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RESEARCH ARTICLE

Hydrogeochemistry and Isotope Characteristics of the Hot Springs in the Wapsalit Area, Buru Regency, Maluku Province, Indonesia

Fathira Pinning[1*], Agus Didit Haryanto[1], Johanes Hutabarat[1]

[1] *Faculty of Geological Engineering, Padjadjaran University, Jl. Dipati Ukur No. 35, Bandung, Indonesia*

Corresponding author: fathira17001@mail.unpad.ac.id
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Abstract

Wapsalit is one of the geothermal areas that is located in Buru Regency, Maluku Province. Wapsalit area has several geothermal manifestations like hot springs, altered rocks, silica sinter and many more. This research aims to determine the characteristics and origin of the fluid in the research area. This research takes 5 samples of hot springs named FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5. Based on the results of chemical analysis, it shows that the 5 samples belong to the bicarbonate fluid type. FATH-1, FATH-3 and FATH-5 belong to the partial equilibrium zone, FATH-2 and FATH-4 belong to the immature water zone. Based on isotope ^{18}O and D analysis, the 5 hot spring samples originated from meteoric water and the fluids interacting with the rocks before heading to the surface.

Keywords: Hydrogeochemistry, Isotope, Hot spring, Wapsalit area, Maluku Province.

1. Introduction

Indonesia is one of the countries that passed by the ring of fire, that's why Indonesia has large geothermal potential. As of December 2019, it was recorded that Indonesia had a total geothermal potential of 23.9 Gwe spread across ±324 locations in Indonesia (EBTKE, 2020). Indonesia's geothermal potential environment is in two types of geological environment, namely in a volcanic environment (80%) and a non-volcanic environment (20%). The complex tectonic setting in Indonesia has resulted in Indonesia having a non-volcanic geothermal system. Based on the results of the PDSMBP investigation, potential non-volcanic geothermal locations in Indonesia until 2018 are spread over 136 locations or around 38% with a total resource of 4.035 Mwe (ESDM, 2019).

The total production of geothermal resources in Indonesia recorded in 2019 was only 2.130,6 Mwe. The Geothermal Power Plants currently in production all come from high-temperature geothermal systems (EBTKE, 2020). However, geothermal areas located in non-volcanic environments are still not optimally developed. This is because there is not much data and knowledge regarding the characteristics of geothermal systems in non-volcanic geothermal areas.

The initial stage was carried out to be able to provide detailed information about the characteristics of geothermal fluids and origin of fluid in geothermal, using hydrogeochemical and fluid isotope methods. Through a hydrogeochemical approach, the characteristics of the geothermal fluid can be known (Aulia et al., 2022). Through a stable isotope approach, by measuring the composition of $\delta^{18}O$ and δD in a sample of geothermal fluid (hot springs), the origin or genetics of the sample can be known (Satrio et al., 2020).

Maluku is one the province in Indonesia that has geothermal potential associated with or related to the non-volcanic geothermal environment (Aji Bintang et al., 2019). One of the areas is Waeapo District, Buru Regency, Maluku Province. In that area it is suspected that there is geothermal potential because there are many variations of geothermal manifestations that appear around the research area, one of several manifestation is hot/warm springs. An area that is known to have geothermal potential is usually indicated by the presence of geothermal manifestations that appear around the area like hot springs, fumarole, mud pools, steaming ground, altered rocks and so on (DiPipo, 2007). The Wapsalit geothermal system is associated with the presence of intrusive rock bodies that are not exposed on the surface. The intrusion body is thought to be a heat source that heats the reservoir fluid (Takodama et al., 2018).

The research aims is to determine the characteristic of the geothermal fluid and the origin of geothermal fluid at the Wapsalit area, Buru Regency, Maluku province using hydrogeochemical and isotope data.

2. Methods

Administratively the research area is located in the Wapsalit Region, Buru Regency, Maluku Province at coordinates 126º49'10.64"- 126º53'37" East Longitude and 3º27'43"- 3º31'13.17" South Latitude (Fig. 1). In this research, geochemistry and stable isotope analyze were carried out in several hot springs in the research area. The hot spring samples taken consisted of 5 hot spring samples coded FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5. The samples were analyzed at the PSDMBP Laboratory and ITB Hydrochemical Laboratory. The anion-cation content was analyzed at PSDMBP Laboratory and stable isotopes (D and ^{18}O) was analyzed at ITB Hydrogeochemistry Laboratory.

The laboratory analysis results will then be analyzed to identify the characteristics of geothermal fluids and genetics/origin from hot spring samples. To identify the characteristics of geothermal fluids, the value of the anion-cation analysis results will be plotted on the Cl SO_4 HCO_3, Cl Li B and Na K Mg ternary diagrams. To find out the genetics of the fluid, the plotting is done on a graphical diagram between the values of D and ^{18}O.

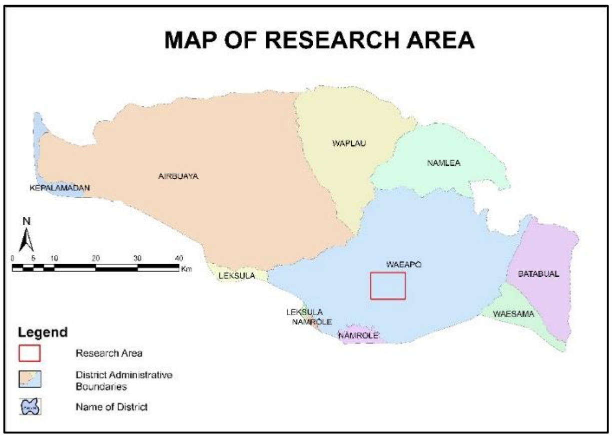

Fig. 1. Map of Buru Regency, the research area is in Waeapo District.

3. Geological Setting

The geological map of Buru Quadrangle shows that the research area consists of 3 (three) rock units namely Wahlua Complex, Terrace Deposits and Alluvium (Tjokrosapoetro et al., 1993) (Fig. 2).

The units of the rock will be explained from the oldest to the youngest. The Wahlua Complex consists of schist, phyllite, meta arkosic sandstone, quartzite and marble. This units is the oldest rock unit on Buru Island which has a Peremian age. Terrace Deposit consists of boulders, gravel, sand, silt, and clay. Alluvial consists of boulders, gravel, sand, silt and mud (Tjokrosapoetro et al., 1993).

The geological structure in the research area is dominated by faults that appear around the research area. These include the Wapsalit Fault which has a SW-NE direction, the Waetina Horizontal Fault which has a SW-NE direction, and the Waekedang Fault NW-SE. The Waekedang Fault is suspected of controlling the emergence of geothermal manifestations on the surface (Takodama et al., 2018).

The faults developed in the research area are grouped into the Wapsalit Fault, Waekedang Fault, Debu Normal Fault and Waemetar Fault Complex (Zarkasy et al., 2007: Pinning et al., 2021). Indications of geological structures found in the research area are sharp river bends and landslides along Pemali Hill (Pinning et al., 2021).

Geothermal manifestations as a whole appear at the Wahlua Complex. Geothermal manifestations in the Wapsalit area consist of hot springs, alteration rocks, sintered silica and many more. Hot springs are located around the Pemali River / Wae Metar River with a temperature range of 97ºC with a pH value of 6-8. Alteration rocks are exposed throughout the research area. These rocks experience alteration due to geothermal activity in the research area. Megascopically, these rocks have a yellowish-red to brownish colour.

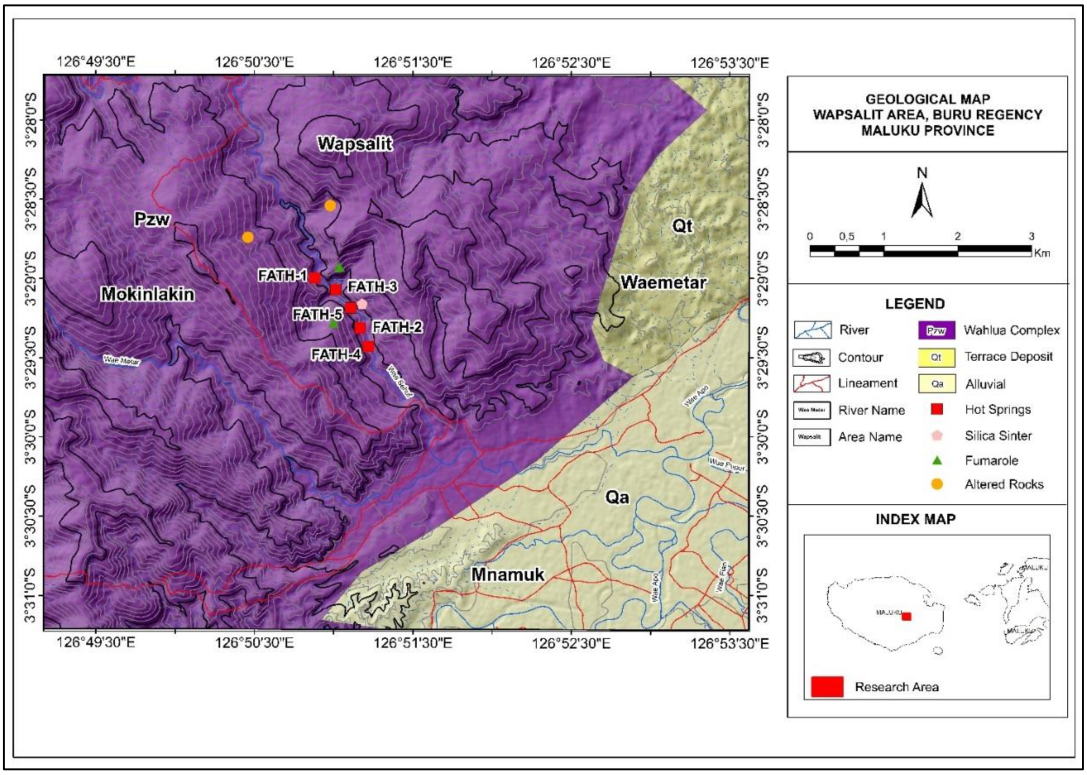

Fig. 2. Geological map in the research area (Tjokrosapoetro et al., 1993).

4. Result

Manifestations of hot springs in the Wapsalit area consist of warm springs to hot springs with a temperature range of 77-97ºC. This research was conducted by taking samples at five points of hot springs (Fig. 3). The manifestation hot springs description is shown in Table. 1, the result of the anion-cation analysis is shown in Table. 2 and Table. 3 shows the result of the isotope (^{18}O and D) analysis.

The results of chemical analysis (anion and cation) in Table. 2 show that the 5 hot springs sample in the research area have an ion balance of less than 5%. This indicates that the results of the chemical analysis are feasible to be used for geochemical interpretation, especially to identify the characteristics of geothermal fluids based on triangular diagram plotting which refers to Giggenbach, 1988.

Stable isotope analysis results for the 5 hot spring samples did not differ much. The value of ^{18}O ranges from -3.76 to -4.64. While the value of D ranges from -30.22 to -33.59.

Table 1. Physical characteristics of the 5 hot spring samples in the research area.

No.	Sample Code	Coordinate	T Water (ºC)	T Air (ºC)	pH	Description
1	FATH-1	3º28'59,774"S, 126º50'52,867"E	77.3	23	8.9	Clear, smell of sulfur, no taste, there are bubbles, appearance around altered rocks.
2	FATH-2	03˚29'18,75"S, 126˚51'10,07"E	79.3	23	6.5	A bit murky, smell of sulfur, has taste, appearance like pool.
3	FATH-3	03º29'4,251"S, 126º51'0,768"E	97.73	27	8.7	Clear, smell of sulfur, has taste, there are bubbles, appearance from fracture altered rocks.
4	FATH-4	03º29'25,642"S, 126º51'13,177"E	91	27	6.6	Clear, smell of sulfur, has taste, there are bubbles, appearance beside of Pemali river.
5	FATH-5	03˚29'11,094"S, 126˚51'6,538"E	89.7	26	8.6	Clear, smell of sulfur, has taste, there are bubbles, appearance from fracture altered rocks.

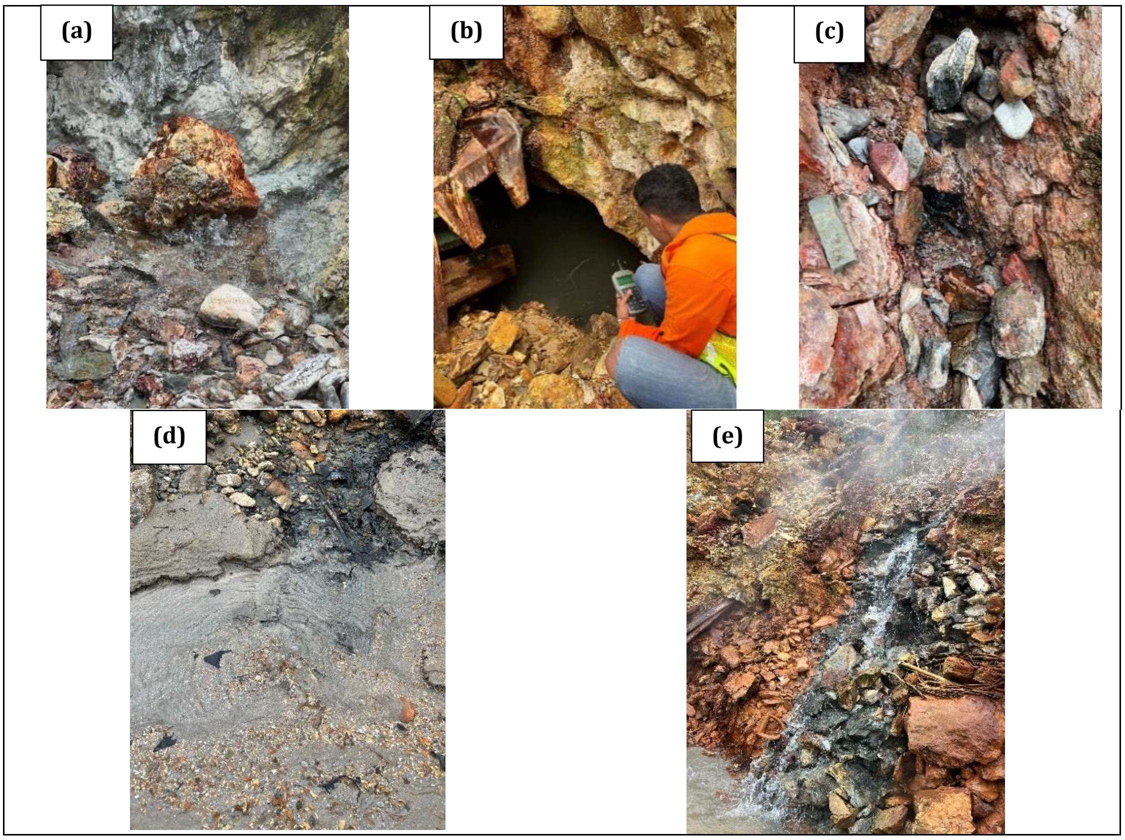

Fig. 3. Variation of manifestation hot springs in the research area (a) FATH-1 classified as bicarbonate water, (b) FATH-2 classified as bicarbonate water, (c) FATH-3 classified as bicarbonate water, (d) FATH-4 classified as bicarbonate water and (e) FATH-5 classified as bicarbonate water.

Table 2. Anion-cation analysis results from the 5 hot spring samples.

Concentration	Sample Code				
	FATH-1	FATH-2	FATH-3	FATH-4	FATH-5
SiO_2 (mg/L)	169.16	104.33	366.60	134.77	307.48
B (mg/L)	32.50	11.25	27.22	9.45	30.56
Al^{3+} (mg/L)	0.09	0.37	0.08	0.04	0.10
Fe^{3+} (mg/L)	0.0018	0.07	0.0018	0.0018	0.0018
Ca^{2+} (mg/L)	2.03	11.85	8.67	3.76	6.21
Mg^{2+} (mg/L)	2.28	7.39	3.23	2.64	1.94
Na^{+} (mg/L)	843.15	312.00	808.62	303.69	826.92
K^{+} (mg/L)	70.67	18.59	57.58	15.24	68.92
Li+ (mg/L)	5.42	1.98	4.75	1.70	5.15
As^{3+} (mg/L)	0.40	0.20	0.40	0.40	0.40
NH_4^{+} (mg/L)	5.12	48.50	6.45	24.40	5.47
F^{-} (mg/L)	6.68	1.27	5.77	2.09	5.58
Cl^{-} (mg/L)	240.66	38.00	139.33	19.00	183.67
SO_4^{2-} (mg/L)	7.42	252.15	30.28	117.01	10.90
HCO_3^{-} (mg/L)	1107.30	843.90	556.47	684.05	586.70
CO_3^{2-} (mg/L)	529.45	0.00	684.18	60.48	800.86
Meq. Cation	39.84	18.22	39.39	15.60	39.25
Meq. Anion	43.09	20.22	36.79	16.31	42.01
Ion Balance (%)	-4	-5	2	-2	-3

Table 3. Stable isotope analysis results from the 5 hot spring samples.

Concentration	Sample Code				
	FATH-1	FATH-2	FATH-3	FATH-4	FATH-5
^{18}O (‰)	-3.76 ± 0.00	-4.39 ± 0.01	-4.12 ± 0.02	-4.64 ± 0.01	-3.95 ± 0.02
D (‰)	-30.22 ± 0.09	-33.59 ± 0.05	-31.32 ± 0.09	-30.67 ± 0.04	-31.29 ± 0.09

5. Discussion

5.1 Geoindicator

The Cl SO_4 HCO_3 ternary diagram is used to interpretate the type of fluid in geothermal (Hidayatullah et al., 2021). The percentage of the anion-cation analysis results of the hot spring samples was calculated and then plotted on diagram.

Based on the percentage calculation results and plotting on the 5 hot spring samples, shows that all samples (FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5) are classified as bicarbonate fluid type because it has a more dominant HCO_3 content than Cl and SO_4 content (Fig. 4).

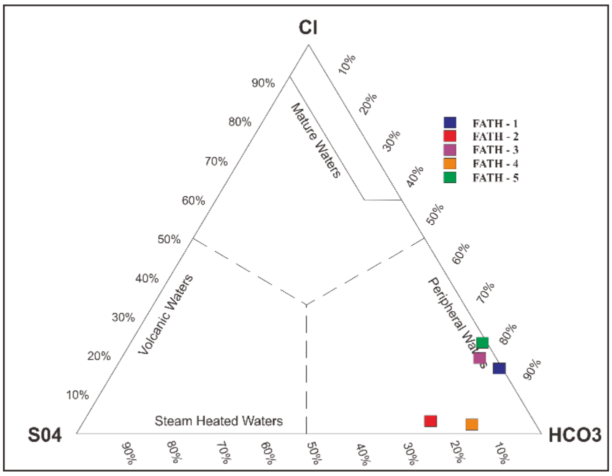

Fig. 4. Cl-SO_4-HCO_3 ternary diagram; the 5 hot spring samples are classified as HCO_3 water (Giggenbach, 1989).

This type of fluid is interpreted that the fluid comes from the condensation of CO_2 gas. The CO_2 gas in the fluid will be released in the liquid phase which will increase the solubility of silica (this can be seen in the relatively high silica content in the 5 hot springs). Furthermore, geothermal fluid containing CO_2 gas condenses in the aquifer and interacts with meteoric waters or groundwater as it heads to the surface. This causes an increase in the HCO_3 content.

FATH-2 and FATH-4 experience slight mixing with sulfate water, this is characterized by a relatively high SO_4 content. So it can be interpreted that FATH-2 and FATH-4 experienced a slight mixing of steam and gas condensation on their way to the surface (Nicholson, 1993).

The Cl Li B ternary diagram is used to find out the origin of the geothermal fluid using the calculation of the Cl, Li and B content and then plot it on the ternary diagram (Ardelia et al., 2023).

Based on the results of calculating the contents of Cl, Li and B and after plotting it on the Cl Li B ternary diagram shows that the 5 hot springs sample (FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5) is in the Li-B zone (Fig. 5). The existence of all the hot spring samples that became one group indicates that the 5 hot spring samples came from the same reservoir.

The low of B content in the geothermal fluid indicates that during the passage to the surface, the surrounding rock is slightly diluted (Giggenbach, 1991). The 5 hot spring samples had a relatively higher B content, and the 5 hot spring samples are in the Li-B area. It can be interpreted that during the passage to the surface, there was a process of dilution of the surrounding rock towards the geothermal fluid.

The Na K Mg ternary diagram is used to determine the equilibrium of the geothermal fluid using the calculation of the of Na, K and Mg content (Idroes et al., 2018).

Based on the results of calculations for the content of Na, K and Mg, it shows that the 3 hot spring samples (FATH-1, FATH-3 and FATH-5) are in the partial equilibrium zone, the other 2 hot spring samples (FATH-2 and FATH-4) are plotted in the immature water zone (Fig. 6).

FATH-1, FATH-3 and FATH-5 still characterize the reservoir. The 3 hot springs (FATH-1, FATH-3 and FATH-5) indicate that when the geothermal fluid appears on the surface as a manifestation, the hot springs have reached equilibrium with slight mixing of meteoric water. FATH-2 and FATH-4 show high Mg content more than Na and K content. In the geothermal reservoir, the Mg content is low which only around 0.1 mg/kg (Nicholson., 1933 ; Iqbal et al., 2019). The high of Mg content, indicates that hot springs mixing with meteoric water (Lihayati et al., 2022). This indicates that the two hot springs samples (FATH-2 and FATH-4) indicates that they have been mixed with meteoric water very dominant.

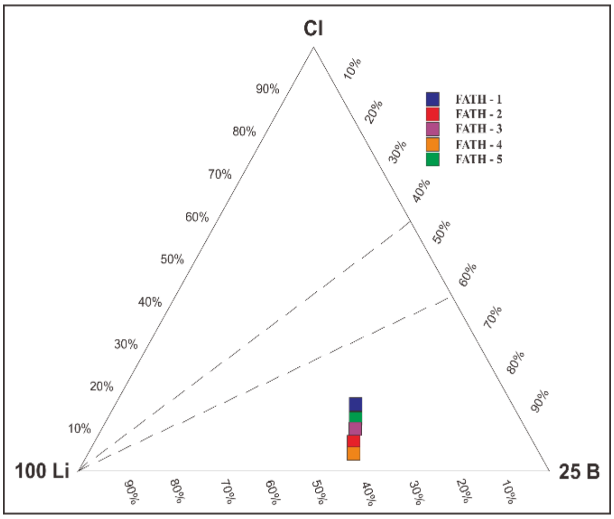

Fig. 5. Cl-Li-B ternary diagram; the 5 hot spring samples are in Li-B zone (Giggenbach, 1989).

5.2 The origin of geothermal waters

The composition of ^{18}O and D isotopes in geothermal fluids is used to determine the origin of the geothermal fluids (Zhao et al., 2018). The values of isotopes ^{18}O and D contained in Table 3 will be plotted on a graphical chart based on Craig (1961) combined with the Global Meteoric Water Line values.

Based on the plotting results (Fig. 7) it shows that the 5 hot spring samples (FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5) are near the meteoric line. This indicates that the 5 samples came from meteoric water. However, all of these samples have oxygen shifting. So this can be indicate that geothermal fluids experience reactions with low-medium temperature rocks before heading to the surface (Nicholson, 1993). There is a reaction between the geothermal fluid and the rock which causes the transfer of oxygen from the rock to the fluid.

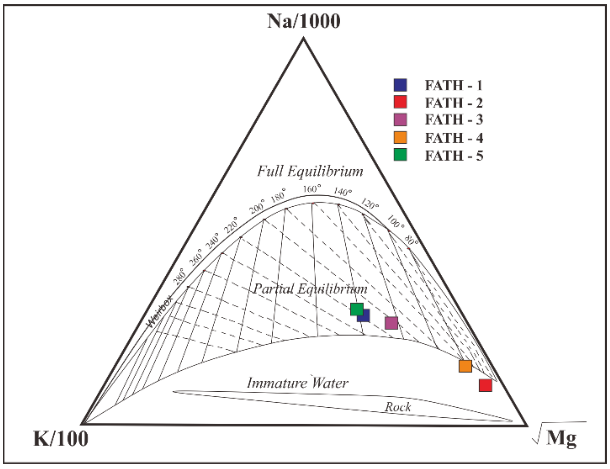

Fig. 6. Na-K-Mg ternary diagram shows that FATH-1, FATH-3 and FATH-5 are in partial equilibrium zone, FATH-2 and FATH-4 are in immature water zone (Giggenbach, 1989).

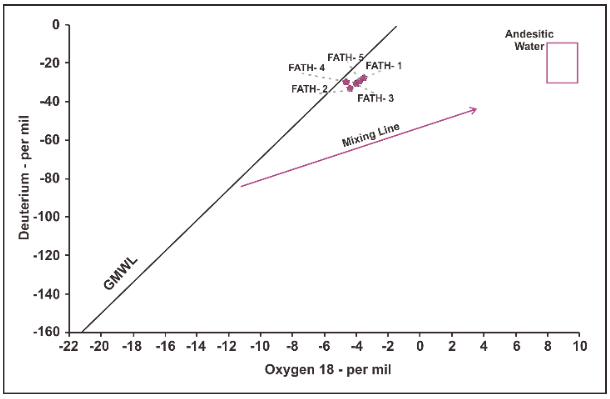

Fig. 7. Isotope ^{18}O and deuterium graphic (Craig, 1961).

6. Conclusion

The 5 Wapsalit hot spring samples (FATH-1, FATH-2, FATH-3, FATH-4 and FATH-5) has dominant HCO_3 content which are classified as bicarbonate fluid type. FATH-1, FATH-3 and FATH-5 belong to the partial equilibrium zone, FATH-2 and FATH-4 belong to the immature water zone. Based on isotope ^{18}O and D analysis, the 5 hot spring samples originated from meteoric water and the fluids interacting with the rocks before heading to the surface.

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