.2	24.6	2104
S2	73.49	1,515.8	24.6	1,103
S3	25.99	274.50	-	-
S4	40.61	473.1	-	-
S5	22.23	135.8	24.6	147
S6	38.24	2,262.00	24.7	2369
S7	37.35	19,375.00	24.7	20,670
S8	32.47	1,378.7	24.7	1,465

The results of T measurements in the field and laboratory clearly show different results, because the sample conditions in the laboratory do not match the actual conditions in the field. Therefore, the T values in the field and laboratory cannot be compared. The EC values in the field and laboratory show similarities, meaning that high EC values in the field will be followed by high EC values in the laboratory (Figure 3). EC data from the laboratory are used to verify the field data. Because valid T data are only obtained from the field, the relationship between T and EC that is analyzed next is based on field data.

Figure 4 shows the relationship between T and EC values in the field. The left image shows all data analyzed, while the right image only shows data from warm/hot springs. Warm/hot springs are believed to be influenced by geothermal activity, while cold/normal springs are not related to geothermal activity.

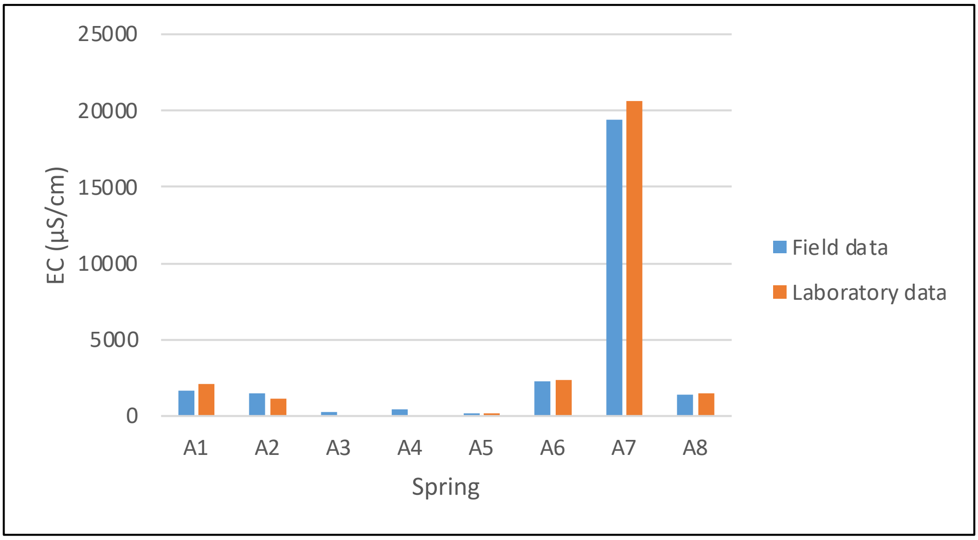

Fig. 3. EC values measured in the field and laboratory.

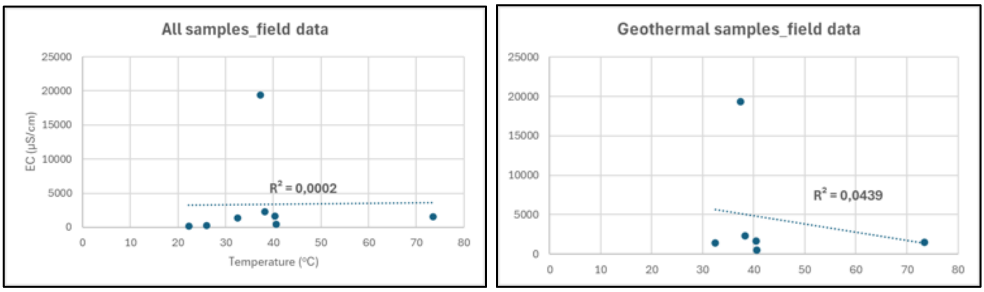

Fig. 4. Relationship **between** T and EC of groundwater from springs in the Ungaran area.

Figure 4 shows that the R^2 values in both graphs show a very low correlation (R), at 1.4% for all samples and 20.9% for geothermal springs. This indicates that the T and EC values in the studied springs are very poorly correlated, meaning that the relationship between the two variables cannot be formulated. This means that hotter springs do not always have higher EC, and vice versa. Therefore, the relationship between T and EC in the Ungaran area, whether related to geothermal or not, is uncertain. An increase in T is not always followed by an increase in EC; in other words, T does not affect the EC value of the spring water. This very poor relationship indicates that there are other variables controlling EC.

The highly variable T and EC values prompted researchers to conduct geological interpretations. A literature review indicated that increases in T are often accompanied by increases in EC. However, this does not apply to groundwater at different locations, as each location has its own unique characteristics. Various geological conditions, particularly rocks and hydrochemical processes, result in variations of T and EC in each spring. The hydrochemistry of springs in the Ungaran area has been studied using groundwater chemistry data [6]. Furthermore, from the literature review and primary data collected in this study, interpretations can be made as in Table 3.

5 Conclusion

Temperature and EC measurements have been conducted on springs in the Ungaran area, including cold and hot springs. Of the eight springs studied, six were warm/hot springs due to geothermal activity. Field measurements, verified with laboratory EC data, showed that temperature did not correlate with groundwater electrical conductivity.

Table 3. Geological interpretation of T and EC variations in the study area.

Spring	T (°C)	EC (µS/cm)	Geological Interpretation
S1. Nglimut	40.4	1,669.2	Groundwater is controlled by geothermal heat, flowing in fairly shallow volcanic aquifers.
S2. Gedongsongo-1	73.49	1,515.8	Steam-heated water has a high temperature as the upflow part system. A lower EC indicates immature water, meaning meteoric water flows at depth.
S3. Gedongsongo-2	25.99	274.5	Not related to geothermal systems, but the low EC of the spring indicates that these normal springs represent meteoric water in the catchment area.
S4. Gedongsongo-3	40.61	473.1	Hot water with relatively low EC indicates that there has not been much mineral dissolution or that it has been mixed with meteoric water.
S5. Sidomukti	22.23	135.8	Volcanic groundwater located in the infiltration zone, in shallow aquifers, has not undergone much chemical enrichment.
S6. Diwak	38.24	2,262.00	Meteoric water with geothermal influence may be contaminated, causing relatively high EC, or a fairly long groundwater journey.
S7. Kaliulo	37.35	19,375.00	Mature groundwater with limestone influence is part of the groundwater aquifer.
S8. Sendang Kramat	32.47	1,378.7	Warm groundwater flowing in volcanic aquifers is quite shallow.

The correlation between T and EC was very low, at 1.4% for all springs and 20.9 % for geothermally influenced springs. High EC is not always associated with groundwater with high T. The high or low EC is not determined by T, but by other factors that are more influential. These influencing factors are highly dependent on the local geological conditions where the springs emerge. Low EC at the Sidomukti and normal/warm Gedongsongo springs indicates meteoric water in the catchment area. The EC is moderate in Nglimut, Gedongsongo, Diwak, and Sendang Kramat, indicating the influence of geothermal activity and its mixing with meteoric water. The high EC value in Kaliulo (19.375 µS/cm) marks groundwater that has undergone a long journey, or is due to the dissolution of limestone.

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