J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

Hydrostructure of Groundwater Manifestation of Gedongsongo Geothermal Ungaran, Semarang, Central Java, Indonesia

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DOI: 10.31284/j.jemt.2020.v1i1.1150

Article info
Received:
20 June 2020
Revised:
14 August 2020
Accepted:
15 August 2020
Published:
3 September 2020

Keywords:
Geothermal manifestation, hydrostructure, Ungaran

Abstract
Groundwater is an important element of the hydrological cycle in geothermal systems. The geological structure of the Plio-Pleistocene volcano and different lithological variations affect the type and response of groundwater to rocks. The research area is located around the Gedongsongo Temple complex, Mount Ungaran, Central Java. Based on the field check location, there are three variations of lithology, the first lithology is a breccia with andesite, basalt, and pyroclastic fragments. The NW-SE-oriented geological structure is flattened to the right slip fault which is the fracture aquifer system on the Southern Slope of Mount Ungaran. In the research area, there is an anomaly in the form of deflection of flow direction pattern caused by structural control factor in the form of fracture, the fracture which becomes the fluid channel media is a tension joint on the shear zone with Northwest strike with dip direction toward Northeast which has NW-SE orientation of right slip fault.

1. Introduction

1.1. Background

Ungaran is the only mountain that has geothermal potential in the North-South series of Mount Ungaran-Telomoyo-Merbabu-Merapi [1] although in reality Mount Telomoyo also has limited manifestations. Gedongsongo is an area that has a manifestation of hot water on Mount Ungaran. The development of Gedongsongo research began with [2], which included the Gedongsongo area as a unit of Gajah Mungkur and Sindoro Volcanic Unit in a stratigraphic. But there is no research related to groundwater which is an important element of the hydrological cycle in geothermal systems. The relatively young geological structure and different lithological variations affect the type and response of groundwater to rocks. Based on these explanations the author feels the need to research groundwater hydrostructure in the manifestation of Gedongsongo geothermal Ungaran, Semarang, Central Java.

Figure 1. Research area in the Gedongsongo Temple complex, Semarang Regency, Central Java

1.2. Research Area

The research area is located around the Gedong Songo Temple complex, Mount Ungaran, Central Java. The journey is 20 km from Semarang City to the South (Figure 1).

2. Method

The purpose of this study was to determine the distribution of aquifer types and rock response to groundwater. The method used consists of image interpretation and surface mapping which includes mapping of rock distribution, rock sampling, measurement of groundwater level, and measurement of structural data.

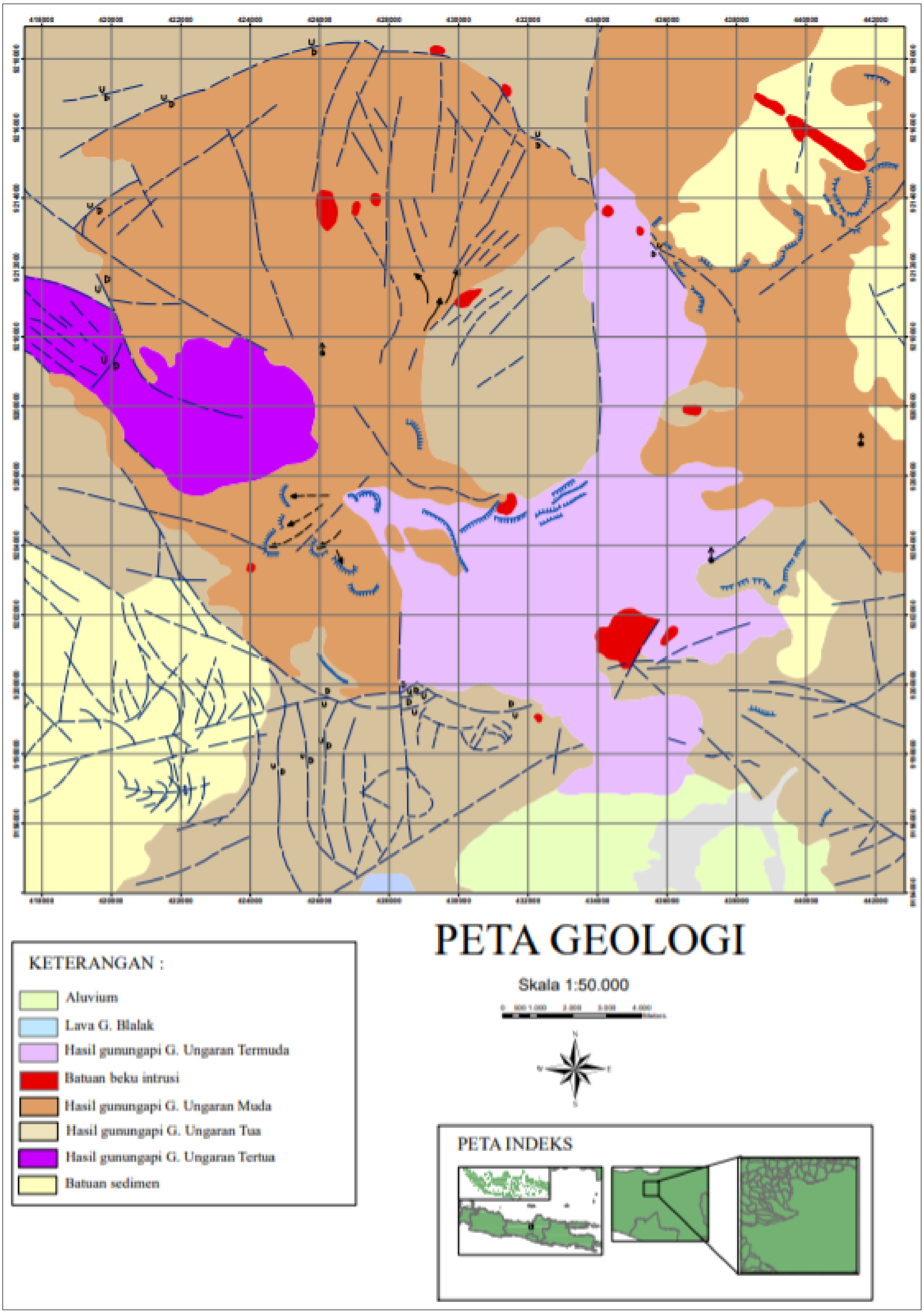

Figure 2. Regional Geological Map of the research area.

3. Regional Geology

Volcano activity is activated by the convergent movement of the Eurasian plate versa Hindi-Australian plate [3], Based on the map of the Ungaran sheet[4], the stratigraphy of the research area consists of two units, the Youngest and Youngest Ungaran Volcanic Output unit. The youngest Ungaran unit consists of lava and andesite lava flows composed of hornblende and augite minerals [1]. Then for the Young Volcano Unit consists of andesite hornblende augite lava flow [5][1] (Figure 2). The regional geological structure of the study area consists of North Northwest-South Southeast formed by contact of rock units and Northeast-Southwest which is formed by the flow of lava tongue [1].

4. Result

4.1. Geology of Research Area

Based on the field check location, there are three variations of lithology, the first lithology is a breccia with andesite, basalt, and pyroclastic fragments (figures 1 and 2), the second lithology is conglomerate with andesite, basalt, and pyroclastic fragments (figures 3 and 4), and the last is andesite lava (figure 6). Geological structures were also found in the form of strike-slip fault with shear fracture and gash fracture data (figure 5).

Figure 3. (From left to the right) Figure 1 is a picture of breccia outcrop, figure 2 is the lithology of altered breccias to be argillic. In figure 3 is a conglomerate outcrop, figure 4 is a photo of conglomerate lithology. Figure 5 is a left slip fault, figure 6 is a lithological photo of andesite lava.

4.2. Manifestation

Figure 4. Argillic alteration in breccias (top left), prophylactic in tuffs (top right), manifestations of hot springs (left bottom), manifestations of gases in the form of fumaroles (right bottom).

Based on the field check, four types of manifestations were found, namely alteration, hot springs, and fumaroles. There are 2 types of alteration types in the study area, namely argillic and prophylitic types, then hot springs located around the prophylitic alteration.

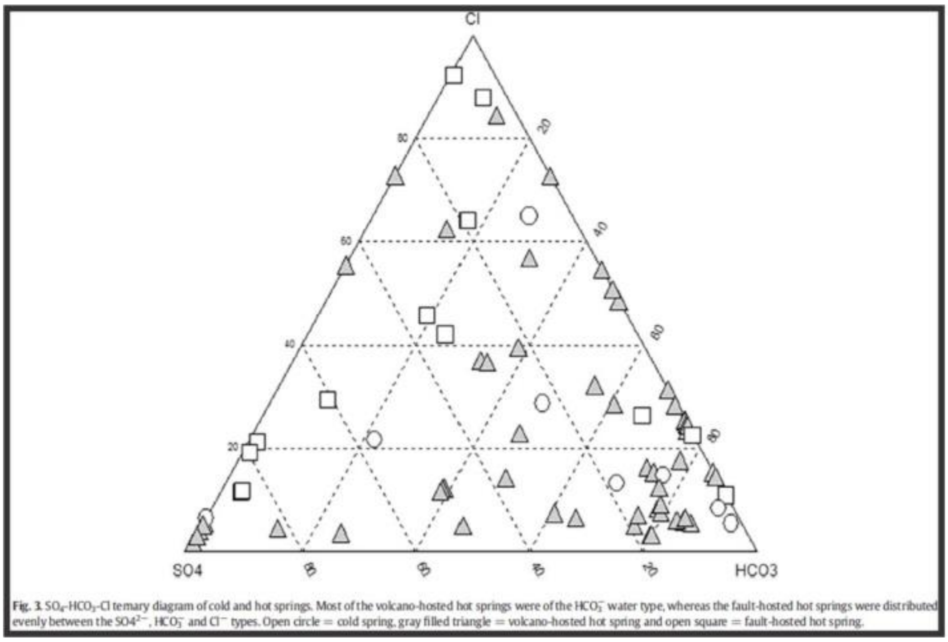

Figure 5. Ternary diagram of a hot and cold spring [6]

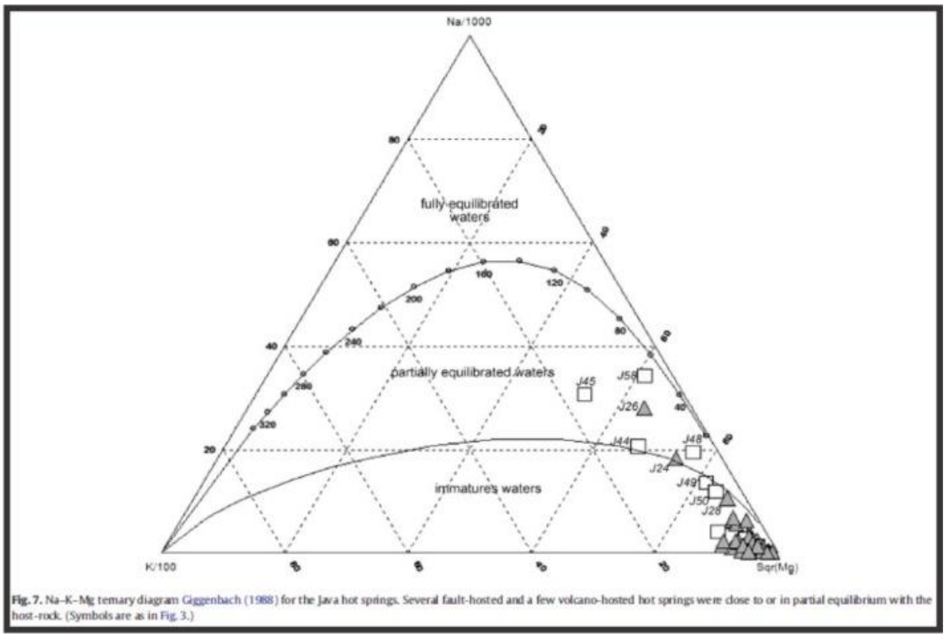

Figure 6. Ternary diagram for Java hot springs [6].

The results of the geochemical analysis of hot water manifestations using a ternary diagram found the percentages of SO_4, HCO_3, Cl, and dominated by HCO_3^-, from the triangle cycle above (figure 1), there is a small gray triangle which is cold water, then which has a shaped square is a hot spring. Then for the next picture (figure 2), divided into 3 types in the form of fully equilibrated waters, partially equilibrated waters, immatures waters.

Table 1. Chemical analysis of water collected in the Gedongsongo and surrounding areas [7]

Location	Code	Temp (°C)	pH	EC (mS/cm)	HCO_3^-	F^-	Cl^-	NO_3^-	SO_4^{2-}	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	$\delta^{18}O$ (‰)	δ^2H (‰)
Gedongsongo	UGW-1	21.9	3.45	0.56	-	0.12	0.84	0.08	247	14.26	0.43	5.04	13.44	42.45	-7.88	-46.70
Gedongsongo	UGW-2	40.0	5.36	0.39	58.6	0.21	1.16	TR	136	25.31	0.64	8.63	10.34	32.55	-7.86	-49.33
Gedongsongo	UGW-3	56.0	6.10	0.33	200	0.12	0.77	TR	31.8	14.09	0.5	7.9	15.14	37.13	-7.95	-50.21
Gedongsongo	UGW-4	32.2	6.00	0.3	465	0.05	0.76	TR	2.61	10.73	0.5	5.46	14.65	35.85	-8.17	-50.57
Gedongsongo	UGW-5	-	6.31	0.04	39	0.004	0.66	TR	3.53	2.315	0.02	1.18	0.65	3.54	-8.19	-50.71
Bumen	UGW-6	20	6.23	0.32	240	0.01	0.94	0.10	2.59	11.89	0.28	4.56	13.52	44.19	-7.60	-47.46
Bumen	UGW-7	19	6.25	0.33	248	0.01	0.98	TR	2.60	12.28	0.29	4.67	14.02	45.71	-7.60	-47.71
Banaran	UGW-8A	20	6.04	0.27	207	0.09	2.46	TR	0.11	10.42	0.13	5.58	11.29	37.06	-7.48	-46.62
Banaran	UGW-8B	18	6.02	0.29	221	0.01	2.44	TR	0.08	10.30	0.14	5.57	11.18	37.06	-7.51	-47.02
Kaliulo	UGW-9	43.5	7.23	19.83	419	0.43	5339	0.16	13.0	5147	TR	181.9	34.60	50.77	3.95	-20.78
Kaliulo *	UGW-10	21	7.23	0.7	320	0.25	75.30	1.16	15.0	43.95	0.56	3.41	17.37	92.79	-4.92	-31.03
Gedongsongo	UGW-11	18	5.42	0.18	57.3	0.01	0.65	0.04	50.3	6.78	0.04	3.14	5.61	18.16	-7.96	-50.02
Candi village *	UGW-13	18	6.65	0.18	97.6	0.06	9.1	14.55	6.40	8.11	0.11	8.14	4.97	19.15	-6.94	-43.83
Gelaran *	UGW-14	18	6.98	0.16	105	0.07	1.80	10.44	2.25	7.81	0.037	4.28	4.96	19.80	-7.33	-45.36
Kendalisodo	UGW-15A	35.2	6.84	4.58	1732	0.06	997.8	0.07	0.10	700.2	16.08	44.15	117.7	217.3	-5.30	-39.36
Kendalisodo	UGW-15B	38.1	6.78	5.21	1824	0.06	1088	0.11	0.00	746.1	17.01	47.11	126.0	278.4	-5.26	-39.78
Kendalisodo **	UGW-16	23.8	7.87	0.51	351	0.08	7.21	3.01	4.43	23.19	0.29	6.35	26.92	62.08	-6.13	-39.05
Diwak	UGW-17A	**39.5**	**6.80**	**2.11**	**1435**	TR	**111.4**	**0.05**	**0.08**	**128**	**147.3**	**1.90**	**30.39**	**134.5**	-6.47	-39.9
Diwak **	UGW-17B	27.5	7.40	0.5	292	0.12	19.21	TR	1.40	46.2	35.69	0.60	6.92	19.37	-4.76	-28.7
Kaliulo*	UGW-18	26.4	7.10	0.29	203	0.12	12.61	4.62	7.24	41.9	12.08	0.10	13	5.25	-5.61	-32.9
Tangkil	UGW-19	24.9	7.10	0.31	157	0.07	2.94	2.86	0.52	69.7	15.74	0.18	3.58	10.15	-6.3	-38.4
Derekan	UGW-20	25.8	7.00	0.21	145	0.05	1.48	3.52	1.03	69.5	11.99	0.20	3.66	6.01	-5.98	-36.9
Derekan	**UGW-21**	**38.5**	**6.90**	**2.5**	**1560**	TR	**119**	TR	**0.31**	**131**	**155.1**	**2.20**	**31.25**	**144.3**	-6.56	-41.3

Note: Concentrations are in ppm.
* Well water.
** River water.

From the chemical analysis of the manifestation of hot water there are concentrations of well water and river water in ppm units collected from the Gedongsongo area in the form of 15 data from 11 different regions obtained results of the highest temperature, SO_4^{2-}, S^2H are in the Gedongsongo area, then the pH, HCO, NH4 -, the highest is in Kendalisodo, EC, the highest is in Kaliulo, F, Cr, Na^+, K^+, Mg^{2+} the highest is in the Kaliulo area, the highest NO_3 is in Candi Village, Ca^{2+} in Diwak, and SO in Tangkil area. The existing geothermal system on the island of Java by showing the physiochemical data associated with hot spring, cold spring, and acid lake crater. Geothermal areas can be divided into Volcanic-hosted and Fault-hosted geothermal systems based on their geological associations. In Java, there are currently 5 volcanic-hosted that have generated electricity while fault-hosted has not been explored because it is assumed that energy is insufficient, as [8]wrote, a faulted-hosted geothermal field located close to volcanic activity which indicated heating of meteoric water circulation in such geological conditions on the island of Java. The geothermal systems carried are classified into volcano-hosted and fault-hosted based on 25 samples of existing geothermal systems, 8 considered as fault-hosted (Pacitan, Maribaya, Batu Kapur, Pakenjeng, Cilayu, Cikundul, Cisolok, and Parangtritis) and 17 considered as volcano-hosted (Segaran, Arjuna-Welirang Volcano, Mount Lawu, Mount Ungaran, Candi Dukuh, Dieng, Kalianget, Mount Slamet, Ciawi, Kampung Sumur, Tampomas, Cipanas, Ciater, Darajat, Kamojang, Pangalengan, and Patuha). All volcano-hosted geothermal systems are in the quaternary volcanic belt, while most faulted-hosts geothermal systems are in the tertiary volcanic belt (Figure 7). Based on water chemistry data that geothermal fluid types include water chloride, bicarbonate, and sulfate which the dominant element is bicarbonate [9].

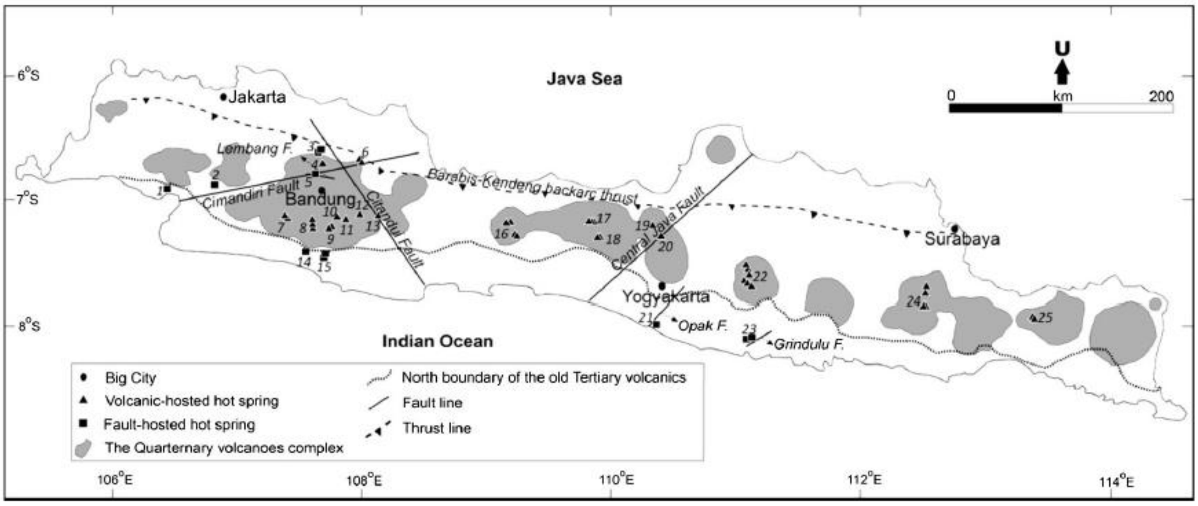

Figure 7. Java Geothermal System [8]

4.3. Hydrostructure

In the study area, there is two rock behavior to groundwater, the first is the aquifuge system, marked with red areas on the map and is an aquifer composed by basaltic volcanic igneous rocks so that it has the nature of rock body behavior with a permeability price that is close to zero (Figure 4). The second is the aquiclude system, the distribution of this system is marked in blue on the map and composed by andesite breccia rocks so that in this system groundwater can flow from upstream to downstream on the slopes of Mount Ungaran. In addition to the intergranular aquifer system on Mount Ungaran, the NW-SE orientation structure found on the right slip fault became the fractured aquifer system on the Southern Slope of Mount Ungaran. Figure 5 shows the relationship between the groundwater level contour elevation map (Equipotential Line) and a land flow map (Streamlines) or commonly referred to as Flower. This depiction of flowers is done by pulling arrows perpendicular to the contour of the groundwater level elevation. Naturally, groundwater flow will intersect perpendicular (90°) to groundwater contours under homogeneous and isotropic aquifer conditions due to the influence of gravitational potential and has a flow direction from high elevated groundwater level (hydraulic head) to lower groundwater level [7]. In the research area, there is an anomaly in the form of deflection of flow direction pattern caused by structural control factor in the form of fracture, the fracture which becomes the fluid channel media is a tension joint on the shear zone with Northwest strike with dip direction toward Northeast which has NW-SE orientation of right slip fault (Figure 8). Based on the interpretation of lineament from the DEM SRTM of Mount Ungaran image on the South Slope it was found to have 2 general directions, they are Northwest-Southeast and Northeast-Southwest with analysis of the main stress from Northeast-Southwest (Figure 10), then from the image and topographic map the main fault appears with the direction of right movement. Analysis of shear fracture and gash fracture on the minor right fault zone found that the right fault is up with major stress of 15 degrees from the regional major stress that is interpreted as an antithetic R shear fault.

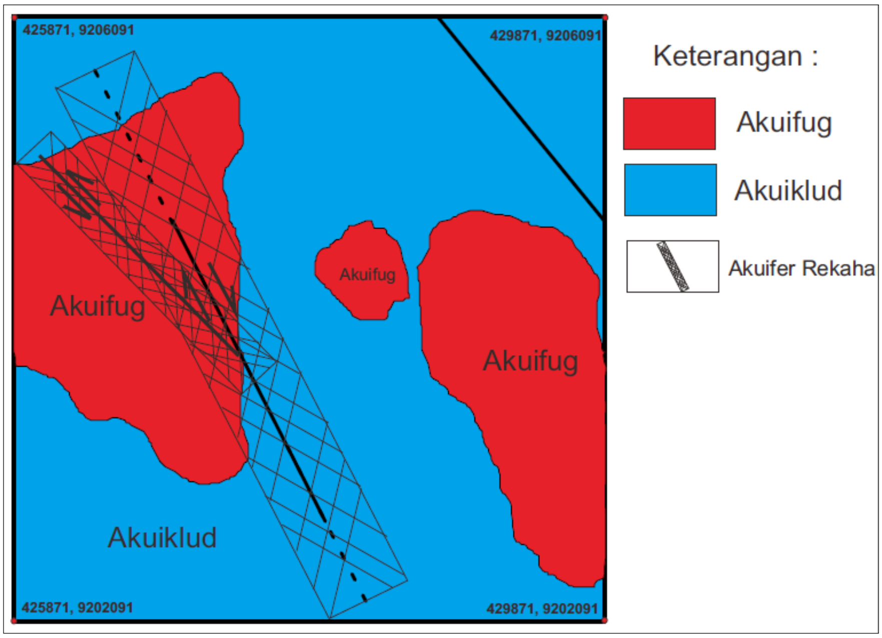

Figure 8: Aquifer Distribution Map

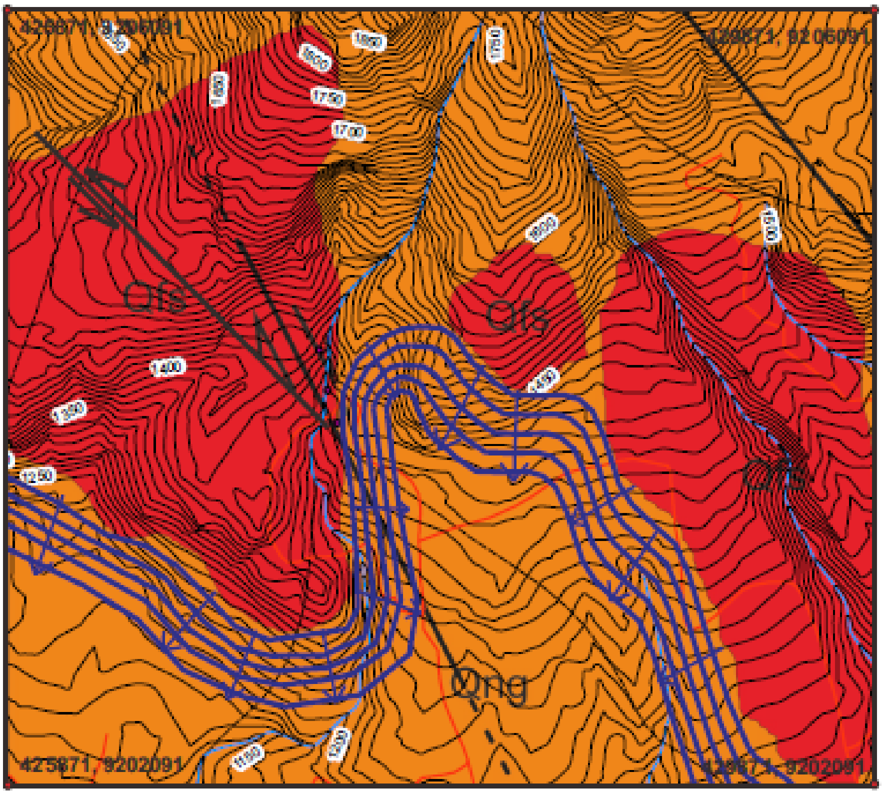

Figure 9: Map of groundwater flow patterns on the southern slope of Mount Ungaran

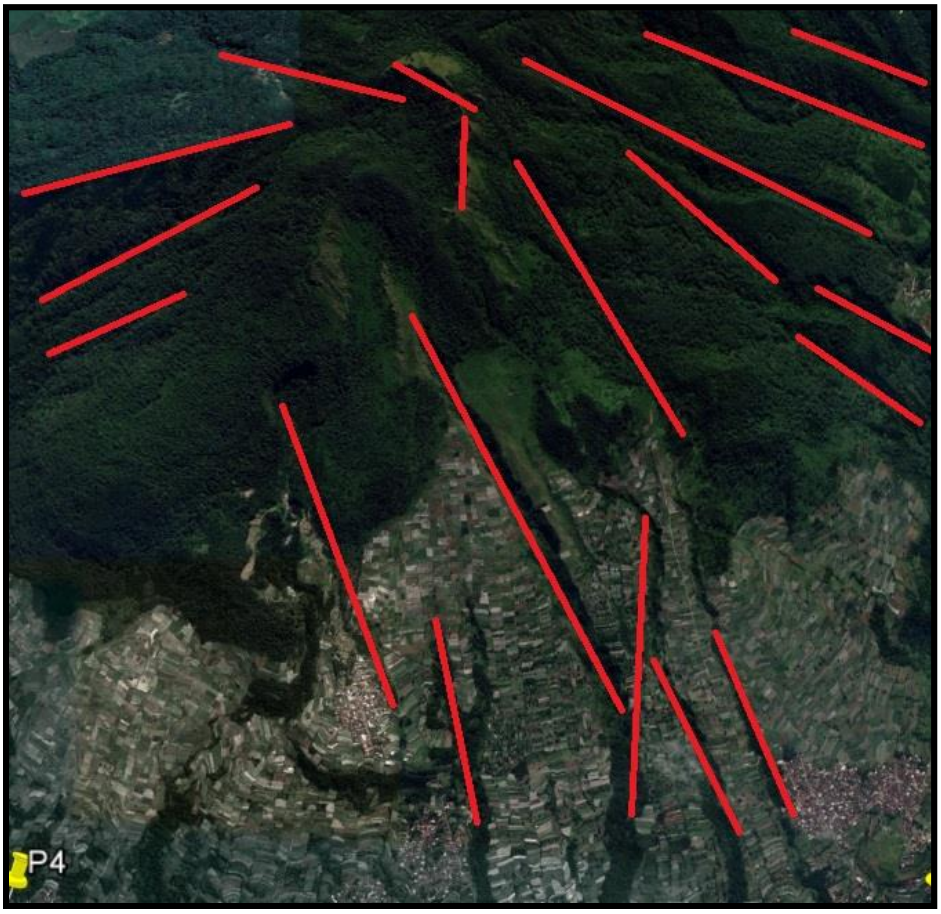

Figure 9: Interpretation of Mount Ungaran's South Slope Straightness

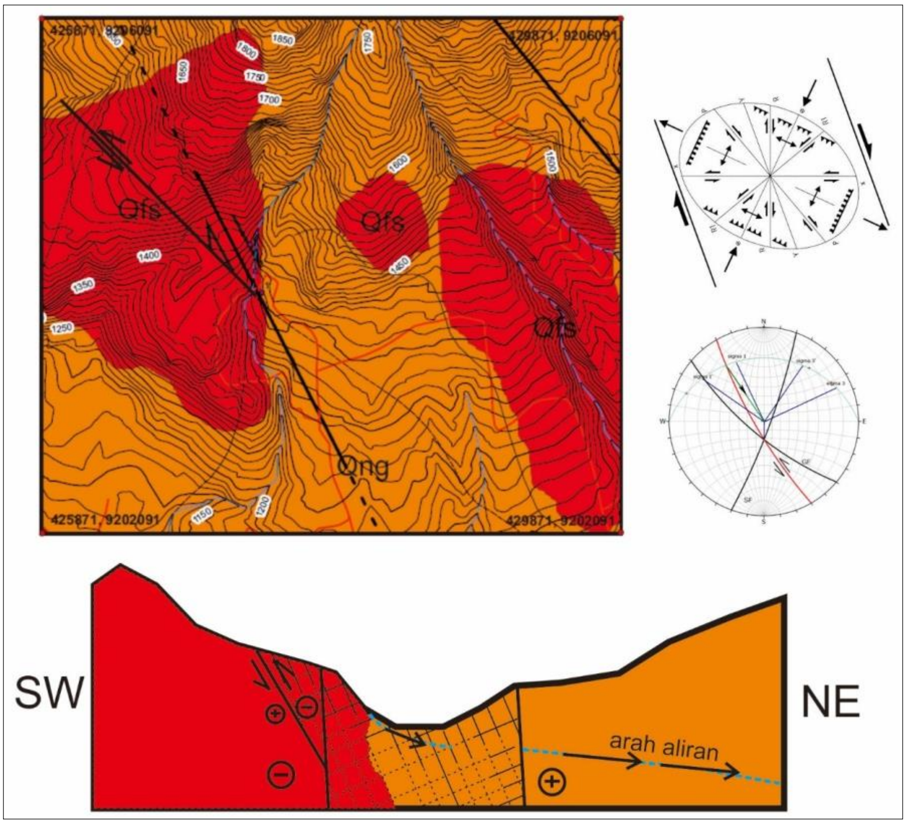

Figure 10: Hydrostructure Model of the Research Area

5. Conclusion

Two types of aquifers are found, namely intergranular aquifer and fractured aquifer. The fracture aquifer is controlled by a NW-SE oriented right slip fault structure.

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