CONCEPTUAL MODEL AND RECHARGE AREA ANALYSES OF GEOTHERMAL SYSTEMS IN GEDE-PANGRANGO AND PANCAR, BASED ON GEOCHEMICAL AND HYDROGEOLOGICAL DATA

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ABSTRACT

The research area has two geothermal systems, i.e. Gede-Pangrango and Pancar, which cover Cianjur, Sukabumi, and Bogor districts, West Java. Determination of the geothermal systems' conceptual model and recharge areas are the purpose of this research. The main data are stable isotope ^{18}O, ^{2}H, and tritium from cold springs and river water, also complementary secondary data. The Gede-Pangrango geothermal system has two hot springs, chloride-sulfate water (51ºC) and chloride-bicarbonate water (40ºC). Solfatara (167ºC) and fumarole (70ºC) are at the Mt. Gede's peak. Its reservoir has a temperature of (t_{Na-K})=275-295ºC, chloride concentration: 3144 mg/kg and at elevation 250 to -500 m. The clay rock is at elevation 1,000 to 250 m. The Pancar geothermal system has two hot springs, sulfate water (54ºC) and chloride-sulfate (66ºC). Its parent fluid has a temperature of (t_{Na-K})=190-210ºC, chloride concentration: 4055 mg/kg and at elevation -1,000 to -1,750 m. The clay rock is at elevation 0 to -1,000 m. The ^{18}O and ^{2}H isotope analysis shows that the recharge area of the Gede Volcano geothermal system is at elevation 1,100-1,200 m, latitude 9,263,000-9,263,500 mS, located in a high FFD zone (30-60 km/100 km^2), and volcanic rock, while the recharge area of the Pancar Volcano geothermal system is at elevation 850-900 m, latitude 9,263,500-9,263,800 mS, located in a medium FFD zone (20-30 km/100 km^2) and sedimentary rock. The value of cold water tritium in the study area is 2.04-3.66 TU, indicating that cold water in the research area is a mixture of submodern groundwater (infiltrated before 1952) and groundwater which recently infiltrated the ground.

1. INTRODUCTION

Gede Volcano is a Type A Quartenary Volcano, part of island-arc volcanoes. It formed twin volcanoes with the older Pangrango Volcano. This volcano is a stratovolcano with a crater stretching from north to northwest for 1,000 m. The geothermal potential is indicated by solfatars and fumaroles on the Gede's crater and also by hot springs spreading around the volcano. These surface manifestations became tourist destination, e.g. hot springs baths in Ciater and Cikundul. Based on Ministry of Energy and Mineral Resources (ESDM) data (2017), it is speculated that resources in this area are about 75MWe, with reserves being about 85 MWe.

Much research has been done about hydrotermal systems in the Gede-Pangrango volcanic area. Therefore, this study includes conceptual model analysis and determining the recharge areas of hydrothermal fluids, using isotope ^{18}O, ^{2}H, and tritium (T) as primary data, also supported by secondary data.

2. GEOLOGY

Physiographically, the Gede-Pangrango and Pancar Volcanoes are part of the Quartenary Volcano unit (van Bemmelen, 1949). The Gede Pangrango area is limited by old volcanoes in the south, east, and north, then by Mount Salak in the west. The research area is formed by regional geologic structures around it, which have northwest-southeast and west-east structures (Pulunggono and Martodjojo, 1994). Both structures show the same pattern as Sumatra (age of Top Cretaceous-Pliocene) and Java (Low Miocene) (Pulunggono and Martodjojo, 1994). The northeast-southwest Cimandiri fault and crater opening of Gede-Pangrango also affect the geologic condition.

In regards to morphology and topography, the Gede-Pangrango area is a high terrain area, having an elevation of about 300-3,019 m asl. Based on the morphology of the research area, Gede-Pangrango is classified as a high entalpy geothermal system on a high terrain. This geothermal system could be found in arc-island and arc-volcano areas which are indicated by andesitic volcanic and rough topography. Likely common manifestation types on this system area are fumaroles, heat ground, and sulfate acid springs (Nicholson, 1991).

Stratigraphy map result of complication from earlier researchers (ESDM, 2008; Effendi et al, 1998; Sudjatminko, 1972) showed that the research area is controlled by two dominant lithological features, i.e. Tertiary sedimentary and volcanic lithology on the north and south and Quartenary volcanic lithology in the middle. Volcanic rocks located in the middle of the research area consists of alluvial deposit, Gede Volcano's eruption products, Pangrango Volcano and Mount Salak. Gede Volcano's deposits consist of lava flow rocks, breccia and lahar, basalt andesitic lava flow, basalt lava flow, and boulder and andesitic breccia. Pangrango Volcano's deposit consists of lahar with andesitic components.

3. SAMPLING AND ANALYSIS

Cold water samples were taken on some springs and rivers on different elevations and latitudes from June until July 2017. Those cold water samples were checked for temperature, pH, and flow rate before being entered into glass bottles or polythen bottles with 30-60 ml volumes. It was made sure that there were no air bubbles inside the bottles, to avoid fractionation. Geothermal manifestation data in the research area were obtained from secondary data (Iscwahyudi, 2014; Priatna, 2009; Asnawir, 2017). Manifestations in the study area are divided into two groups; they consist of hot spring water and geothermal gas. Both of them exist in the Pancar Volcano and Gede-Pangrango Volcano. Pancar Volcano's manifestations are on the Pancar Volcano and Kawah Merah, Bogor. Gede-Pangrango Volcano's gas manifestations are at the peak of the Gede Volcano, they are fumaroles and solfatars, while the hotsprings are at the slope and foot of Gede Volcano.

Isotope content analysis of cold water was done in the Laboratorium of Isotope Radiation Technology Research and Development Center (P3TIR), Batan, Jakarta, Indonesia. Isotope stabil content is stated with δ; it is a relative ratio difference of $^2H/^1H$ or $^{18}O/^{16}O$ in sample to $^2H/^1H$ or $^{18}O/^{16}O$ ratio in Standard Mean Ocean Water (SMOW). Isotope tritium content of cold water is stated by TU.

4. RESULT AND DISCUSSION

Geothermal fluids analysis results, based on data from Iscwahyudi (2014), show that the research area has two geothermal systems (based on Cl-Li-B diagram): Pancar Volcano geothermal system and Gede-Pangrango Volcano geothermal system. Based on the geological map, these two geothermal systems lie in the Quartenary Gede Volcano environment and are supposed to have close relations with magmatic activities that are still storing heat sources from the magma kitchen. Permeable zones around Gede Volcano have a role in the movement of convection heat fluidsuntil the fluids can reach or are near the surface.

Hydrothermal flows in the geothermal field are open systems (Clark, 2015) (**Figure 3**). These hydrothermal processes began when meteoric water on the surface infiltrated permeable zones and entered below surface. These fluids were heated by heat sources that came from Gede Volcano's magma. Convection force from below the surface made heated fluids move up to the reservoir of each geothermal system.

4.1 Geothermal system Gede-Pangrango Volcano

Based on magnetotelluric data (MT), reservoir rocks in the Gede Volcano system are at volcanic rocks lithology (ESDM, 2008). These reservoir rocks are present at 250 to -500 m elevation. Geothermometer calculation results by Giggenbach (1991) and Arnorson et al (1989) showed that the reservoir temperature is 275-295°C. There is only one phase fluid inside this reservoir, with chloride concentration being too great (Cl) (3144 mg/kg), based on heat balance and mass balance calculations (Nicholson, 1993).

From the reservoir, heat fluids move up to near surface through permeable zones. Along the movement, heat fluid also forms cap rock as the result of hydrothermal alteration from volcanic rocks around it (ESDM, 2008). Cap rocks for this system are at 1,000-250 m elevation.

Inside the geothermal fluids in the Gede-Pangrango geothermal system are the reservoir's elements and also magmatic volatiles, which can be seen from HCl concentration (ESDM, 2008) in surface gas manifestations. Geothermal fluid that is close to the surface will be boiled to liquid and gas phase at 167°C; this is similar to the solfatars' temperature on the surface. The gas phase has a lighter mass and contains CO_2, N_2, NH_3, and SO_2, so it moves up vertically to the surface and mixes with meteoric water (**Figure 4**). Gas manifestations on the surface presented as fumarole and solfatar with surface temperatures of 71 and 167°C respectively.

Part of the liquid phase will move up vertically and close to the reservoir fluid surface and mix with meteoric water, groundwater, and vapour condensation fluid residue that came from magmatic activity. This is also shown by equal chloride and sulfate values (653.89 and 604.65 mg/kg) on the Gede's slope, where there are chloride-sulfate hot springs. Geothermal gas manifestations and also sulfate water are on the upflow zone which is marked with a low Na/K value ratio.

Another reservoir fluid from Gede Volcano then moves laterally away from the reservoir. During the movement, the fluid experiences conductive cooling at 80°C temperature (based on K-Mg temperature); this process does not involve mass change inside the fluid but only heat change. Closer to the surface, the reservoir fluid is mixing with groundwater (24°C temperature) and with a yielding hot water manifestation in the form of chloride bicarbonate in the outflow zone at the Green Apple region (**Figure 1**), marked by higher Mg^{2+} (**Figure 2**) and HCO^{3-} concentration (152.22 and 584.75 mg/kg) compared to another manifestation, also by isotope plotting, close to the local meteoric water line ($\delta^2H = \delta^{18}O + 12$) (**Figure 5**). The geothermal system of Gede Pangrango is a water-dominated geothermal system, based on plotting in log (CO_2/Ar) vs log (H_2/Ar) in the diagram, with values being 2.71 to 3.5 and -0.48 to 0.3.

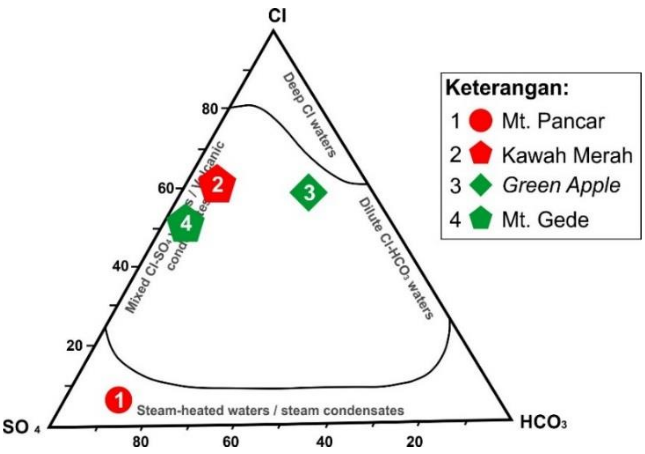

Figure 1. Determination of hot water type in study area using Cl-SO4-HCO3 diagram. There are the dominant anion in water (Nicholson, 1993).

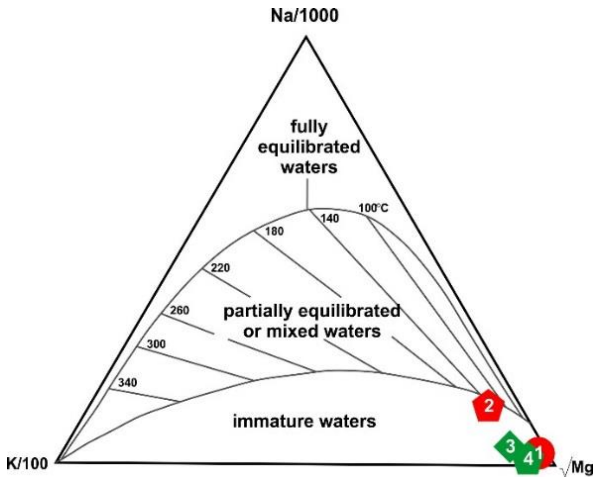

Figure 2. The Na-K-Mg diagram shows that water manifestations in the research area are contaminated by groundwater and immature waters.

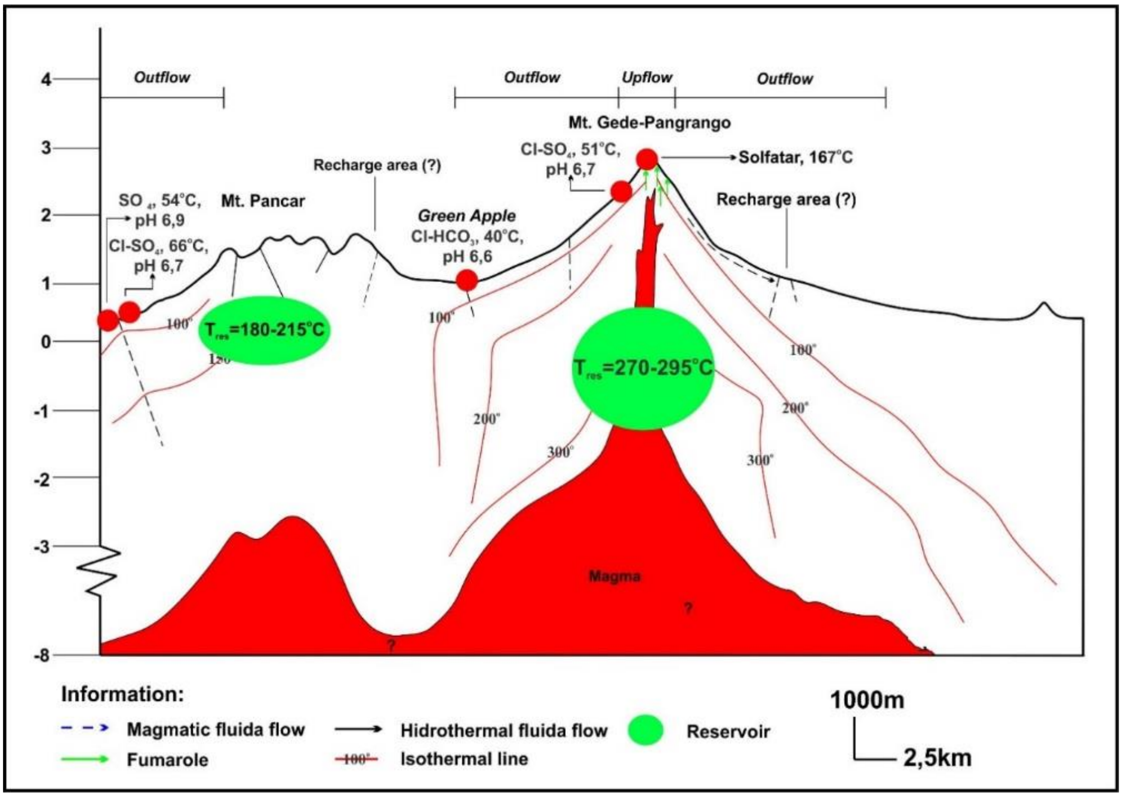

Figure 3. Cross section that draws on a conceptual model of geothermal systems in Gede-Pangrango Volcano and Pancar Volcano and hydrothermal flow in the study area.

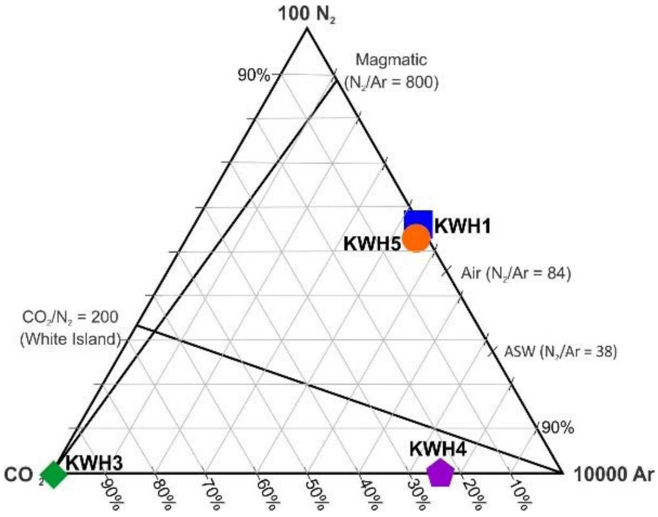

Figure 4. Based on N_2-Ar-CO_2 diagram, gas manifestations in Gede Volcano come from mixing of magmatic gas and air.

4.2 Geothermal system Pancar Volcano

Based on audio magnetotelluric (AMT) data from Daud et al (2015), the reservoir of the Pancar geothermal system is estimated to be on clastic sedimentary rocks and at -1,000 to -1,750 m elevation. The reservoir temperature in this system is 180-215^{0}C, based on water geothermometer measures by Giggenbach (1991). Chloride composition in the reservoir is 4055 mg/kg, according to heat balance and mass balance calculations (Nicholson, 1993).

Similar to the Gede-Pangrango geothermal system, heated fluid moves up through the permeable zone around Pancar geothermal system (**Figure 3**). On top of the reservoir, hot fluids form cap rock as a result of hydrothermal alteration from sedimentary rocks (Daud et al, 2015) at 0 to -1,000 m elevation.

Close to the surface, geothermal fluids will be boiling, then mixing with meteoric water, vapour condensat and groundwater, marked by high Mg^{2+} concentration (**Figure 2**) and also by isotope plotting close to the local meteoric water line (**Figure 5**). Manifestations on this system are sulfate (pH=6.7) and chloride-sulfate hot water (**Figure 1**), marked with dominant SO_4^{2-} concentration (699.4 and 705.5 mg/kg), although manifestations in Kawah Merah showed high chloride concentration (1240.9 mg/kg). This chloride-sulfate hot water is a result of condensat water residue and reservoir water mixing.

4.3 Recharge area of geothermal system

Determination of the meteoric water recharge area for the geothermal system is according to Craig research (1961, in Nicholson, 1993), which states that the geothermal ^{2}H fluid isotope composition is similar to local meteoric water on that system; however the ^{18}O isotope composition is heavier than local meteoric water. Based on plotting results of cold water ^{18}O and ^{2}H, it is known that cold water in the research area had a local meteoric line equation $\delta^2H = \delta^{18}O + 12$ (**Figure 5**). This equation tends to have ^{18}O isotope lighter than global meteoric water line ($\delta^2H = \delta^{18}O + 10$), according to Craig (1961, in Nicholson, 1993), showing local geographic influences (Dansgaard, 1964).

To conduct recharge area analysis, knowing the groundwater isotope that has infiltrated the reservoir is mandatory. In this process, ^{2}H isotope composition was assumed not to change during the ^{18}O enrichment because of the water-rocks interaction process. Calculation results using heat equilibrium equation and isotope equilibrium showed that the ^{18}O and ^{2}H composition inside Gede-Pangrango are -4.1% δ^{18}O and -47.5% δ^2H, and inside Pancar reservoir are -6.6% δ^{18}O and -44.3% δ^2H.

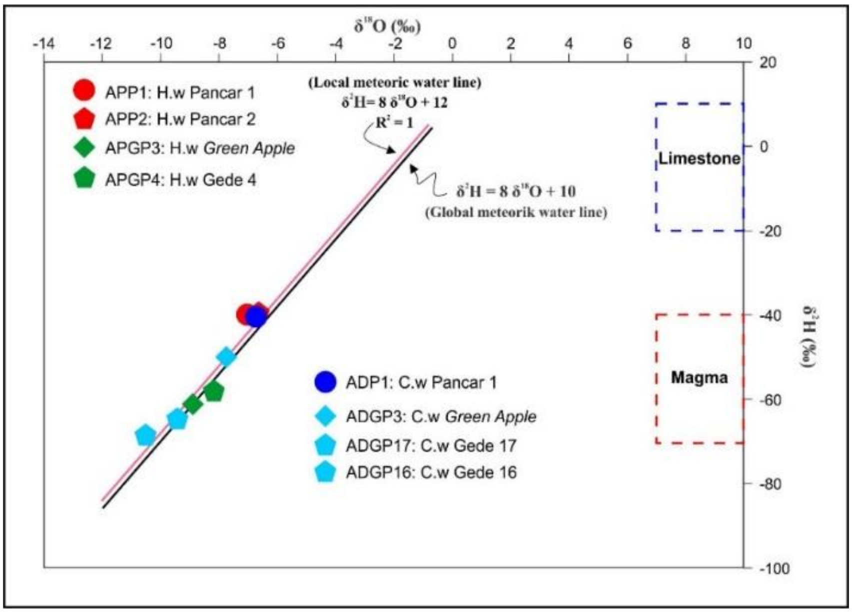

Figure 5. Local meteoric water line in research area and global meteoric water line.

Then the correlation between isotope and elevation and latitude analysis was established to get the linear equation that describes the groundwater source position. Based on the isotope composition plot in the reservoir, it is known that groundwater inside the reservoir was undergoing isotop enrichment; as the result corrections had to be done by determining the intercept of ^{18}O and ^{2}H isotopes. Result of the ^{18}O and ^{2}H isotope interception value was used to determine elevation and latitude of the recharge area.

Based on the plotting of elevation vs isotope ^{18}O (Elevation = -632.5 $\delta^{18}O$ – 3,574) and ^{2}H (Elevation = -81.075 $\delta^{2}H$ – 2,695.2) diagram and latitude vs isotope ^{18}O (Latitude = 5504.8 $\delta^{18}O + 9.10^6$) and ^{2}H (Latitude = 729.4 $\delta^{2}H + 9.10^6$) diagram, generally the recharge area within the research area is at elevation of about 850-1,160 m and latitude of about 9,263,000-9,265,800 mS. Recharge areas should be in locations that have hot water manifestation. Because of this, recharge areas are limited to locations that have Gede-Pangrango and Pancar manifestations.

The recharge area for Gede Volcano is at 1,100 to 1,160 m elevation, located on the north valley of the Gede Volcano geothermal system (9,263,000-9,263,500 mS) (Figure 11). Equally, the recharge area of Pancar Volcano is located in the south valley of Pancar Volcano, at 850 – 900 m elevation and latitude 9,265,300-9,265,800 mS (Figure 12).

The recharge area of the Gede Volcano geothermal system lies on volcanic rock. This unit consists of lava and pyroclastic. Based on the geological map, the north to west part of the recharge area is affected by older volcanic lithology than Gede volcanic rocks that were experiencing an erosion process and also a tectonic process, compared to the southeast part. This showed in high FFD values (30-60 km/100 km2) (Ischwahyudi, 2014). Therefore, the lithology on the north and west parts are estimated to be more permeable than the southeast part, which means they could absorb more meteoric water (**Figure 6**).

The recharge area of Pancar Volcano geothermal system lies on sedimentary rock. Based on the geological map, sedimentary rock in Pancar Volcano consists of the Jatiluhur Formation which is sandstone and claystone. Beside that, Pancar Volcano is strongly influenced by an active geological structure, with FFD values ranging from 20-30 km/100 km^2 (Iscwahyudi, 2014). Therefore, the Pancar Volcano area is a more permeable geothermal system. The southern part of this area is quite good for infiltration by meteoric water.

Cold water tritium analysis in the research area showed values of 2.04-3.66 TU, which indicates that cold water is mixing with submodern groundwater (infiltrated before 1952) and groundwater which recently infiltrated the ground.

5. CONCLUSION

Based on the geological, geochemical, and geophysical data analysis of the research area, the conclusion obtained from this research are:

1. The geothermal systems are associated with Quartenary magma activity of Gede Volcano.

2. There are two geothermal systems, firstly the geothermal system of the Gede Volcano that has a relatively west-east regional structure. Reservoir temperature is 270–295ºC, at elevation 250 to -500 m, and it has 3144 mg/kg of Cl composition in the reservoir. Cap rock is located at 1,000 to 250 m elevation. Manifestations present as fumarole, solfatara, Cl-HCO_3 and Cl-SO_4 water. It is a water-dominated geothermal system. Secondly, the Pancar Volcano geothermal system has a relatively northwest-southeast regional structure. Reservoir temperature is 180–215ºC, at elevation -1,000 to -1,750 m and 4055 mg/kg Cl composition in the reservoir. Cap rock is located at 0 to -1,000 m elevation. Geothermal manifestation presents as Cl-SO_4 and SO_4 water.

3. The recharge area for the geothermal system of Gede Volcano is located at 1,100-1,200 m elevation, 9,263,000-9,263,500 mS latitude, high FFD zone: 30-60 km/100km2, and has volcanic rock lithology, whereas the geothermal system of Pancar Volcano is located at 850-900 m elevation, 9,265,300-9,265,800 kmS latitude, medium FFD zone: 20-30 km/100km2, and has a sedimentary rock lithology.

4. Cold water from research area is a mix of submodern groundwater (infiltrated before 1952) and groundwater which recently infiltrated the ground.

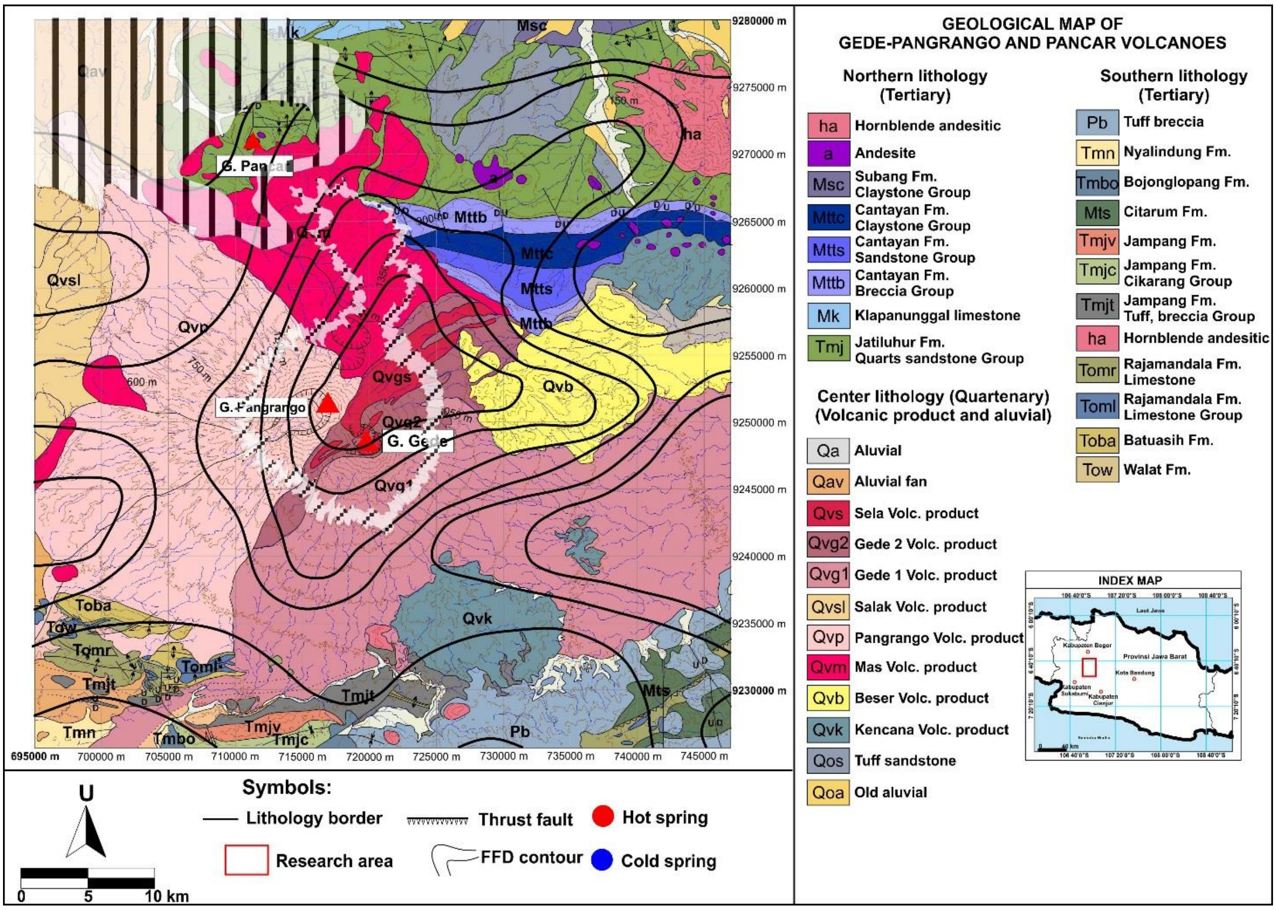

Figure 6. Final map that shows recharge areas for geothermal systems in Gede-Pangrango Volcano and Pancar Volcano, based on lithology and isotope analyses.

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