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THE ROLE OF FRACTURE DENSITY IN MANIFESTATIONS OF UPFLOW AND OUTFLOW ZONES OF MOUNT UNGARAN GEOTHERMAL SYSTEM

* Brany Kurnianto[1,2], Emi Sukiyah[3], Agus Didit Haryanto[3] and Budi Muljana[3]

[1]Doctor Program of Geological Engineering, Universitas Padjadjaran; [2] Geological Engineering Study Program, Institut Teknologi Nasional Yogyakarta, Indonesia; [3] Department of Geoscience, Universitas Padjadjaran, Indonesia

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ABSTRACT: Geothermal exploration requires the identification of upflow and outflow zones in geothermal resources, especially when determining the best drilling locations. As a Geothermal Working Area (WKP), Mount Ungaran in Central Java is still unexplored. Understanding this region's geothermal system necessitates a comprehensive strategy that combines geochemical and structural research. This study uses geochemical indicators (HCO_3, Na/K, and CO_2) and fracture density (Fault Fracture Density, or FFD) analysis to identify the upflow and outflow zones. Geothermal fluid flow may be influenced by areas with high structural density that are identified by FFD analysis. These zones are made up of interconnecting faults and fractures. Geothermal flow zones can be more precisely defined by using geochemical indicators, which offer more information on the properties of subterranean fluids. The findings show a high link between FFD and geochemical indicators, corroborating the initial theory that the upflow zone is most likely situated in the crater area close to Mount Ungaran's volcanic body. Future drilling recommendations in Mount Ungaran are based on this study, which emphasizes the value of combining structural and geochemical techniques in geothermal exploration.

Keywords: Fracture density, Upflow – Outflow manifestation, Geothermal, Mount Ungaran

1. INTRODUCTION

Geothermal energy provides a sustainable substitute for fossil fuels and is a key component of Indonesia's renewable energy policy [1], [2]. Mount Ungaran in Central Java is one of the many geothermal opportunities in the country that is particularly noteworthy for its enormous potential, but it is yet not well investigated [3]. Effective resource use requires an understanding of the subsurface properties of these geothermal systems, with fracture density emerging as a crucial component impacting fluid dynamics inside these reservoirs [4].

Fracture density is the number of faults or fractures in a specific volume of rock [5]. In geothermal settings, these fissures act as channels for fluid flow, which has an immediate effect on heat extraction efficiency [6]. As shown in upflow zones, high fracture densities can increase permeability and make it easier for geothermal fluids to ascend from deeper reservoirs to the surface. The development of outflow zones, where fluids spread laterally, may result from regions with lower fracture densities impeding fluid passage [7].

Researched area is located at Ungaran, Semarang Regency, Central Java (Fig. 1). From an administrative standpoint, this area falls within the Bawen, Bandungan, and Ambarawa sub-districts. Geographically, its boundaries are defined by coordinates 7°05'0" S until 7°15'0" S and 110°15'0" E until 110°30'0" E. Mount Ungaran is one of the interesting geothermal fields in Central Java province and is still included in the Geothermal Working Area (WKP) category which has not been studied further.

The geological structure of Mount Ungaran consists of Quaternary volcanic deposits, primarily andesite lava and volcanic breccia [8], while the downstream region exhibits characteristics of Tertiary sedimentary rocks (Fig. 1; Fig. 3). This stratigraphic arrangement points to a complex geothermal system, especially when paired with intricate tectonic features like fault zones and grabens, especially on the southern slopes [9], [10]. Geothermal features in the region, such as fumaroles, hot springs, and warm springs, signify active subsurface geothermal activity [11].

The research is focused on examining the correlation between fracture Density and the formation of upflow/outflow areas, as well as the various geochemical properties of the resulting fluid. Specifically, the research investigates the influence of joint density on the delineation of upflow and outflow zones within a specific region.

The geothermal system of Mount Ungaran has not been thoroughly investigated, despite its promise, which has resulted in a lack of comprehensive subsurface data. Optimizing exploration and development plans require addressing this gap. In this study, the upflow and outflow zones within the Mount Ungaran geothermal system will be identified by combining fault fracture density studies with geochemical evaluations. This integrated approach can improve the precision of geothermal reservoir models, therefore guiding drilling tactics and resource management.

Examining the relationship between fracture density and geothermal fluid dynamics is essential for the efficient development of geothermal resources. The knowledge derived from Mount Ungaran can enhance geothermal exploration in locations with analogous geological characteristics. Future study should concentrate on high-resolution geophysical surveys and comprehensive geochemical investigations to elucidate the intricacies of geothermal systems such as Mount Ungaran.

The structure of this article is as follows: Data collection methods and analytical tools used to analyse fracture density and geochemical properties are described in depth in the Methodology section. The results of these analyses are shown in the Results and Discussion section, which also compares them with those of other research and interprets the data to determine upflow and outflow zones. The Conclusion section emphasizes the practical implications, summarizes the principal findings, and provides recommendations for future research and industry applications.

2. RESEARCH SIGNIFICANCE

Upflow and outflow zones in geothermal fields are very important to identify. These two zones are very useful in carrying out a geothermal project, such as determining drilling points. The emergence of several geothermal system manifestations in the Gedongsongo area and in the Kaliulo area indicates control by geological structures.

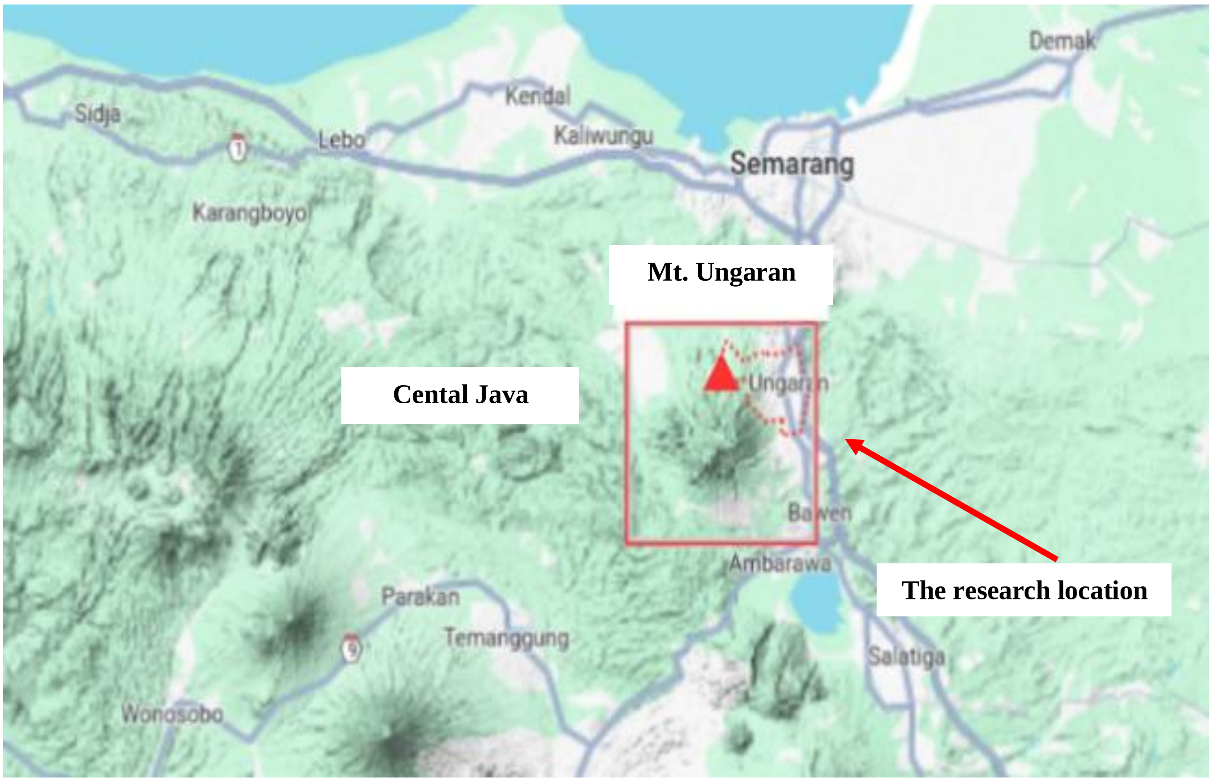
An interesting thing to study in the research area is the characteristics of the geological structure and how they influence the emergence of Upflow and Outflow manifestation zones in the Mount Ungaran geothermal system so that it can support the structural geology interpretation of the geothermal prospect zone.

3. GEOLOGICAL SETTING

Mount Ungaran is located in the Solo zone, a depressed landscape in the form of an inter-mountain plain in the middle of the chain volcano.

The Mount Ungaran typifies a strato-type volcano, characterized by its composition of lava, pyroclastic material, and tuff, exhibiting an andesitic content with a basaltic composition.

These rocks are well deposited around the peaks and bases of volcanoes and cover Tertiary sedimentary rocks. The Mount Ungaran is a Quaternary andesitic volcanic complex [8]. The stratigraphy of this volcano is composed of andesitic lava and pyroclastic breccia of the "post-Caldera" formation



Source: https://www.google.co.id/maps

Fig. 1 Location of research area

This formation was deposited on old volcanic rocks formed before the formation of the Ungaran caldera. The geological structure that develops on this volcano. This complex is controlled by the Ungaran collapse structure which has a west to southeast orientation of Ungaran.

In the area around Gedongsongo, which is located on the southern slopes of the Mount Ungaran, there are fault structures that cut through old volcanic rocks from the Pre-Caldera formation. These fault structures have a northwest-southeast and southwest-northeast orientation. The Mount Ungaran stands at an elevation of around 1300 to 2000 meters above sea level. The geothermal manifestations in this area include fumaroles, steaming Ground, and altered rocks.

Quaternary volcanic complexes in Central Java include the Mount Slamet Complex, Mount Sindoro-Sumbing Complex, Mount Ungaran, the Mount Merapi-Merbabu Complex, Mount Muria Complex, Mount Lasem, and some are included in the Mount Lawu Complex. Mount Ungaran is a strato-type volcano which is located close to the north coast of Java. The research location of Mount Ungaran, included in the northern part of Central Java which is the North Serayu mountain range and the Kendeng anticlinorium zone [12]. This also shows that the study area is mostly composed of volcanic products.

4. METHODS

This research utilized two methods: field observation and studio analysis. Field observations involved collecting primary data on the distribution of manifestations in the research area, including hot springs, cold springs, steamy soil, alteration zones, and fumarole manifestations. Data collection focused on gathering morphological, lithological, and structural/fracture intensity data, as well as physical data on hot springs and fumaroles. The study of morph

characteristics underscores the significance of comprehending active faults for regional development and hazard assessment [13-15]. The interrelationships among these morphometric characteristics can understanding the underlying structure. [16-18].

Studio analysis is carried out through processing satellite images and topographic maps. Image processing was carried out to obtain the percentage of land use area in the research area. The results of image processing and analysis of the research area are based on key image interpretation (hue, texture, pattern, etc.). Studio analysis was also carried out through lineament interpretation of DEM data and Landsat 8 imagery.

This analysis was carried out to obtain the pattern and intensity of fracture alignment and morphological alignment in the research area. Analysis of lineament patterns and intensity using ArcGIS software, producing rose diagrams and graphs. During this stage of interpretation, a Fault Fracture Density (FFD) map will be generated using important information about field hydrology and and conditions within the reservoir [19]. The lineament drawing and structure/fracture measurement data collected in the field. This will help identify the areas with the highest density of structural features, which may be associated with the occurrence of surface manifestations.

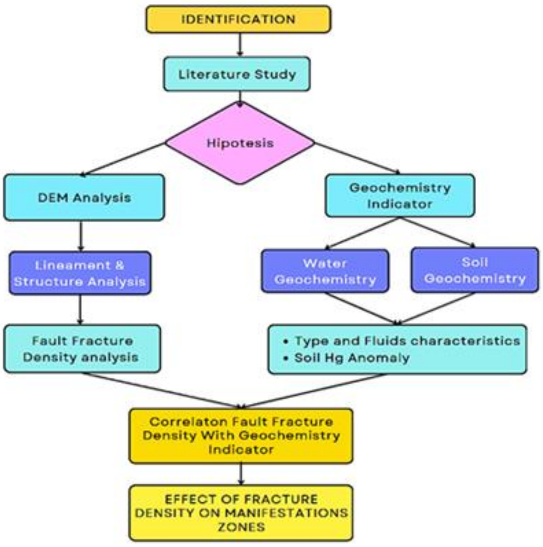


Fig. 2 The scheme of research methods

The researcher initially hypothesized that the geothermal upflow zone on Mount Ungaran is probably situated in the crater area of the volcano. To test this hypothesis, the study utilized two main research methods: geochemical indicator analysis and Fault Fracture Density (FFD) analysis (Fig. 4). The examination of geochemical indicators provides a robust methodology for elucidating the genesis and chemical evolution of geothermal manifestations. This analysis entails a comprehensive study of the chemical composition of geothermal water and gas.

The characteristics and distribution of identified structural areas play a significant role in providing valuable insights into how the alignment of geological features corresponds to the intensity of geological structures and the formation of upflow and outflow zones within the Mount Ungaran geothermal system. By studying these structural areas, researchers can gain a deeper understanding of how the geological features are positioned and how they influence the intensity of geological structures within the Mount Ungaran geothermal system. This knowledge serves as a crucial foundation for accurately assessing and evaluating the geothermal potential of Mount Ungaran.

5. RESULT

5.1 DEM Analysis

Identification of the geological structure of the research area was carried out by observing lineament patterns from a combination of Landsat 8+ETM image maps and DEM maps. Lineaments can be interpreted as linear geomorphological elements that represent geological structures or lithological contacts. The appearance of lineaments on the earth's surface is reflected in the presence of morphological lineaments caused by relief, such as the straightness of valleys, ridges and river [20].

More than 452 lineaments have been identified by Landsat 8 and SRTM resolution of 30 m, lineaments can be identified as long and regional lineaments. SRTM analysis shows several short to moderate lineaments. Based on the results of the lineament analysis on DEM and Landsat 8+ETM imagery and rose diagram analysis, the general direction of force in the research area is N 90^0-103^0/E so it is relatively West - East. The general direction of this geological structure is in accordance with the regional structural pattern, namely in the same direction as the Javanese pattern which is relatively west-east trending (Fig.3).

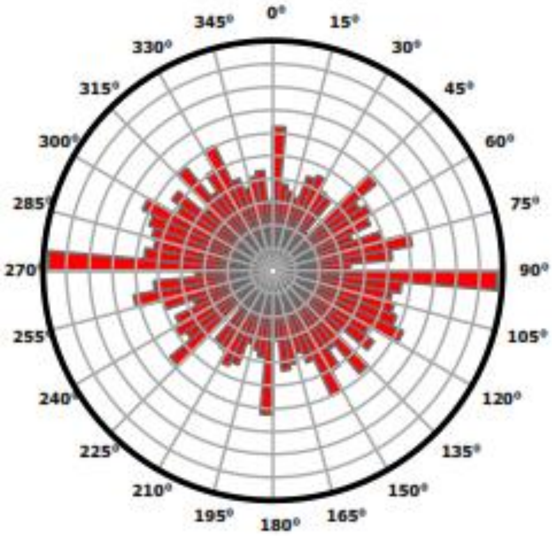


Fig. 3 Rose diagram of geological structure lineament orientation in Landsat Imagery

5.2 Fault Fracture Density (FFD)

Based on the lineament drawing results (Fig. 4), we can identify anomalies in fracture density by creating a Fault Fracture Density (FFD) map. Linearity or straightness in the lineaments is considered as a weak plane that forms a structural path, indicating the location of permeable areas or reservoirs.

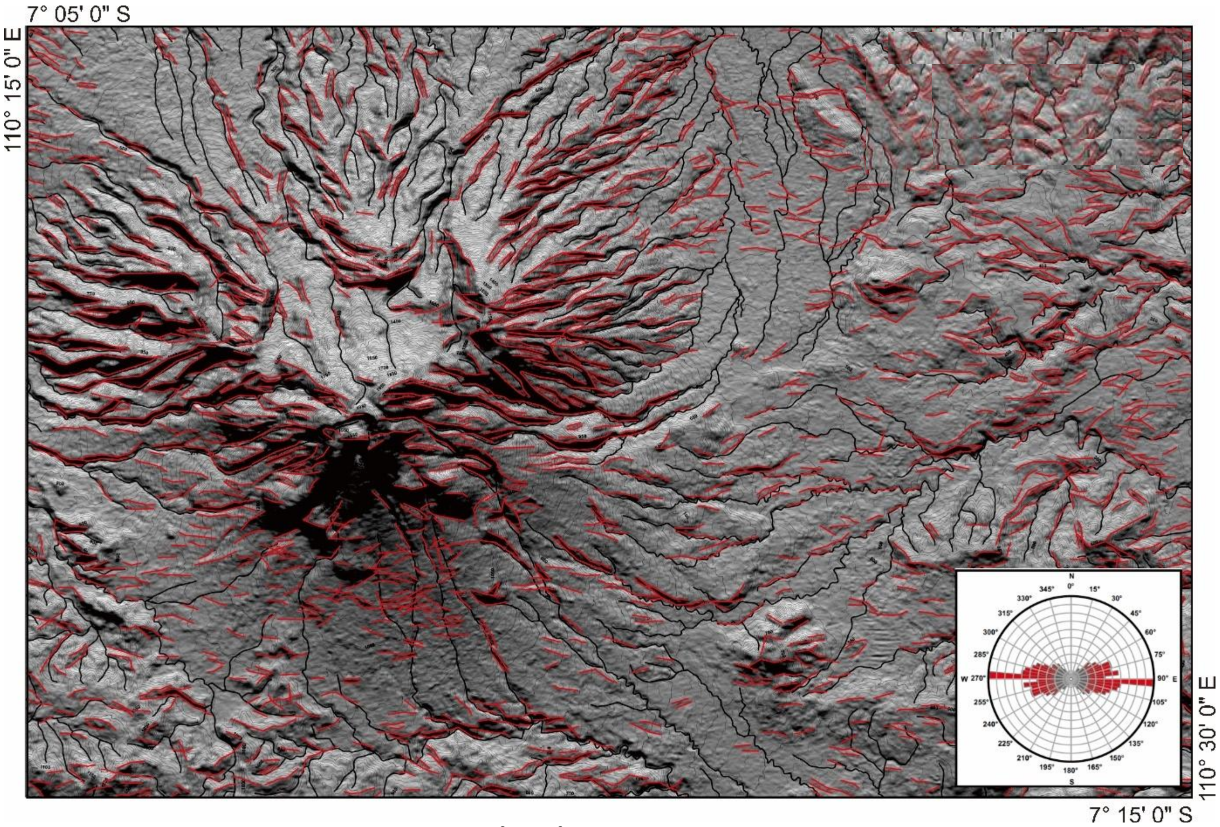


Fig 4. The Lineament map of study area, N 90^0-103^0 E

High structural density may indicate the center of fluid movement, with locations showing the highest structural density being potential areas for fluid movement. Regions with high structural density exhibit numerous lineaments and generally influence phenomena in the study area, such as the Gedongsongo hot springs, gas fumaroles in temple villages, and steamy soil around the Gedongsongo temple.

Geothermal manifestations in the Gedongsongo area consist of fumaroles, hot springs and steamy soil. The air temperature in this area is 24.9^0 C. Fumaroles are a geothermal manifestation that has a water-dominated system and emits wet steam. This manifestation is located along a relatively straight river with a direction of N 5^o E. Joint has a direction of N100^0 E/70^0. Fumaroles appear in the valley and the western part of the river cliff and have relatively constant gas gusts with a temperature of 89.7^0 C. This area is the upflow zone of the Mount Ungaran geothermal system.

Fig. 6 The fumaroles in Gedongsongo with temperatures 89.7^{0}C blowing steam containing CO_2.

Fig. 7 The appearance of the item river slip fault in the direction N 5^0 E

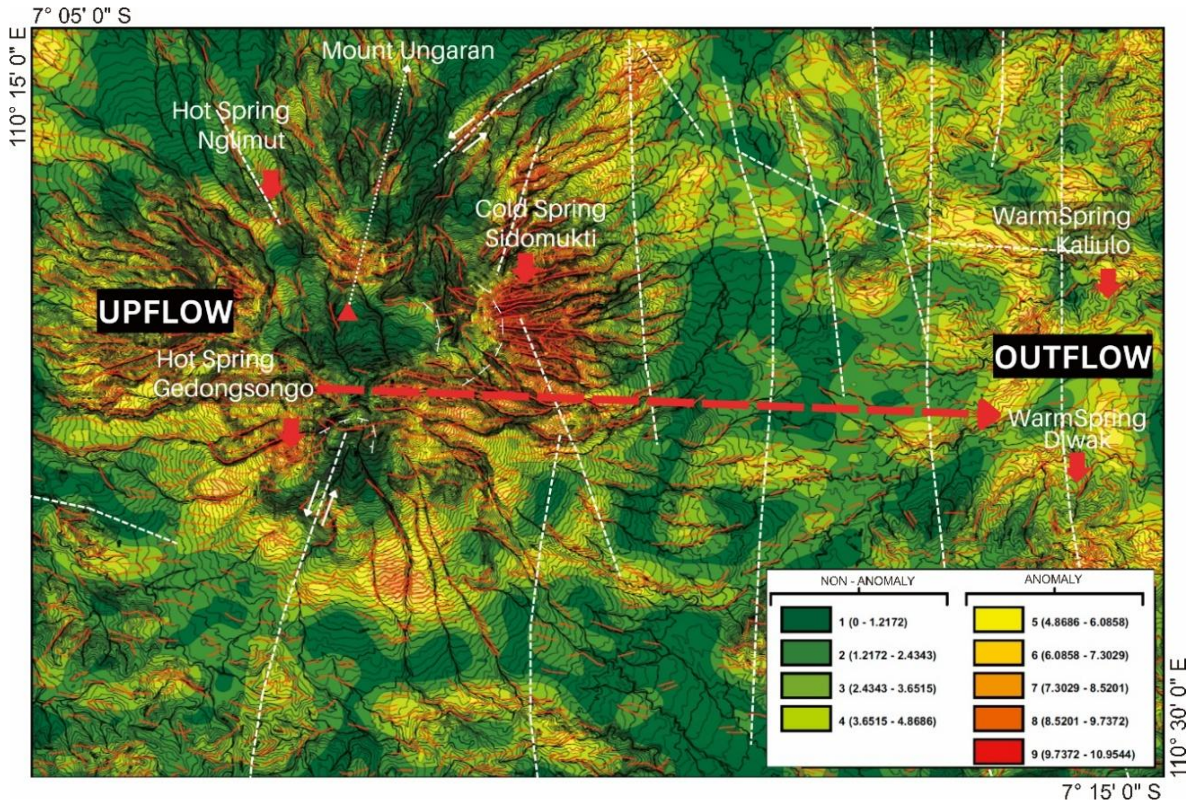


Fig. 5 The Fault Fracture Density map of study area, with Mount Ungaran Geothermal Manifestation

Hot springs are also found around Fumarola Gedongsongo. These hot springs have murky water with a whitish gray mud color, occupying the western and eastern parts of the river valley. Temperatures range from 61.4^0C – 71.6^0C.

The geothermal prospects for Mount Ungaran and its surroundings which have the highest-medium structural density are shown in red-yellow, then those for low structural density are shown in dark green and light green (Fig.5).

The areas with structural density in red (9.7 until 11 km^{-1}) include Gedongsongo village, Nglimut-Gonoharjo village. This area is the area where the upflow manifestation of geothermal fluid from Mount Ungaran appears (Table 1).

Table 1. Comparative data on joint density anomalies in the Mount Ungaran geothermal field

Location	Density (km^{-1})	Type Spring	Anomaly
Gedongsongo	11	Hot Spring	UpFlow
Nglimut	9.7	Hot Spring	UpFlow
Sidomukti	8	Spring	Cold Water
Kaliulo	8.5	Hot Spring	Out Flow
Diwak	9.6	Hot Spring	Out Flow

The areas with orange structural density (8.5 until 9.6 km^{-1}) include Kaliulo village and Diwak village. This area is an outflow of geothermal fluid from Mount Ungaran.

The area where the Manifestation appears in the Diwak area is indicated by the warm springs from which tanks have been made for the water to be taken and used to make Javanese crackers "legendar". The air temperature is 35.5^0 C, the warm spring temperature is 39.2^0 C – 40.7^0 C. The blowing of gas bubbles is relatively constant, the air shows a sulfur smell. There is travertine and the water tastes salty.

The bedrock is volcanic breccia and carbonate sandstone. Meanwhile, areas with low structural density (3.6 - 4.8 km-^{1}) are Pertapan, Bandungan, and Bawen sub-districts shown in light green.

5.3 Water Geochemistry

Geothermal geochemical fluid analysis using water geochemistry is used to determine the origin of the fluid, water type and temperature of the geothermal reservoir. 6 water samples were obtained (for anion and cation analysis), consisting of 2 hot water samples in the upflow zone (Gedongsongo hot water) and 4 hot/warm water samples in the outflow zone, namely hot/warm water in the Diwak, Kaliulo.

From Table 2, it can be seen that sulfate compounds dominate the composition of hot water in the Gedongsongo area with very large electrical conductivity values. Apart from sulfate compounds, the hot water here also contains quite large amounts of silica and sodium. This may be influenced by alteration rocks which are mostly converted into clay minerals. The hot water in Gedongsongo includes sulfate water with very acidic conditions.

Table 2. Chemical composition of spring water manifestations of Mount Ungaran

Element	GDS	DRK	DWK	KLU	NGL
Na^+	14.96	169.35	159.43	4747	265
K^+	5.63	33.68	32.13	0.19	27
Li^+	0.01	0.2	0.19	1.99	-
Ca^{++}	31.17	176.26	160.19	67.20	180
Mg^{++}	12.35	141.5.	136.10	36.48	143
Fe	7.03	0.89	0.22	0.14	0.73
As^-	0.00	0.10	0.10	0.10	0.01
SiO_2	114.18	151.85	152.28	56.28	42.0
B	0.18	6.19	5.46	191.1	-
HCO_3^-	0	1516.83	1394.11	3745.89	1817.8
CL^-	0.85	98.69	91.85	5139.94	50.10
$SO4^-$	200	1.63	0.84	17.25	7.00
F^-	0.01	0	0	0	0
pH	3.18	6.70	7.30	7.51	5.60
Umhos/cm					

Table 3. Data on hot/warm water manifestations in Ungaran field

Hot Spring	Water (^{0}C)	Air (^{0}C)	pH
Gedongsongo1	96.4	24.1	6.92
Gedongsongo2	85.1	22.1	3.18
Nglimut	45.6	29.5	8.30
Kaliulo	40.16	28.1	7.51
Diwak	38.6	28.0	6.70
Derekan	38.6	28.1	7.30

The hot water in Diwak and Derekan (Table 3) is a type of carbonate water with a high concentration of bicarbonate compounds. In addition to bicarbonate, it also contains sodium, calcium, magnesium, and chlorine ions in similar proportions.

On the other hand, the chemical composition of the hot water in Kaliulo is primarily characterized by sodium, bicarbonate, and chloride content, with a chloride water type and neutral acidity.

5.4 Cl, SO_4, HCO_3 diagram

Water chemistry analysis on the Cl, SO_4, HCO_3 triangle diagram is used to determine the type of fluid and composition of the geothermal fluid. Water samples were taken at fumaroles and hot springs (Table 4). Several hot water samples were taken from Gedongsongo, Nglimut, Diwak-Derekan and Kaliulo.

The results of plotting water chemistry data on the Cl-HCO_3-SO_4 diagram (Fig. 8) show that the types of water or geothermal fluid in Ungaran include: chloride, bicarbonate and sulfate water.

Bicarbonate water is represented by sample codes NGL, DRK and sample DWK. With a Ca element content (159 until 265ppm), while sulfate water is found in samples GD-01 and GD-02. This type of sulfate water contains 200-350 ppm SO_4, bicarbonate water has an HCO_3 concentration of 58.6-1824 ppm, while chloride water has a Cl content (5900 ppm). The high chloride content in hot water is influenced by water trapped in marine volcanic sediments of tertiary age.

5.5 Soil Geochemistry (Hg Anomaly)

Magma or hydrothermal fluid can heat ground water to form a system of hot water and water vapor, then deposits several types of metal elements in the soil [21]. Thus, the concentration of metal elements such as mercury (Hg) and carbon dioxide gas, for example, found in the soil can be an indicator of the existence of a hot water system and water vapor below the surface. Relatively high Hg anomalies are characteristic of a structure associated with geothermal springs [22].

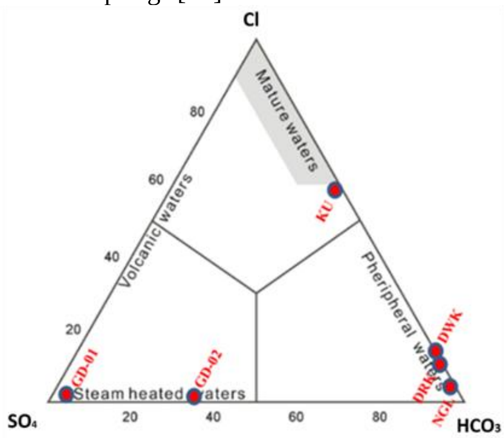


Fig 8. Fluids Geochemistry Mount Ungaran Manifestation.

Additionally, a high concentration of 320 ppb was also observed at station 13. Analysis of soil samples and soil gas samples using primary data from samplings carried out by the STTNAS Yogyakarta expert team in collaboration with the Central Java Mining Service in 2006 (Fig. 9). Soil sampling was conducted at a depth of 1 meter at the specific location marked in Figure 9. The samples were then sent to the Volcanology chemistry laboratory in Yogyakarta for analysis. This analysis will help determine the distribution of soil mercury (Hg) concentrations/anomalies, which is essential for identifying potential geothermal prospect areas. Based on the statistical calculations of the Hg concentration data (Table 5), the average Hg concentration is 139.19 ppb, with a standard deviation

Table 5. Hg concentration in soil sampling in the Gedongsongo area.

STA	Hg (ppb)	STA	Hg (ppb)	STA	Hg (ppb)
1.	168	26.	82	52	120
2.	124	27.	174	53	106
3.	146	28.	96	54	204
4.	78	29.	240	55	98
5.	154	30.	62	56	84
6.	64	31.	46	57	62
7.	128	32.	72	58	186
8.	72	33.	160	59	142
9.	94	34.	98	60	160
10.	82	35.	242	61	94
11.	144	36.	118	62	52
12.	106	37.	200	63	80
13.	320	38.	102	64	190
14.	162	39.	86	65	122
15.	104	40	74	66	114
16.	100	41	0.59	67	102
17.	166	42	1.69	68	132
18.	124	43	1.41	69	202
19.	112	45	1.07	70	142
20.	88	46	0.71		
21.	294	47	0.96		
22.	920	48	1.92		
23.	120	49	1.74		
24	108	50	70		
25.	76	51	142		

Min = 46
Mean = 139.59
Median = 114
Standard deviation = 115.9
Threshold value = 357.22

Table 4. Cl-SO_4-HCO_3 Percentage

Location	Cl	SO_4	HCO_3	TOT	% CL	% SO_4	% HCO_3
GD-01	0.76	350	155.2	506	0.15	69.2	30.6
GD-02	0.85	200	0.00	200	0.42	99.5	0.00
DRK	98.6	1.63	1516	1617	6.10	0.10	93.8
DWK	91.8	0.84	1394	1486	6.18	0.06	93.7
KU	5139	17.2	3745	8903	57.7	0.19	42.0
NGL	50.1	7.00	1817	1874	2.67	0.37	96.9

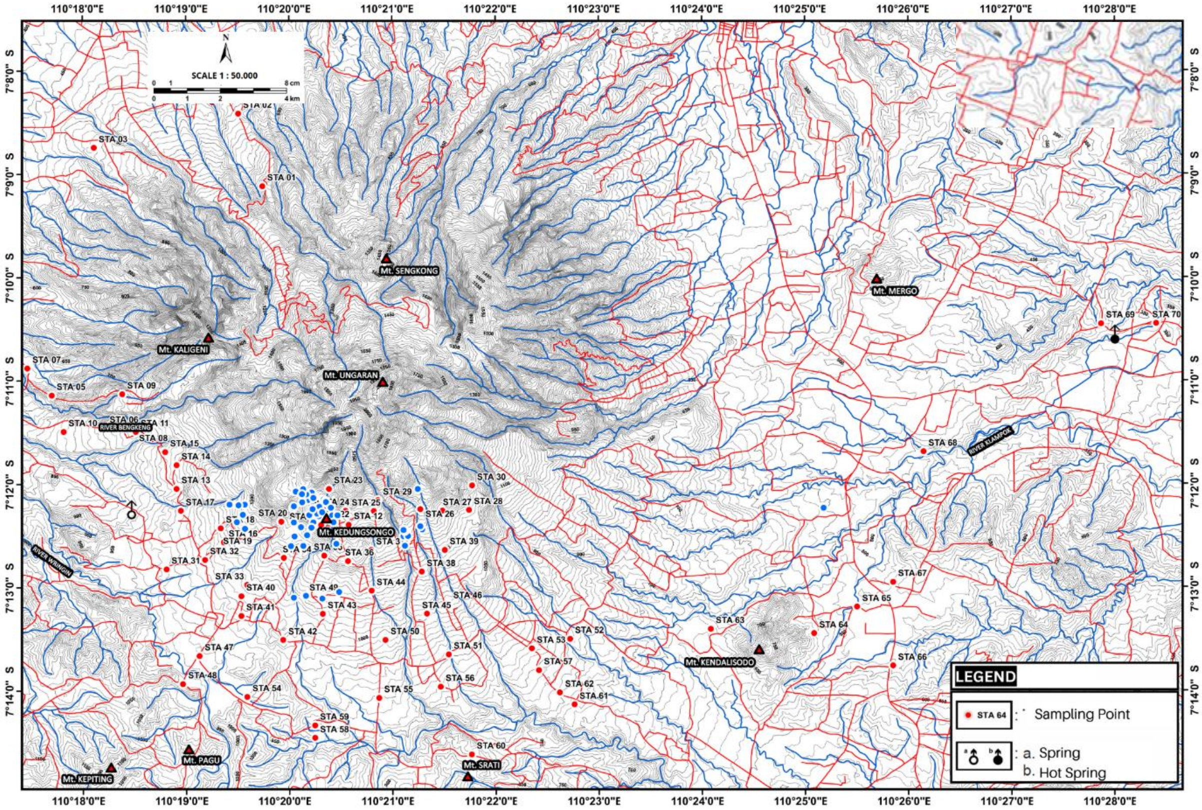


Fig 9. Soil Geochemistry Sampling Station from East to West Mount Ungaran

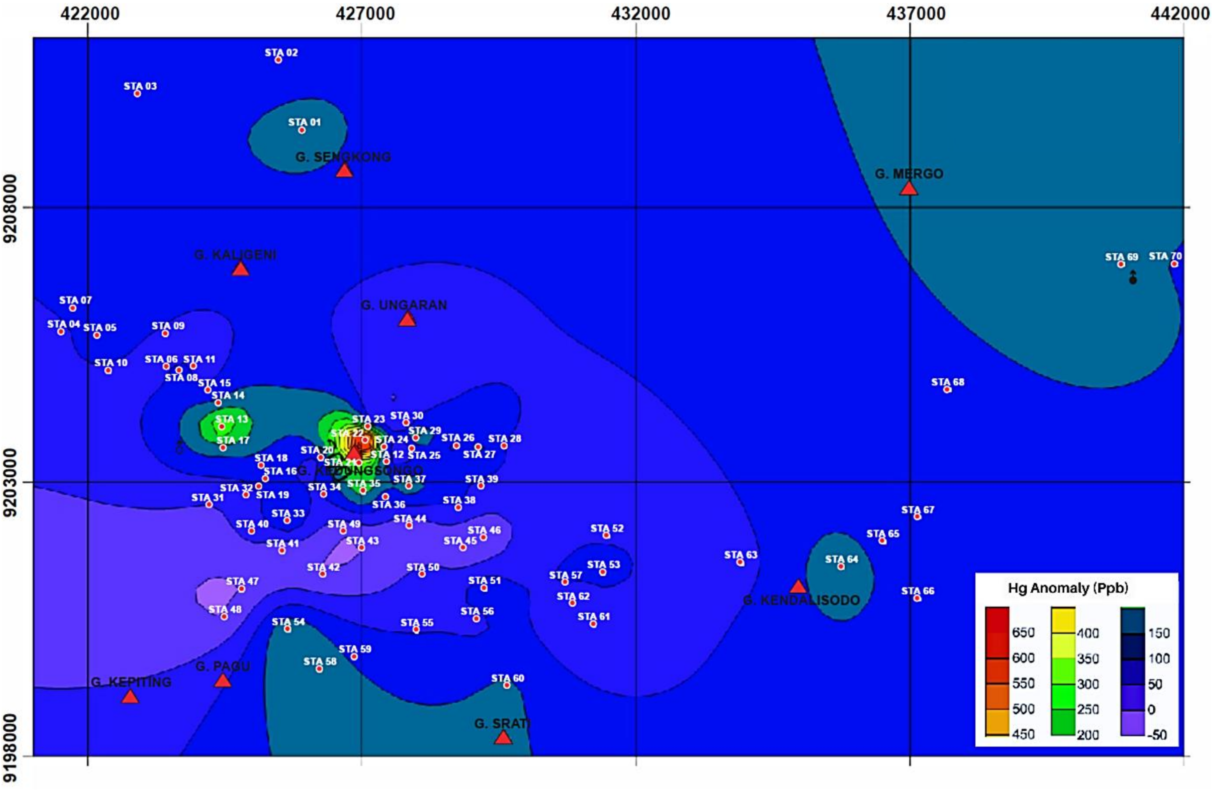


Fig.10 Anomaly contour of Hg anomaly (Orange to Red) Area

According to [11], the presence of mercury (Hg) anomalies indicates that geothermal activity below the surface is closely linked to fractures. It is suggested that temperature measurements in sample holes related to geothermal phenomena should be taken at a depth of 1-5 meters below the ground. The large deviation is due to the significant difference between the maximum and minimum concentration values.

The Hg anomaly at station 22 is 920 ppb, which is well above the threshold value of 115.9 ppb. This very high Hg concentration may be influenced by faults in the survey area which encourage the release of hydrothermal solutions in the area [23]. Hg concentration anomalies are also shown in the Hg anomaly distribution map presented in (Fig.10).

The area at the foot of Mount Ungaran has a low-density value, indicating poor permeability of the surface (Kali Ulo and Diwak) which appear at the foot of Mount Ungaran (discharge area).

In the Diwak and Kali Ulo areas, based on the FFD analysis, it seems that local structures have control over the release of hot fluids. This means that areas with local structural control can serve as outlets.

6. DISCUSSION

Based on the data analysis, it can be seen that the alignment in the research area tends towards the West - North East (Fig 3). From the Fault Fracture Density (FFD) map, the study area can be grouped into two categories, namely high fracture density in red (>9.7 km^{-1}) and low fracture density in yellow (<4.8 km^{-1}.).

In areas with high-density values, we can observe geothermal manifestations such as hot springs and fumaroles. This indicates that the surface lithology has good permeability, allowing geothermal manifestations to reach the surface through local fractures as a direct flow zone (Upflow) in the research area (Fig 7).

The crater area and body of Mount Ungaran are interpreted as recharge zones because the rocks on the surface are assumed to have good permeability based on the FFD map. The West - East direction also shows the direction of geothermal fluid flow in the research area. This is supported by the presence of hot spring for hot fluids, turning them into edge zones or outflow zones in the Mount Ungaran geothermal system (Fig 7).

The correlation of FFD and geochemical indicators is crucial to reinforce the analysis results for determining the upflow-outflow zone in the Mount Ungaran geothermal area. According to the FFD analysis, the straight orientation pattern of the surface geological structure tends to be oriented from West to East, indicated by high fracture density values (>9.7 km^{-1}).

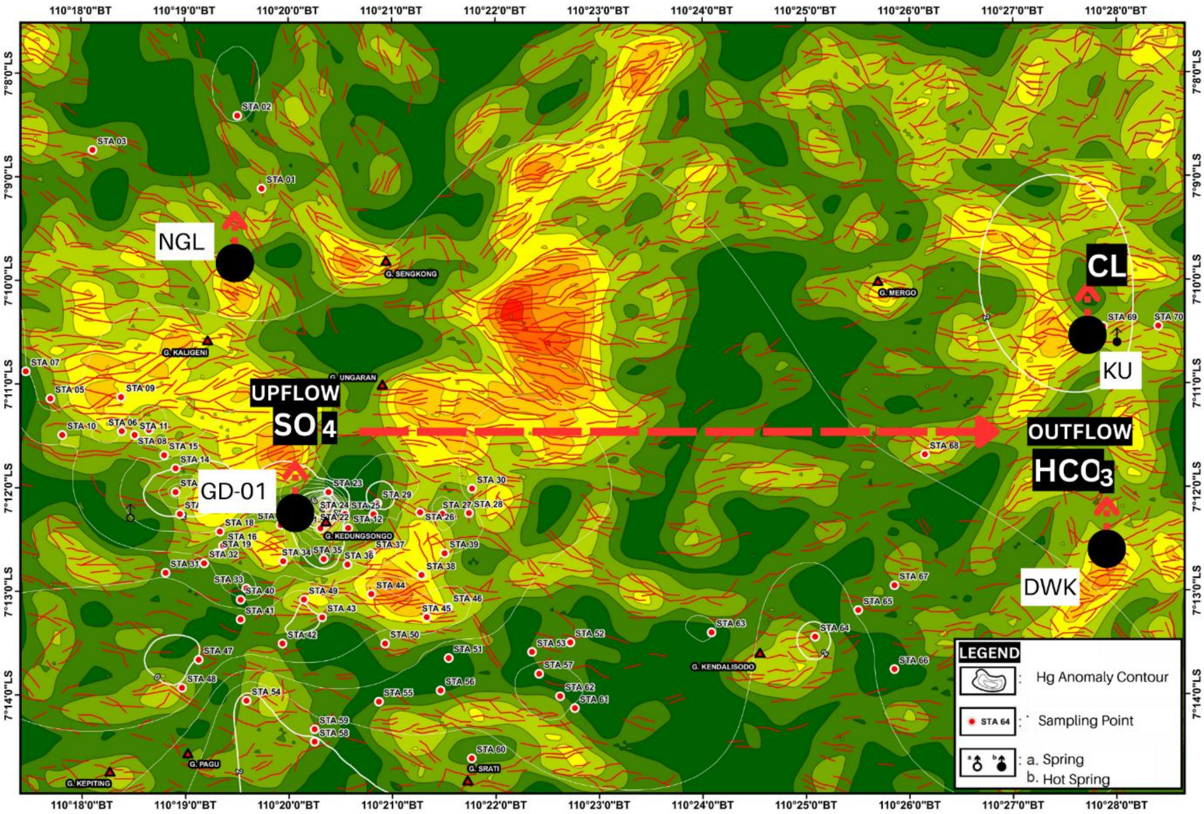


Fig. 11 Fracture density correlation with fluids geochemistry and soil Hg

This suggests that the geothermal fluid will flow in the same direction as this pattern due to a permeable zone, causing the geothermal fluid to flow towards a lower elevation (outflow zone) at the foot of Mount Ungaran in the Diwak and Kaliulo areas. Additionally, the presence of warm water sources at the foot of the mountain in the research area supports this conclusion (Fig 11).

The results of the FFD analysis also correlate very well with the analysis of geochemical indicators in the research area, where the results of the geochemical indicators from the correlation map (Fig 11) are sufficient to describe the upflow-outflow zone in the research area using comparison. Geochemical indicator elements Cl, SO_4, HCO_3, and Hg anomalies in soil samples.

The upflow zone is identified by the presence of sulfate water in samples GD-01 and GD-02. This type of sulfate water contains 200-350 ppm SO_4 (Fig. 11).

The manifestation temperature ranges from 85°C to 96°C (Table 3), placing it in the high-temperature category. On the other hand, the outflow zone exhibits low-temperature springs in the Diwak and Kali Ulo areas, with temperatures ranging from 38°C to 40°C. Bicarbonate water is represented by samples with the codes NGL and DRK, as well as sample DWK. With a calcium (Ca) content of 159-265 ppm, the bicarbonate water has an HCO_3 concentration of 58.6-1824 ppm, while the chloride water has a Cl content of 5900 ppm. The high chlorie concentration of 58.6-1824 ppm, while the chloride water has a Cl content of 5900 ppm. The high chloride content in hot water is influenced by water trapped in marine volcanic sediments of tertiary age.

The concentration of metal elements such as mercury (Hg), which is found in the soil can also be an indicator of the existence of a permeability zone or reservoir zone below the surface which is related to the fracture system in the geothermal system

Based on the threshold value, it is apparent that there is a Hg anomaly of 920 ppb at station 22. There is also a relatively high concentration of 320 ppb at station 13. The elevated Hg concentration may be attributed to faults in the survey area that promote the release of hydrothermal solutions. Additionally, Hg concentration anomalies are depicted in the Hg anomaly distribution map presented in (Fig.10).

On the map, you can see that the high concentration of mercury (Hg) is indicated by yellow-orange contour lines, located to the northwest and northeast of Gedongsongo temple. The accumulation of these large Hg deposits in the soil surface content might have been influenced by a fault in this location.

7. CONCLUSION

Analysis concludes that the upflow zone is located on the southern slope of Mount Ungaran, while the outflow zone is at the foot of the volcano. This is supported by the results of geochemical indicator analysis. The FFD analysis indicates that the geothermal fluid flows from the heat source (upflow zone) due to the presence of permeable rocks, following a west-east pattern in the geological structure, which results in manifestations at the foot of Mount Ungaran (Diwak and Kali Ulo) and supports the geochemical analysis. Therefore, it can be concluded that fracture density influences the emergence of the upflow and outflow manifestation zones. The author suggests the need for additional data, specifically exploration drill data and geophysical studies using the mt (magneto telluric) method, to better understand the geothermal system on Mount Ungaran, especially in identifying surface fault geological structures and their relationship with subsurface geological structures.

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