Study on geochemistry of sea water intrusion effect in Jailolo geothermal system

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Abstract. The possibility of seawater intrusion in geothermal systems is very likely to occur. This is caused by several locations of geothermal systems which are very close to the coast. This paper presents a geochemical analysis of the data manifestations of water and gas, to determine the effect of sea water on the Jailolo geothermal system. From the results of the water analysis, it is clear that the effect of sea water intrusion on the Jailolo geothermal system is shown in the anions and cations diagrams, which is almost all of the plots very close to the seawater points. So that the next analysis is focused on the position of mixing sea water with reservoir water and correction of the parameters that are affected by the mixing of sea water. It is intended that the resulting geochemical model can describe the actual reservoir conditions. If we did not include the correction factor to the calculation this will lead into mislead assessment of the reservoir temperature of geochemistry model which is the final result of the study/assessment. It is also necessary take into account for the next step of the process which is exploitation phase.

Keywords: Geochemistry, sea water intrusion, Jailolo

1. Introduction
Indonesia have geothermal potential spread across in 342 locations. Some geothermal areas located in eastern of Indonesia with focus in seaside are Jailolo, Atadei, Ulumbu, Lahendong. Those locations of geothermal potency (seaside) have challenge to be developed. One of the challenges is possibility of sea water intrusion into the geothermal field.

Figure 1 shows Jailolo geothermal prospect that is located in seaside. Administratively, Jailolo geothermal prospect area is located in the Sub-district Jailolo, West Halmahera district, North Maluku Province.

Scope of this assessment only focus in geochemistry parameters that showing area of sea water intrusion in Jailolo geothermal prospect area, constructing geochemistry model with including of possibility of sea water intrusion and creating conceptual model of Jailolo geothermal prospect area. Furthermore, the geochemistry analysis is focused on parameters that indication of sea water intrusion.

2. Hypothesis
Sea water intrusion is the movement of saline water into freshwater aquifers, because saline water has a higher density than freshwater, it is denser and has a higher water pressure.
Figure 2 shows hydrology model of sea water intrusion based on different density value of sea water and ground water as of intrusion area can be calculated. The formulation of sea water intrusion was made by Badon-Ghijben (1888, 1889) and Herzberg (1901), thus called the Ghyben–Herzberg: [1].

\[
z = \frac{\rho_f}{\rho_s - \rho_f} h \tag{1}
\]

In geothermal prospect area nearby the beach it could happen in static condition (exploration phase) or dynamic condition (exploitation phase) because of mass extraction by production well.

Figure 1. Location of Jailolo geothermal prospect showing manifestation distribution and samplings.

Figure 2. Hydrology model of sea water intrusion
3. Data analysis
In geochemistry study there are several steps for analysis: to define the water geochemistry, to define isotope geochemistry, to define gas geochemistry, geothermometer as well as to define conceptual geochemical model.

3.1. Water chemistry
Water chemistry is initially analyzed in terms of the relative concentrations of major anions (HCO₃, SO₄ and Cl) by the triangular diagram of major anions adapted from Giggenbach [2]. The anions diagram shows in figure 3 [2] and figure 4 that all the thermal waters are Cl-rich, almost all of the plot very close to the seawater points. Such an alignment is most likely the graphical expression of seawater dilution.

By water chemistry analysis it can be identified the sea water intrusion in the Jailolo geothermal system. The result indicates that the intrusion only occurs in several manifestations (not directly in the reservoir zone).

3.2. Gas chemistry analysis
Gas Chemistry analysis to identify origin of gas manifestation by plotting the samples in diagram triliner N₂-He-Ar. Figure 5 shows plots of samples on “free air” trend nearby N₂/Ar = 84, it indicates that the gas sample came from “magmatic gas” and also geothermal system Jailolo associated with volcanic activity [3]. Another analysis to identify the possible upflow and outflow zones by plotting the samples in trilinear diagram N₂-He-Ar.

3.3. Geothermometer
Geothermometer in this study uses some geothermometer calculation equations by Fourier (1979), Truesdell (1979) and Giggenbach (1998) [4]. And detailed calculation using Na/K component after corrected by sea water fraction. The result shows that the average reservoir temperature before correction is 192 °C and after correction the reservoir temperature is 205 °C.

3.4. “Chloride plots”
Chloride plot is to give understanding about mixing process of sea water combined with other elements that put in the plots. The result is shown in figure 6 to figure 8.

Figure 3. Triangular plots between the major anionic constituents.  
Figure 4. Triangular plots between Cl-Li-B.
Chloride plots are useful to investigate both the behavior of the analyzed chemical constituents and the relationships among the water samples collected in the Jailolo prospect, which is essential for individuating active processes (e.g., mixing, boiling, separation of solid phases, etc.). This is also a necessary propaedeutic step before tackling chemical geothermometry.

Br/Cl and Na/Cl in figure 6 ratios of samples plotting is slightly lower than the seawater value line that are observed in some thermal waters discharging on the western coast of the Jailolo, whereas all the other thermal waters are plotted along the dilution line of average seawater. The plot (Br/Cl, Na/Cl) shows that local seawater has Cl concentration lower than the thermal water samples 9, 13 and 14, probably because it is affected by mixing with river water.

The correlation plots of K/Cl and Ca/Cl in figure 7 shows similar spreads of points dictated by the acquisition of both chemical constituents, with respect to the seawater dilution line.

Figure 8 these two plots (a and b) have similar spread of points, which are controlled by loss of these two chemical components, with respect to the seawater dilution line. It must be underscored that both the acquisition of K and the loss of Mg and SO₄ reflect the occurrence of water-rock interaction at relatively high temperature, whereas the acquisition of Ca is controlled by both CO₂ partial pressure and temperature [5].
3.5. Mixing model correction
Correction between graphic mixing models was done to predict the related reservoir temperature in with the subsurface condition. Parameter of element Cl plays as an important role to adjustment of reservoir temperature. The deviation between before and after correction is about 40 °C as shown in figure 9 after correction of Cl value from the sea water fraction.

3.6. Conceptual model
Conceptual model is used specifically to show intrusion zone using Ghyben-Herzberg equation: in hydraulic static condition, area interface between freshwater and sea water by differentiating the density value. Figure 10 shows the Jailolo conceptual model with upflow zone on the center of Mt. Jailolo and spread out manifestations indicating outflow zone. Figure 11 shows cross section of Jailolo conceptual model along the line indicating the intrusion area (interface) between seawater and ground water zones using data from table 1.

Figure 7. Correlation plots of chloride versus (a) potassium and (b) calcium.

Figure 8. Correlation plots of chloride versus (a) magnesium and (b) sulfate.
As shown in table 1, level of fresh water is unavailable, it is an adjustment of level freshwater using elevation from the contour map as a data of $h_f$ which assumption of the data 50% lower than ground elevation. Table 1 is the result of calculation using equation 1.

4. Discussion
Early identification of sea water intrusion in Jailolo geothermal system is based on analysis of water and gas chemistry from manifestation samples. Result assessment show the tendency that some manifestations are intruded by sea water. It is shown by the result of assessment using trilinear diagram.
such as Cl-SO$_4$-HCO$_3$ and Cl-Li-B. Calculation of water proportion is calculated using fluid sample equation, as shown by the following equation:

\[
\text{\% intrusion} = \frac{(\text{Sample Data} - \text{Data Meteoric Water})}{\text{Sea Water Data}}
\]  

(2)

where:
- Meteoric data is taken from analysis of cold water sample
- Sea water data is taken from analysis of local sea water chemistry

The result is shown in table 2.

In order to make a reliable assessment, some of the analysis needs to make correction to describe any sea water intrusion. Combination of the chemistry parameters with the sea water can be drawn using regression linear to see which parameter that would be affected statistically. In figure 12 it is the result of linear regression with the R is value creation of each parameter to identify level of assessment accuracy.

![Figure 11. Cross section of Jailolo conceptual model](image)

| Elevation (from contour map) | Ground water level | Interface (Z), m |
|-----------------------------|--------------------|------------------|
| 50                          | 25                 | 1000             |
| 100                         | 50                 | 2000             |
| 150                         | 75                 | 3000             |
| 200                         | 100                | 4000             |
Table 2. Calculation result of proportion sea water in fluid manifestation.

| Sample label | Cl  | Na  | SO₄ | Mg  | Ca  | K   | HCO₃ | Br  |
|--------------|-----|-----|-----|-----|-----|-----|------|-----|
| 1            | 6%  | 7%  | 10% | 6%  | 14% | 13% | 216% | 6%  |
| 2            | 6%  | 7%  | 8%  | 6%  | 14% | 12% | 151% | 6%  |
| 3            | 6%  | 7%  | 9%  | 5%  | 13% | 13% | 185% | 6%  |
| 4            | 8%  | 8%  | 8%  | 6%  | 12% | 14% | 137% | 8%  |
| 5            | 12% | 13% | 11% | 8%  | 13% | 19% | 158% | 11% |
| 6            | 17% | 16% | 16% | 14% | 30% | 25% | 121% | 16% |
| 7            | 20% | 19% | 19% | 17% | 33% | 31% | 141% | 20% |
| 8            | 23% | 23% | 22% | 20% | 39% | 33% | 141% | 23% |
| 9            | 106%| 97% | 92% | 79% | 201%| 136%| 80%  | 100%|
| 10           | 42% | 38% | 23% | 20% | 124%| 69% | 9%   | 36% |
| 11           | 36% | 31% | 10% | 16% | 121%| 68% | 105% | 35% |
| 12           | 51% | 41% | 22% | 22% | 215%| 78% | 61%  | 49% |
| 13           | 88% | 85% | 77% | 64% | 154%| 110%| 71%  | 81% |
| 14           | 114%| 104%| 104%| 88% | 224%| 142%| 91%  | 111%|
| 15           | 1%  | 1%  | 5%  | 0%  | 0%  | 4%  | -4%  | 1%  |
| 17           | 5%  | 5%  | 7%  | 0%  | 35% | 9%  | -16% | 5%  |
| 18           | 3%  | 3%  | 4%  | 0%  | 22% | 4%  | -15% | 31% |
| 19           | 13% | 12% | 8%  | 8%  | 36% | 26% | 527% | 11% |
| 20           | 16% | 16% | 11% | 11% | 39% | 30% | 496% | 15% |
| 21           | 3%  | 3%  | 3%  | 3%  | 16% | 7%  | 401% | 1%  |
| 22           | 4%  | 4%  | 2%  | 5%  | 14% | 7%  | 515% | 2%  |
| 23           | 3%  | 4%  | 4%  | 4%  | 19% | 9%  | 465% | 2%  |
| 29           | 55% | 53% | 50% | 51% | 71% | 63% | 61%  | 54% |
| 30           | 33% | 30% | 31% | 31% | 52% | 44% | 129% | 31% |

Figure 12. Plotting correlation between data analysis with R value.
5. Conclusion
The result of integrated analysis of the Jailolo geothermal prospect area indicates there are sea water intrusion effects. It is proved on the basis of assessment of some manifestation data. However, some manifestations did not show intrusion into the Jailolo reservoir.

Correction must be applied in some analysis procedures to reduce the sea water intrusion effect. Calculation of the reservoir temperature by geothermometer equation following Tom Powell Spreadsheet shows temperature before correction is 192 °C. After the correction, the reservoir temperature is 205 °C. Deviation between before and after correction is not very high because of Na/K value is the main parameter used in that equation. Na/K is minor component that exist in sea water and reservoir fluid, so the result of this assessment only as information. Calculating temperature reservoir by using reading on mixing model shows value 150 °C before correction and 190 °C after correction. It shows high deviation since Cl is one parameter used in this analysis. This concentration is valuable parameter affected if intrusion invade into the reservoir. Cl is also major component that exist in sea water and fluid reservoir. All data is then integrated to represent reservoir conceptual model of the Jailolo area as well as sea water intrusion position.

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