Geochemical Prospecting Investigation in Non-Volcanic Geothermal Area: A Case Study of Sajau, East Tanjung Palas, Bulungan, North Kalimantan

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Abstract. Indonesia has at least 324 prospects of geothermal which ensuring the great potential of sustainable and low-emission energy. About 96% (26.5 GWe) of the total Indonesian geothermal prospects are located in volcanic environment, while the 4% (1.2 GWe) come from the non-volcanic environment. Thus, the geochemical analysis is aimed to investigate the prospect of geothermal energy in the non-volcanic environment. The methods are geological mapping and geochemical analysis by manifestation geochemistry and soil geochemistry. Geological mapping is conducted to provide data about lithologies, structures, and manifestations of geothermal. Geochemical exploration relies on the analysis of water samples from manifestations to characterize the fluid and its origin, understand the fluid equilibrium, and interpret reservoir temperature. Soil geochemistry is aimed to identify permeability zone and structures in purpose to identify the prospect area. This paper will briefly illustrate the fundamental concept of non-volcanic geothermal, conceptual model, and potential of the research area. We anticipate this paper to become a turning point for further research in geothermal as promising alternative energy and specifically to broaden the view of non-volcanic geothermal system in Indonesia.

1. Introduction

Indonesia geologically located at the intersection of the Eurasian, Indian-Australian, and Pacific plates. As a result, the tectonic setting foments magmatic and volcanic processes to form volcanic and non-volcanic geothermal areas. About 96% (26.5 GWe) of the total Indonesian geothermal prospects located in volcanic environment, while the 4% (1.2 GWe) come from non-volcanic environment [1]. Contrary to volcanic geothermal areas, non-volcanic geothermal areas haven't been widely developed and fully utilized because their presences are limited compared to volcanic geothermal systems. Hence, the research of non-volcanic geothermal is needed to be done for further development in this field. Kalimantan is one of the islands along with Sulawesi, Sumatra, and Papua which contributes to non-volcanic geothermal prospects. The formation of a geothermal system in Kalimantan is related to the old subduction tectonic system which consists of plutonic rock as heat source and sedimentary rocks as reservoir and cap rock. This paper is an overview of the potential of non-volcanic geothermal resources.
based on geochemical data in Sajau, East Tanjung Palas, Bulungan, North Kalimantan. We anticipate this paper to become a turning point for further research in geothermal as promising alternative energy and specifically to broaden the view of the non-volcanic geothermal system in Indonesia.

2. Methodology
Geological mapping is carried out in 54 km² area in Sajau, East Tanjung Palas, Bulungan, North Kalimantan by observing outcrops to collect data about rock units, structures, geothermal manifestations, and geological parameters that affect the formation of the geothermal system in the research area.

The geochemical analysis is carried out by manifestation geochemistry method and soil gas geochemistry method. Manifestation geochemistry method is aimed to analyze the existence and percentage of elements that present in geothermal manifestations. This method is done by in-situ tests to measure several parameters and geochemistry sampling of water to provide data about: 1) Characteristics of hot water to determine the type of water, fluid equilibrium, and water formation environment. 2) Geothermal isotopes to determine the origin of the geothermal fluid. 3) Interpretation of temperature below the surface to assume the subsurface temperature.

Soil gas geochemistry method is aimed to understand the permeability zone and structural zone for determining the prospect area. In determined locations, one-meter depth drilling is done to measure soil and air temperature. Soil samples are collected for Hg and CO₂ analysis.

3. Result and Discussion

3.1. Geological analysis
The research area located in Sajau, East Tanjung Palas, Bulungan, North Kalimantan bounded by UTM coordinates 292000 mE – 301000 mE and 552000 mN–558000 mN covering an area of about 54 km². The research area consists of two formations: Sembakung Formation with Eocene age and Sajau Formation of Pliocene-Pleistocene age [2]. As the result of geological mapping, the researcher concludes that research area consists of three different units of rock and alluvial deposit. Sembakung Formation made of claystone unit. Sajau Formation consists of quartz-sandstone unit and conglomerate unit as shown in Figure 1.

Claystone unit shown by green color has 43% coverage of the research area. This unit is dominated by claystone with intercalation of siltstone and limestone. Quartz-sandstone unit shown by yellow color is dominated by quartz-sandstone which indicates that the source material is from volcanic activity. Sandstone and claystone are also found as intercalation. Conglomerate unit shown by orange color is characterized by conglomerate which fragments vary on the size, sandstone, siltstone, and claystone. This unit covering the research area about 35%. Alluvial deposit is found in north-east part of the research area, deposited in the river bank covering partial part of conglomerate unit and quartz-sandstone unit. Structures in the research area are faults and joints. Structures in the research area are Wonomulyo normal left slip-fault and Wonomulyo right normal slip-fault [3].
3.2. Manifestations’ geochemical analysis
In the research area, there are geothermal manifestations in the form of hot springs. Four manifestations of hot spring are located in Tanjung Agung, Wonomulyo, and Sajau, precisely in the Apan River. This method is done by in-situ tests to measure several parameters and geochemistry sampling of water. The manifestations are named as Sajau 1, Sajau 2, Sajau 3, and Sajau 4 (Figure 1). One additional sample of cold water analyzed as comparison to water samples from geothermal manifestations (Tables 1 and 2). The data show that Sajau 1, Sajau 2, and Sajau 3 have similar properties of manifestation temperature, and pH while Sajau 4 is relatively distinct. All of hot water manifestations have a similar pH.

Before further analysis, data must be processed using ion balance method to determine the level of balance between cation and anion ions present in hot water samples. The analysis data can be used in subsequent geochemical interpretations if the equilibrium value between cation and anion ions is below 5% (Table 3).
Table 1. Surface data geothermal manifestation on research area.

| No | Code       | Manifestation Temperature (°C) | pH     | Debit (l/s) | EC (µS/cm) | Remarks                                      |
|----|------------|--------------------------------|--------|-------------|------------|----------------------------------------------|
| 1  | AP Sajau 1 | 74.5                           | 7.21   | 0.2         | 5650       | Dimension 10×5m, siltstone, few sulphur deposit and H₂S & CO gas |
| 2  | AP Sajau 2 | 80.3                           | 7.16   | 0.3         | 5580       | Dimension 10×5m, siltstone, few sulphur deposit |
| 3  | AP Sajau 3 | 85.8                           | 7.25   | 0.2         | 5640       | Dimension 10×5m, siltstone, few sulphur deposit |
| 4  | AP Sajau 4 | 58.2                           | 7.23   | 0.2         | 2270       | Dimension 10×5m, siltstone, few sulphur deposit |
| 5  | AD KM-17  | 26.8                           | 6.72   | -           | 190        | Cold water sample from river                 |

Table 2. Surface manifestations’ data.

| Chemical Content | AP Sajau 1 | AP Sajau 2 | AP Sajau 3 | AP Sajau 4 | AD KM-17 |
|------------------|------------|------------|------------|------------|----------|
| Al³⁺ (mg/L)      | 0.43       | 0.01       | 0.01       | 0.01       | 0.01     |
| Fe³⁺ (mg/L)      | 0.48       | 0.02       | 0.02       | 0.05       | 0.07     |
| Ca²⁺ (mg/L)      | 3.64       | 3.42       | 4.08       | 7.40       | 1.00     |
| Mg²⁺ (mg/L)      | 0.50       | 0.51       | 0.50       | 0.55       | 1.11     |
| Na⁺ (mg/L)       | 940.64     | 939.51     | 975.77     | 410.00     | 2.39     |
| K⁺ (mg/L)        | 48.95      | 46.89      | 48.90      | 21.63      | 3.89     |
| Li⁺ (mg/L)       | 1.41       | 1.37       | 1.40       | 0.57       | 0.01     |
| As³⁺ (mg/L)      | 0.01       | 0.20       | 0.50       | 0.01       | 0.01     |
| NH₄⁺ (mg/L)      | 29.61      | 31.16      | 28.74      | 9.74       | 0.91     |
| F⁻ (mg/L)        | 6.50       | 8.20       | 8.00       | 3.60       | 0.01     |
| Cl⁻ (mg/L)       | 955.80     | 901.95     | 982.73     | 417.32     | 1.12     |
| SO₄²⁻ (mg/L)     | 69.04      | 73.65      | 92.63      | 34.48      | 10.47    |
| HCO₃⁻ (mg/L)     | 716.32     | 804.63     | 840.27     | 406.27     | 9.09     |
| CO₃²⁻ (mg/L)     | 0.00       | 0.00       | 0.00       | 0.00       | 0.00     |
Hence, the fluid type of geothermal manifestations’ is chloride shows that four manifestations samples lie in the same boundary line between Cl and HCO₃ (Figure 40). Plotting chemical composition of water samples is aimed to obtain the type of hot water, the origin of Mg, and Cl.

The determination of hot water type is based on the value of chloride (Cl), sulphate (SO₄), and bicarbonate (HCO₃) as data is shown in Table 3. The result of Cl-SO₄-HCO₃ ternary diagram plotting shows that four manifestations samples lie in the same boundary line between Cl and HCO₃ (Figure 2). Hence, the fluid type of geothermal manifestations’ is chloride-bicarbonate water type.

**Table 3. Ion balance data analysis.**

| Chemical Content | Mol Eq Weight | Equivalent Value |
|------------------|--------------|------------------|
|                  | Weight       | AP S 1 | AP S 2 | AP S 3 | AP S 4 | AD KM-17 |
| Cl⁺              | 26.9816      | 0.048  | 0.001  | 0.001  | 0.001  | 0.004    |
| Fe³⁺             | 55.847       | 0.026  | 0.001  | 0.001  | 0.003  | 0.004    |
| Ca²⁺             | 40.08        | 0.182  | 0.171  | 0.204  | 0.369  | 0.050    |
| Mg²⁺             | 24.312       | 0.041  | 0.042  | 0.041  | 0.045  | 0.091    |
| Na⁺              | 22.9898      | 40.915 | 40.866 | 42.443 | 17.834 | 0.104    |
| K⁺               | 39.102       | 1.252  | 1.199  | 1.251  | 0.553  | 0.099    |
| Li⁺              | 6.939        | 0.203  | 0.197  | 0.202  | 0.082  | 0.001    |
| As³⁺             | 74.922       | 0.000  | 0.008  | 0.020  | 0.000  | 0.000    |
| NH₄⁺             | 18.03858     | 1.641  | 1.727  | 1.593  | 0.540  | 0.050    |
| meq (milliequivalent) of total cation | 44.308 |
| F⁻               | 18.9964      | 0.342  | 0.432  | 0.421  | 0.189  | 0.001    |
| Cl⁻              | 35.453       | 26.962 | 25.443 | 27.722 | 11.772 | 0.032    |
| SO₄²⁻            | 96.0616      | 1.437  | 1.533  | 1.929  | 0.718  | 0.218    |
| HCO₃⁻            | 61.01732     | 11.739 | 13.186 | 13.770 | 6.658  | 0.149    |
| CO₃²⁻            | 60.00935     | 0.000  | 0.000  | 0.000  | 0.000  | 0.000    |
| meq (milliequivalent) of total anion | 40.481 |

| Ion balance (%) | 4.515 | 4.267 | 2.136 | 0.233 | 0.338 |

*Plotting the chemical composition of water samples is aimed to obtain the type of hot water, the origin of the fluid, and the environment occurrence of hot spring were based on Cl - SO₄ - HCO₃, Na-K-Mg, and Cl-Li-B diagram [4].

The determination of hot water type is based on the value of chloride (Cl), sulphate (SO₄), and bicarbonate (HCO₃) as data is shown in Table 3. The result of Cl-SO₄-HCO₃ ternary diagram plotting shows that four manifestations samples lie in the same boundary line between Cl and HCO₃ (Figure 2). Hence, the fluid type of geothermal manifestations’ is chloride-bicarbonate water type.*

![Figure 2. Cl-SO₄-HCO₃ Ternary Diagram Plot.](image-url)
The fluid type is shown by high content Cl (chloride) content as the dominant element (main anion) and also the presence of HCO$_3$ that quite significant. The fluid is formed as the result of chloride water dilution by groundwater or meteoric water during lateral flow. Chloride-bicarbonate fluid indicates a transition zone between upflow zone and outflow zone [5]. All the manifestation samples have dominant chloride element and the significant amount of HCO$_3$, the emergence of the significant amount of HCO$_3$ element is affected by condensed CO$_2$ gas in groundwater near-surface that contains very little amount of oxygen (O$_2$). This type of water (chloride-bicarbonate water) is formed due to the interaction of chloride water and bicarbonate water during its lateral flow through the crack or fault in the rock.

Na/1000-K/100-√Mg ternary diagram to evaluate the state of the water-rock interaction equilibrium and reservoir temperature [6]. It is observed that AP Sajau 1, 2, 3, are in the partial equilibrium water zone. It means the fluid originates directly from the reservoir where the influence of surface water or meteoric water dilution is limited. AP Sajau 4 manifestation is in the partial equilibrium water zone but close to the boundary between the partial equilibrium water and immature water zones, which shows that the fluid comes directly from the reservoir with the influence of meteoric water.

Figure 3. Na/1000-K/100-√Mg Ternary Diagram Plot.

Figure 4. Cl/100-Li-B/4 ternary diagram plot.
Based on the results of the Na/1000-K/100-√Mg ternary diagram in Figure 3, an approximate temperature of the geothermal reservoir can be obtained. AP Sajau 1, AP Sajau 2, and AP Sajau 3 show reservoir temperature is in the range of 150-185°C, while AP Sajau 4’s reservoir temperature in the range of 125-185°C. All the manifestations are classified into medium enthalpy geothermal system (T = 125-225°C) [7].

The determination of the environment origin of the fluid is done with Cl/100-Li-B/4 ternary diagram [8]. Based on the observation, all samples are plotted adjacent to each other with Cl and B as dominant elements (Figure 4). It can be interpreted that the geothermal fluid in its formation is influenced by interaction with volcanic or intrusive environment with sedimentary rock. Chloride (Cl) element originates from interactions with volcanic/intrusive rock while Boron (B) element is associated with sedimentary rock which rich in organic matter [5]. It can be concluded that all fluid samples are from the same reservoir.

The use of isotope in this study is to analyze the origin of geothermal fluid. This method uses stable isotope $^{18}$O and $^2$H. The samples used are water samples from the manifestations: AP Sajau 1, 2, 3, and 4. In addition, cold water samples are analyzed for comparison purpose, namely Apan river water (US Apan), KM-17 waterfall (AT KM17), cold water SP 4 (AD SP4), cold water Wonomulyo (AD WNM), cold water GK 32, and river water SJ 25.

For the meteoric water trend line, global meteoric water trend line is used. Based on the result of the isotope distribution graph in Figure 5, nearly all cold water samples (SP 4 AD, US Apan, AD GK 32, AS SJ 25, AD SP 4, AT KM-17) are on the meteoric trend line, while AD WNM falls different to other cold water samples because AD WNM sample is groundwater taken from local drinking water producers’ well, so the isotope composition is slightly different from other cold water samples which from surface water. AP Sajau 1, 2, 3 and 4, which are represented by bullets, are plotted in the right part of the line which indicate the origin of hot springs. The positive shifting of $\delta^{18}$O (to the right of meteoric water trend line) shows the tendency of interactions and dilutions by meteoric water. Data indicate that the influence of meteoric water is increasing towards the southwest (AP Sajau 4). It can be concluded that the upflow zone is at the center of the research area while the outflow area is in southwest.

Figure 5. Isotope $^{18}$O and deuterium graph of Sajau geothermal field.
Table 4. The geothermometer data of Sajau geothermal field.

| Parameters                  | AP Sajau 1 | AP Sajau 2 | AP Sajau 3 | AP Sajau 4 |
|-----------------------------|------------|------------|------------|------------|
| pH                          | 7.21       | 7.16       | 7.25       | 6.72       |
| SiO₂ (mg/L)                 | 137.14     | 131.65     | 134.82     | 83.77      |
| Ca (mg/L)                   | 3.64       | 3.42       | 4.08       | 7.40       |
| Na (mg/L)                   | 940.64     | 939.51     | 975.77     | 410.00     |
| K (mg/L)                    | 48.95      | 46.89      | 48.90      | 21.63      |
| Silica (SiO₂) geothermometer (°C) |         |            |            |            |
| Quartz, no steam loss       | 155.632    | 153.154    | 154.593    | 127.534    |
| Quartz, maximum steam       | 148.126    | 146.067    | 147.263    | 124.56     |
| Chalcedony                  | 131.106    | 128.316    | 129.936    | 99.829     |
| Na/K geothermometer (°C)    |            |            |            |            |
| Truesdell (1976)            | 126.538    | 123.177    | 123.505    | 127.651    |
| Tonani (1980)               | 130.5      | 126.98     | 127.323    | 131.666    |
| Anorsson (1983)             | 169.071    | 166.396    | 166.658    | 169.954    |
| Fournier (1979)             | 166.729    | 163.862    | 164.142    | 167.676    |
| Nieva & Nieva (1987)        | 154.643    | 151.841    | 152.115    | 155.568    |
| Giggenbach (1988)           | 185.041    | 182.316    | 182.582    | 185.94     |

SiO₂ and Na-K geothermometers are used to estimate the subsurface temperature of AP Sajau 1, AP Sajau 2, AP Sajau 3 and AP Sajau 4. Based on SiO₂ geothermometer results, reservoir’s temperature varies from 99-195°C. The reservoir’s temperature results from Na-K geothermometer vary from 125 to 185°C. Hence the geothermal system classified into medium enthalpy geothermal system [7]. The data is shown in Table 4.

3.3. Soil gas geochemical analysis

Hg element evaporates easily and forms sulphides due to geothermal activity. The Hg concentration will be accumulated in the soil layer (horizontal distribution), generally is located one meter below the soil surface. Soil samples are analyzed using Atomic Absorption Spectrophotometer (AAS) to obtain values of mercury concentration in gas form from each sample. The analysis shows that Hg values vary from 9.16 ppb - 882 ppb. The map of Hg anomaly presents the concentration of Hg element below low anomaly limit value (142 ppb) is marked as yellow and the area of high anomaly value limit of 314 ppb is marked as red (Figure 6). The area with high Hg concentration is located along the lineament of fault which controls the appearance of surface manifestations in the form of hot springs. High Hg element indicates a permeable zone (usually associated with fault or joint) and also a character of upflow zone. CO₂ values vary from 0.03 % to 3.74%. Hg distribution map is overlayed by CO₂ distribution. It shows that CO₂ value doesn’t provide a significant influence on Hg concentration, so the CO₂ anomaly in the study area has no relation with the geothermal system. Based on the discussion above, a geothermal conceptual model is made based on geology and geochemistry (Figure 7). The formation of a geothermal system in the Sajau area is interpreted to be influenced by two things, the structure which influence the appearance of surface manifestations and heat source that affected by the geothermal gradient and depth of the circulated groundwater.
Figure 6. Hg anomaly map of Sajau geothermal area.

4. Conclusion
Based on isotope data and geoinicator diagram Cl-SO$_4$-HCO$_3$, Cl/100-Li/B/4, and Na/1000-K/100-$\sqrt{Mg}$ from samples of four hot springs in research area show chloride-bicarbonate type of geothermal fluid. [5] indicates this type of fluid’s occurrence depends on chloride water dilution from surface water, which in this research area, the source of high HCO$_3$ content is from the condensed CO$_2$ in groundwater near the surface which contains less O$_2$. Reservoir’s temperature results from geothermometer Na-K and SiO$_2$ vary from 125 to 185°C hence the geothermal system classified into medium enthalpy geothermal system [7]. The temperature of manifestation varies from 58.2 to 85.8°C.

Based on geological aspects and fluid geochemical analysis, the formation of a geothermal system in the region of Sajau is influenced by two factors, the structural pattern which responsible to the appearance of surface manifestations and heat source which is affected by the geothermal gradient and the depth of water is circulated. The anomaly of Hg element on the surface is formed from vapor which originates from fluid in reservoir rocks in geothermal systems. Vapor escapes to surface through faults and also permeable zones which will illustrate a pattern of concentration on the surface that is estimated to be similar to below-surface vapor loss pattern [9].
Thus, based on the anomaly distribution map of Hg element, the region with high Hg element is limited to surface manifestations’ area to the west and northwest. It can be concluded that the permeable zone of the geothermal region is narrowly limited to the appearance of geothermal manifestations in the form of hot springs. The modified conceptual model is based on the conceptual model of fault-controlled system [10]. Based on the temperature and the enthalpy value, the best utilization method of Sajau's prospect geothermal area is direct use. Low enthalpy geothermal resources can be used for hot spring tourism, soil sterilization in agriculture, aquaculture, and greenhouse heating.

![Conceptual model of Sajau geothermal area](image)

**Figure 7.** Conceptual model of Sajau geothermal area.

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