Conceptual model and recharge area of geothermal system in Gede-Pangrango and Pancar based on geochemical and hydrogeology

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Abstract. The research area has two geothermal system's prospect, ie Gede-Pangrango and Pancar that covering Cianjur, Sukabumi, and Bogor, West Java. Determination of geothermal system's conceptual model and recharge area are purpose of this research. The main data are stable isotope ^{18}O and ^{2}H from cold springs and river water, also secondary data as complement. Gede-Pangrango geothermal system has two hot springs, chloride-sulfate water (51ºC) and chloride-bicarbonate water (40ºC). Solfatar (167ºC) and fumarole (70ºC) are at the Mt. Gede's peak. It's parent fluid has temperature (t_{Na-K})=275-295ºC. Pancar geothermal system has two hot springs, sulfate water (54ºC) and chloride-sulfate (66ºC). It's parent fluid has temperature (t_{Na-K})=190-210ºC. Based on geophysical data, the reservoir rock of Gede-Pangrango is in volcanic rock, at elevation 250 to -500 m and Pancar is in sedimentary rock, at elevation alteration -1000 to -1750m. Whereas the cap rock is in alteration rock of volcanic and sedimentry. The ^{18}O and ^{2}H isotope analysis shows the recharge area of Gede-Pangrango and Pancar geothermal system at elevation 1100–1156.8 m and 853.5 - 899.12 m plus latitude 9263000–9263500 mS and 9265300–9265800 mS.

Keyword: geothermal system, cap rock, reservoir, parent fluid, recharge area, isotope, Gede-Pangrango, Pancar.

1. Introduction

Geothermal energy is environmental friendly energy, sustainable, and renewable, therefore it is predicted to become a reliable alternative energy in the future. Geothermal energy is obtained through a fluid that carries heat, so it can be used indirectly (geothermal power plant) and directly. The conceptual model of geothermal heat based on Hochstein et al (2000) shows that the volume of geothermal fluid depends on the supply of meteoric water from the aquifer into the reservoir. When the supply of meteoric water decreases, there is a decrease in the volume of geothermal fluid in the reservoir, which will result in a decrease of field production. So the determination of the geothermal fluid recharge area is one of the important things in maintenance fluid production of geothermal field.

Mt. Gede is Quaternary volcano which is part of archipelago arc volcano. Mt. Gede forms a twin volcano with an older Mt. Pangrango. It is a strato volcano with a crater that moved from north to northwest along 1000 m. Evidence of the magmatism activity in Mt. Gede is the presence of fumarole in the crater of Mt. Gede and also hot springs scattered around the volcano. Surface manifestations in this area are generally utilized directly, such as thermal baths in Ciater, Cikundul, and others.

There are so many researches about hydrotermal system in Mt. Gede-Pangrango area. Because of it, this study will include conceptual model analysis and recharge area of hydrothermal fluids determination using isotope ^{18}O and ^{2}H as primary data, also supported with other secondary data.

2. Geology

Physiographically (van Bemmelen, 1949), the study area is part of the Quaternary Volcano Unit. Regionally, the morphology and topography of Mt. Gede-Pangrango is a high terrain, with an altitude between 300-3019 masl. Based on the morphology of the research area, the Mt. Gede-Pangrango and Mt. Pancar are included in the high-enthalpy systems found in the high terrain. Such geothermal systems are commonly found in archipelagic arcs and volcanic arcs characterized by andesitic volcanism and steep topography. The common types of manifestations in areas are fumaroles, steam ground, hot sulfuric acid springs.

The compilation stratigraphy map (**Figure 1**) from previous researchers (ESDM, 2008; Effendi et al, 1998; and Sudjatminko, 1972) showed that the research area was controlled by two dominant lithologies, namely sedimentary and volcanic lithology of Tertiary aged on the north and south while in the middle part dominated by Quaternary volcanic rocks. Volcanic rocks consist of: Alluvial deposite, eruption product of Mt. Gede, Mt. Pangrango, and Mt. Salak. Mt. Gede deposition consist of lava flows of Mt. Gede, breccia and lava, basaltic andesite lava flows, basalt lava flows, and boulder and andesite breccia. The deposition of Mt. Pangrango consists of lava with andesitic components.

The geological structure of the research area cannot be separated from the regional geological structures that exist around it, namely the northwest-east and west-east trending structures. Both of these structures show the same pattern with the pattern of Sumatra and Javanese pattern (Pulonggono et al, 1994). Java pattern that trails west-east and formed in early Miocene. This structural pattern occured due to the compression regime of two tectonic plates that exist in the south of Java Island. The Sumatra pattern that trails northwest-southeast of Cretaceous-Paleocene. This pattern of geological structure is generally dominant in the western part of Java Island, and gradually disappeared to the east. The research area is interpreted to be influenced by the presence of such geological structures as mentioned above. The presence of Cimandiri Fault which flows east-west and the opening of caldera Mt. Gede-Pangrango also influences the geological condition of the research area.

3. Sampling and Analysis

Cold-water samples were collected at several locations of springs and river water at different elevations during the period from June to July 2017. The cold water samples were checked for temperature, pH, and rate flow before they were inserted into glass or polythehe bottles with volume 30-60 ml. Above sample bottles no air bubbles were attempted, to avoid fractionation. Data of geothermal manifestations present in the study area and its surroundings, obtained from secondary data (Iscwahyudi, 2014; Priatna, 2009; Hisni et. al, 2008; Asnawir, 2017). Manifestations in the study area are divided into two groups, consisting of hot springs and geothermal gas. Both groups of these manifestations are located in Mt. Pancar and Mt. Gede-Pangrango areas. Mt. Pancar hot water manifestations are located on Mt. Pancar and Kawah Merah, Bogor. Manifestation of geothermal gases Mt. Gede-Pangrango is located at the peak of Mt. Gede in the form of fumarola and solfatara, while the hot water manifestation is on the slopes and the foot of Mt. Gede-Pangrango.

Analysis of cold water isotope content was conducted at the Laboratory of Research and Development of Isotopes and Radiation Technology (P3TIR), Batan, Jakarta. The stable isotope content is expressed by δ, ie the relative difference of the ratio of $^{2}H/^{1}H$ or $^{18}O/^{16}O$ in sample to the ratio of $^{2}H/^{1}H$ or $^{18}O/^{16}O$ in Standard Mean Ocean Water (SMOW).

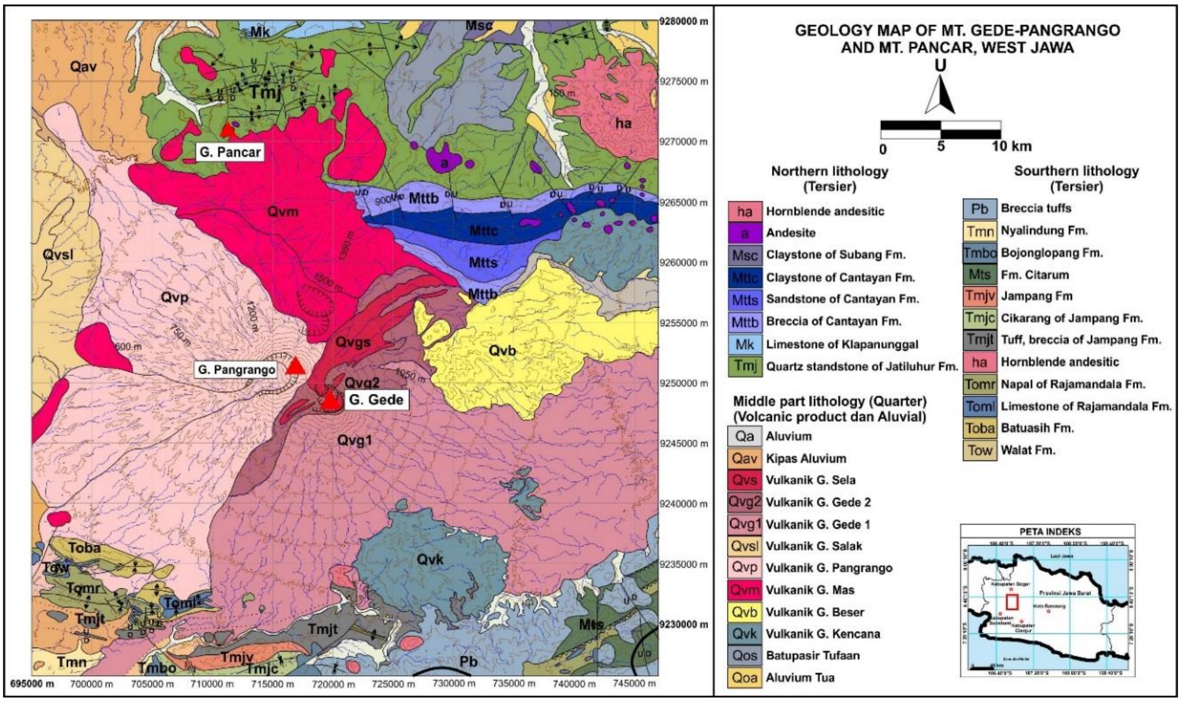

Figure 1. Geology map of research area based on previous researches (compilation from Hisni et al. (2008), Effendi et al. (1998), and Sudjatmiko (1972))

4. Result and Discussion

Based on water chemistry from Ischwahyudi (2014) and plotting in Cl-Li-B diagram, the research area has two geothermal systems, namely the geothermal system of Mt. Gede and Mt. Pancar. Both of those geothermal system lied on Quartenary Gede Volcano environment and supposed to have close relation with magmatic activities that are still storing heat source from magma kitchen. Permeable zones around Mt. Gede have a role in convection heat fluids movement until the fluids could reach or near the surface.

Hydrothermal flows on the geothermal field are open systems (Clark, 2015) (**Figure 5**). This hydrothermal processes were begun when meteoric water on the surface infiltrated permeable zones and into below surface. Those fluids heated by heat source that came from Gede Volcano's magma. Convection force from below surface made heated fluids moved up to the reservoir of each geothermal systems.

4.1. Mt. Gede-Pangrango geothermal system

The hydrothermal process in this system begins when the meteoric water on the surface undergoes infiltration through the permeable zones and enters the subsurface (**Figure 5**). The fluid is then heated by a source of heat derived from the magma of Mt. Gede in the reservoir at the 250 to -500 m elevation. This reservoir is at the volcanic rock, basen on magnetotelluric (MT) data (ESDM, 2008) and has temperature 275-295^{o}C, based on Giggenbach's (1991) water geothermometre and Arnorson's (1983) gas geothermometre.The heated fluid then moved up past the reservoir. During the transportation, the geothermal fluid will form cap rock at 1000 to 250 m elevation, caused by hydrothermal activity around the volcanic rocks (ESDM, 2008).

Inside geothermal fluids on Gede-Pangrango geothermal system occured reservoir's elements and also magmatic volatiles, that can be seen from HCl concentration (ESDM, 2008) on surface gas manifestation. Geothermal fluid that close to surface will be boiled to liquid and gas phase on 167^{o}C temperature, this temparature is similar with solfatar manifestation temperature on the surface. Gas phase is having lighter mass and contains with CO_2, N_2, NH_3, and SO_2, will move up vertically to surface and mixes with meteoric water (**Figure 4**). Gas manifestation on the surface presented as fumarole and solfatar with surface temperatures are 71 and 167^{o}C respectively.

IOP Conf. Series: Earth and Environmental Science 212 (2018) 012044 doi:10.1088/1755-1315/212/1/012044

Part of liquid phase will move up vertically and close to reservoir fluid surface and mixing with meteoric water, groundwater, and vapour condesation fluid residue that came from magmatic activity. This also showed by equal chloride and sulfate values (653.89 and 604.65 mg/kg) on the Gede's slope, which is chloride-sulfate hot springs (**Figure 2**). Geothermal gas manifestation and also sulfate water are on the upflow zone.

Another reservoir fluid from Mt. Gede then move laterally away from reservoir. During the movement, the fluid is having conductive cooling on 80°C temperature (based on Na-K-Mg temperature), this process is not involving mass changing inside fluid but only heat change. Closer to the surface, reservoir fluid is mixture with groundwater (24°C temperature) and yielding hot water manifestation in the form of chloride bicarbonate on outflow zone at Green Apple region (**Figure 2**), marked by higher Mg^{2+} (**Figure 3**) and HCO^{3-} concentration (152.22 and 584.75 mg/kg) compared to another manifestation, also isotope plotting, close to local meteoric water line ($\delta^2H = \delta^{18}O + 12$) (**Figure 6**). Geothermal system of Gede-Pangrango is water dominated geothermal system, based on plotting in $\log(CO_2/Ar)$ vs $\log(H_2/Ar)$ diagram with value are 2.71 to 3.5 and -0.48 to 0.3.

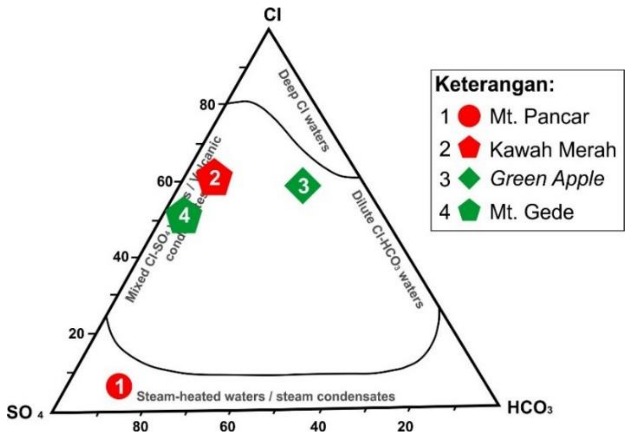

Figure 2. Determination of hot water type in study area used Cl-SO_4-HCO_3 diagram. There are the dominance anionion in water (Nicholson, 1993).

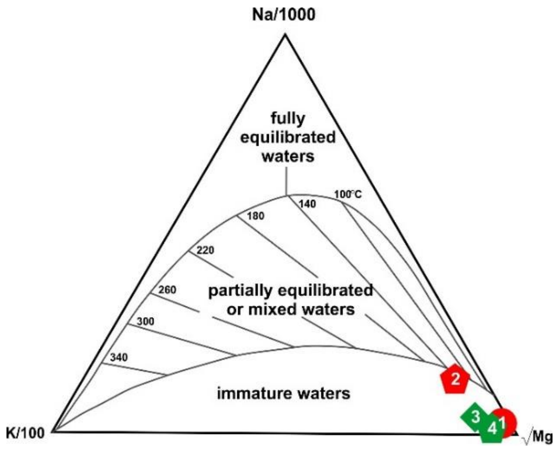

Figure 3. The Na-K-Mg diagram shows that water manifestation in the research area were contaminated by groundwater and were immature.

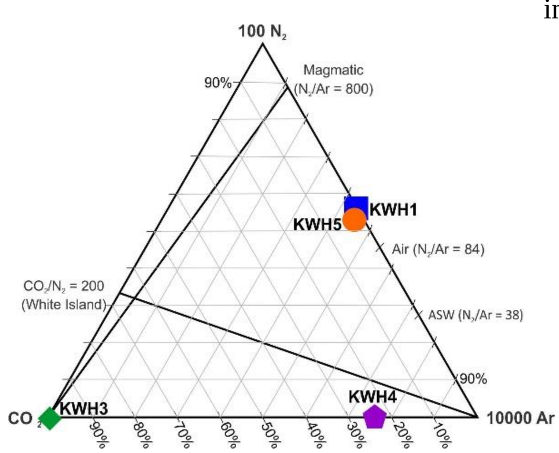

Figure 4. Based on N_2-Ar-CO_2 diagram, gas manifestation in Mt. Gede comes from mixing of magmatic gas and air.

4.2. Mt. Pancar geothermal system

Based on audio magnetotelluric (AMT) data from Daud et al (2015), reservoir for Pancar geothermal system is estimated on clastic sedimentary rocks (Daud et al, 2015) and at -1000 to -750 m elevation. Reservoir temperature on this system is 180-215^{0}C, based on water geothermometer Gigganbach (1991).

Similar with Gede-Pangrango geothermal system, heated fluid will move up through permeable zone around Pancar geothermal system (**Figure 5**). On top of the reservoir, hot fluids will form cap rock as result of hydrothermal alteration from sedimentary rocks (Daud et al, 2015), at 0 to -1000 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 3**) and also isotope plotting close to local meteoric water line (**Figure 6**). Manifestations on this system are sulfate and chloride-sulfate hot water (**Figure 2**), marked with dominant SO_4^{2-} concentration (699.4 and 705.5 mg/kg) although manifestation 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.

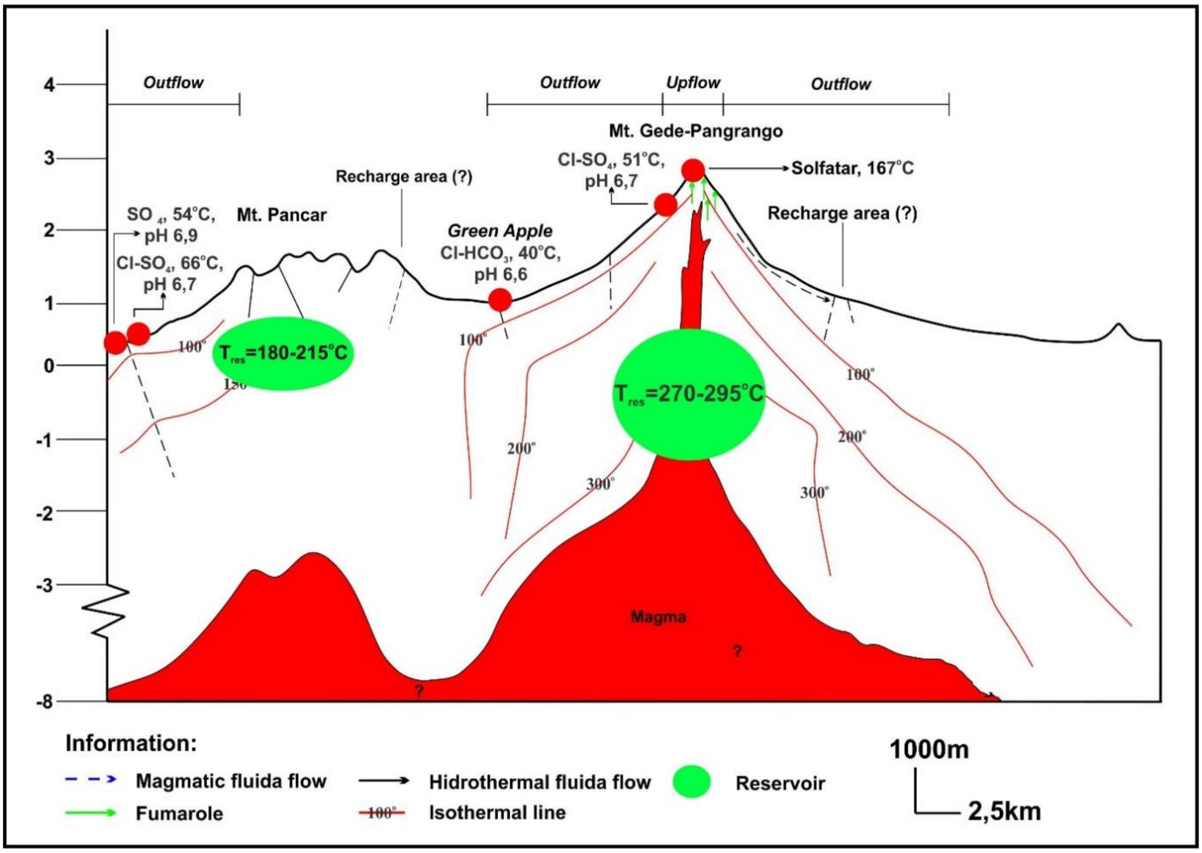

Figure 5. Cross section that draw about conceptual model of geothermal system in Mt. Gede and Mt. Pancar and hydrothermal flow in the study area.

4.3. Determination of recharge area

Determination of meteoric water recharge area for geothermal system is according to Craig research (1961, in Nicholson, 1993), which stated that geothermal ^2H fluid isotope composition is similar to local meteoric water on that system, however ^{18}O isotope composition is heavier than local meteoric water. Based on plotting result of cold water ^{18}O and ^2H, known that cold water in the research area had local meteoric line equation $\delta^2H = \delta^{18}O + 12$ (**Figure 6**). This equation tends to have ^{18}O isotope heavier than global meteoric water line ($\delta^2H = \delta^{18}O + 10$) according to Craig (1961, in Nicholson, 1993), that showed local geographic influence (Dansgaard, 1964).

To conduct recharge area analysis, knowing groundwater isotope that have been infiltrated to reservoir is mandatory. On this process, ^{2}H isotope composition was assumed no change during ^{18}O enrichment because of water-rocks interaction process. So that calculation result using heat equilibrium equation and isotope equilibrium showed ^{18}O and ^{2}H composition inside Gede-Pangrango are -4.1‰ and -47.5‰, and Pancar reservoir are -6.6 ‰ and -44.3 ‰.

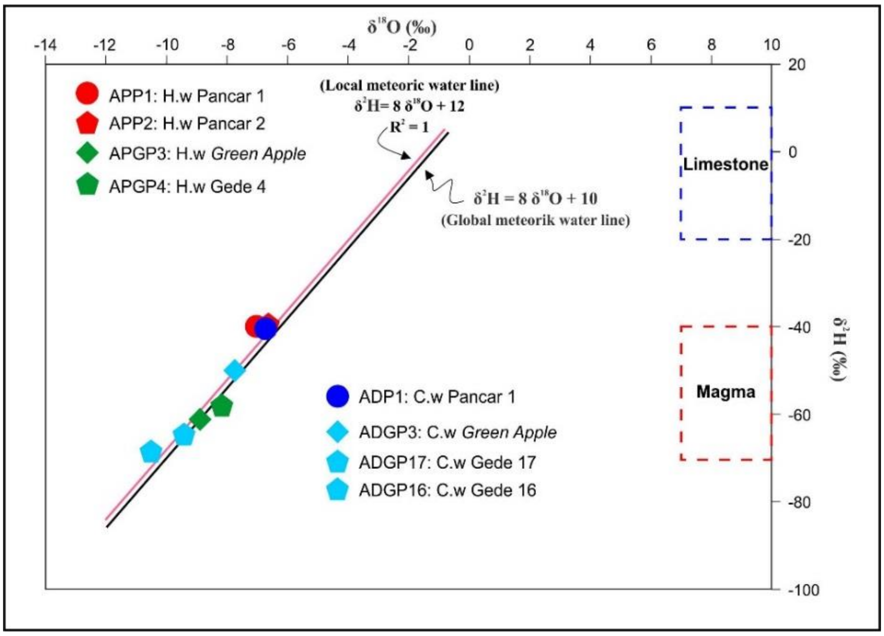

Figure 6. Local meteoric water line research area and global meteoric water line.

Then conducting correlation isotope with elevation and latitude analysis to get linear equation that describe groundwater source position. Based on isotope composition plot in reservoir, it is known that groundwater inside reservoir were having isotop enrichment, as the result correction had to be done by determining intercept ^{18}O and ^{2}H isotope. Result of ^{18}O and ^{2}H isotope interception value used to determine elevation and latitude of recharge area.

Based on plotting of elevation vs ^{18}O and ^{2}H isotope diagram and latitude vs ^{18}O and ^{2}H diagram, generally recharge area of research area is at elevation about 850-1160 m and latitude about 9263000-92658000 mS. Recharge area should be on location that have hot water manifestation. Because of it, recharge area are limited to location that have Gede-Pangrango and Pancar manifestation.

Recharge area for Mt. Gede is at 1100 to 1160 m elevation, located on the north valley of Mt. Gede geothermal system (9263000-9263500 mS). Recharge area of Mt. Gede geothermal system lies on volcanic rock lithology. This unit consists of lava and pyroclastic. Based on geological map, north to west part of recharge area is affected by older volcanic lithology than Gede volcanic rocks that were having erosion process and also tectonic process compared to southeast part (**Figure 7**).

Same thing with recharge area of Mt. Pancar located on south valley of Mt. Pancar, at 850 – 900 m elevation and latitude 9265300-9265800 mS. Recharge area of Mt. Pancar geothermal system lies on sedimentary rock lithology. Based on geological map, sedimentary rock in Mt. Pancar consist of Jatiluhur Formation that were sandstone and claystone (**Figure 7**).

5. Conclusion

Based on the results of geological, geochemical and geophysical data analysis conducted in the research area, as well as the results of the discussion, then obtained some conclusions as follows:

1. The geothermal system is associated with the activity of Mt. Gede magmatism.
2. There are 2 geothermal systems, namely:

   a. Mt. Gede geothermal system, which has a relatively west-east regional trending structure. Reservoir temperature: 270-295°C, at elevation of 250 to -500 m. The cap rock is at an elevation of 1000 to 250 m. Geothermal manifestations present as: fumarole, solfatar, water Cl-HCO_3 and Cl-SO_4. It is a water dominated geothermal system.
   b. Mt. Pancar geothermal system, which has a relatively northwest-southeast-based trending structure. Temperature reservoir: 180 - 215°C, at elevation -1000 to -1750 m. The cap rock is at an elevation of 0 to -1000 m. Geothermal manifestations present as: Cl-SO_4 and SO_4 water.
3. Recharge areas for geothermal systems:
   a. Mt. Gede is at 1100-1200 m elevation, latitude: 9263-9263.5 kmS, and volcanic rock lithology.
   b. Mt. Pancar is at elevation: 850-900 m elevation, latitude: 9265.3-9265.8 kmS, and sedimentary rock.

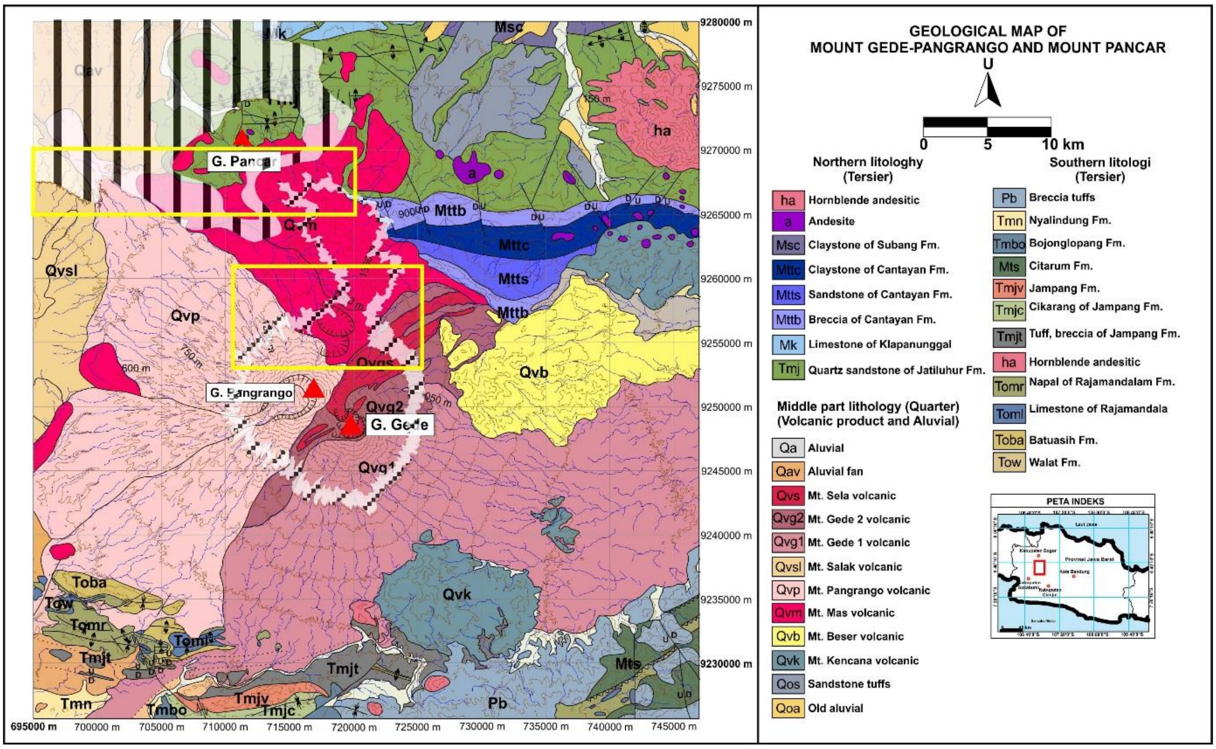

Figure 7. Final map that shows recharge area for geothermal system in Mt. Gede and Mt. Pancar based on lithology and isotope analyzise.

References

[1] Arnorson S and Gunnlaugsson E 1983 Gas Chemistry in Geothermal Systems *Proc. 9th Work. on Geothermal Reservoir Engineering* (California: Standford University) p 231-237

[2] Bammelen R W 1949 *The Geology of Indonesia Vol. 1A* (The Hague) p 26

[3] Clark I 2015 *Groundwater Geochemistry and Isotopes* (USA: Taylor & Francis Group) p 110-111

[4] Dansgard W 1964 Stable Isotopes In Precipitation, *Tellus* **16** p 436-468

[5] Daud Y, Rosid S, Suparno S, Heditama D M, Nuqramadha W A, Fahmi F, Pratama S A and Sulistyo A 2015 *Proc. World Geothermal Congress 2015* p 1-6.

[6] Effendi A C, Kusnama and Hemanto B 1998 *Peta Geologi Bersistem, Indonesia, Lembar: Bogor-9/XIII-D atau 1209-1, Skala 1:100.000, 2nd*, (Indonesia: Geological research and development center)

[7] Giggenbach W F 1991 Chemical Techniques in Geothermal Exploration, Application of Geochemistry in Geothermal Reservoir Development *Series of Technical Guides on The*

Use of Geothermal Energy (Roma: UNITAR) p 119-144
[8] Hochstein M P and Browne P R L 2000 Surface Manifestations of Geothermal Systems with Volcanic Heat Sources *Encyclopedia of Volcanoes* p 835-841.
[9] Ischwahyudi S 2014 Delineasi reservoir system hidrotermal Gede-Pangrango berdasarkan data geokimia fluida dan struktur geologi *Thesis of Geological Engineering* (Indonesia: Bandung Institute of Technology) p 34-52
[10] Ministry of Energy and Mineral Resources (ESDM) 2008 *Survey Pendahuluan Potensi Panas Bumi di Gunung Gede Pangrango* (Indonesia: Energy and Mineral Resourches West Java)
[11] Nicholson K 1993 *Geothermal Fluids Chemistry and Exploration Techniques* (Berlin: Springer-Verlag)
[12] Priatna 1992 *Laporan Penyelidikan Geokimia Gas Gunung Gede* (Indonesia: Directorate General of Energy and Mineral Resources) p. 1-11
[13] Pulonggo A and Martodjojo S 1994 Perubahan Tektonik Paleogen-Neogen Merupakan Peristiwa Tektonik Terpenting di Jawa *Proc. Geologi dan Geoteknik Pulau Jawa* (Indonesia: UGM) p 37-61
[14] Sudjatmiko 1972 *Peta Geologi Bersistem,Jawa, Lembar: Cianjut-9/XIII-E, Skala 1:100.000*, (Indonesia: Geological Research and Development Center)
[15] USGS 2017 ASTER GDEM Mt. Gede West Java http://usgs.co.gov