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The Inventory Data Chemistry Characteristics of Puriala Parora, Toreo, Laonti Hot Springs of the Non-Volcanic Area at Southeast Sulawesi, Indonesia

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ABSTRACT

The first step in inventorying geothermal areas is identifying geothermal area through describing the surface thermal features, then measuring the physical properties (temperature, pH, conductivity, etc) and analyzing the water samples to cluster the type of surface thermal features and supported by the regional geology. Based on the literature data and surface thermal features, Southeast Sulawesi has 15 geothermal areas and numerous active geothermal manifestations there. Geologically, Southeast Sulawesi is associated with a non-volcanic environment with metamorphic and sedimentary rocks mostly. The inventory data was conducted in 2011 and identifying the active geothermal surface features at Puriala, Parora, Toreo, and Laonti Hot Springs. The Parora, Toreo, and Laonti Hot Springs are located near the southeast coastal of Sulawesi, while Puriala hot springs is a little bit far from the coastal area. These hot springs have temperature of 33-50.6^{o}C at air temperature of 27.5^{o}C, neutral pH, manifested at low terrain on altitude of 11-25 m above sea level, the Parora which manifested very near to the coastal line has the higher electrical conductivity of 2,650 µS/cm, while Puriala, Toreo, dan Laonti has lower electrical conductivity of 382-1,256 µS/cm, clearly color, salty, air bubbles, H_2S odour, chloride type and mostly plotted on partial equlibrium zone of Na-K-Mg relative diagram. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi. It is in the Meluhu Formation which consists of Sandstone, quartzite, black shale, red shale, phyllite, slate, limestone and siltstone, which aged Trias-Jura. This paper only discusses the early data inventory of geothermal surface features at geothermal areas of these hot springs, in order to be used for the geothermal society.

1. INTRODUCTION

Indonesia is an archipelagic country, blessed with the geothermal surface features that are scattered in all its territory. Because of its geological setting, Indonesia acquires the abundant of geothermal resources. By December 2022, Geological Agency, MEMR (Geological Agency, 2022) has inventoried 361 geothermal areas, with total potency about 23,060.5 MWe which is consisted of 5,849 MWe of speculative potency; 3,376 MWe of hypothetical potency; 9,251 MWe of possible potency; 1,770 of probable potency; and 3,110.9 of proven potency; but the installed capacity is still about 2,355.43 MWe. Southeast Sulawesi province are part of Zone of Eastern Indonesia, There are 13 geothermal areas have been identified in South East Sulawesi (Geological Agency, 2022). Yushantarti & Hermawan (2019) explained that there are 15 group of surface thermal features identified in Southeast Sulawesi and the area of Southeast Sulawesi is consisted of the leg of southeast Sulawesi land and Buton island. Geologically is formed of Triassic metamorphic rock and tertiary sedimentary rock and the metamorphic rock as the basement (Hermawan, D., Sugianto, A., Yushantarti, A., Dahlan, Munandar, A., Widodo, S, 2011). The identifying of the active geothermal surface features at Puriala, Parora, Toreo, and Laonti Hot Springs was conducted in 2011 and these early data could be used for the geothermal society.

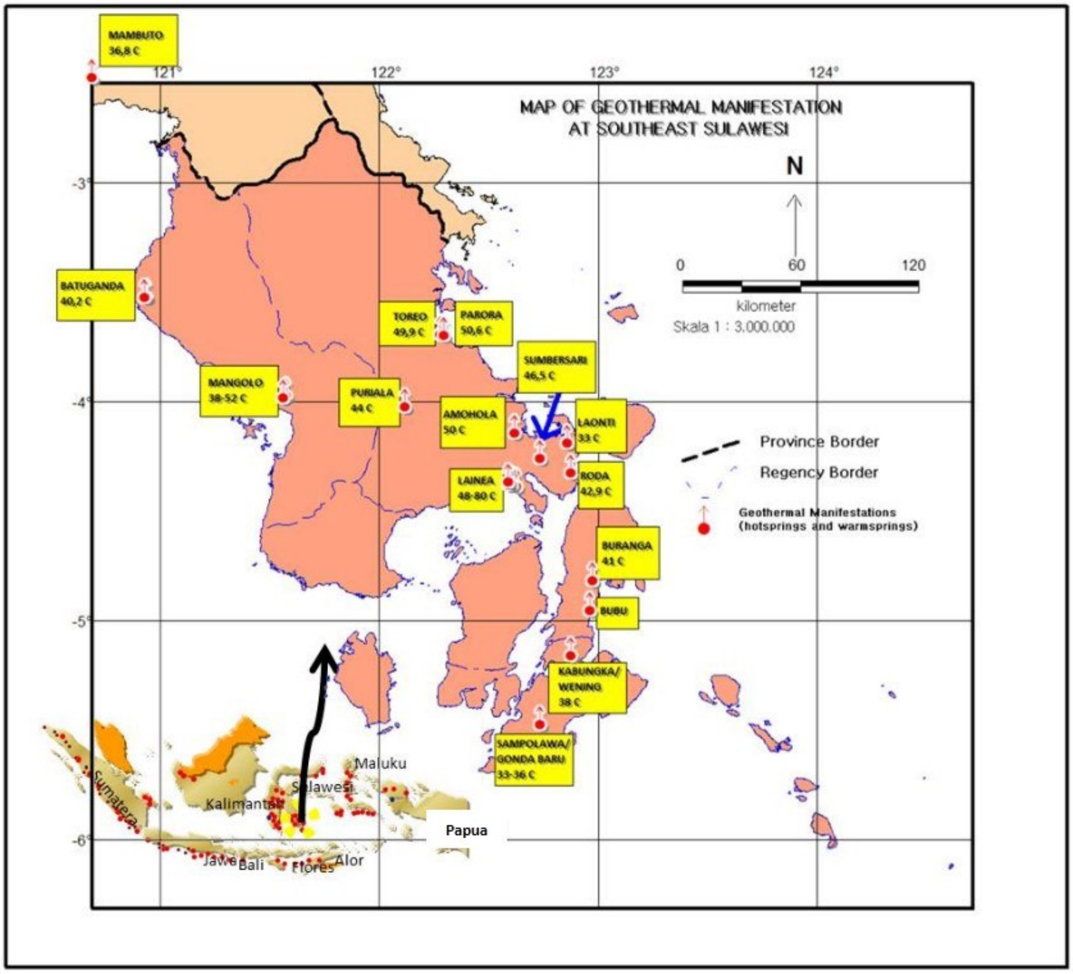

Figure 1: Map of Geothermal Manifestation at Southeast Sulawesi Map Location of South East Sulawesi, Indonesia (Yushantarti & Hermawan, 2019)

2. METHOD

The methods are using inventory of surface geothermal features, sampling the waters of them, classifying the type of manifestation, and interpreting for thermal water analysis for type of the water and consideration the temperature reservoir with water geothermometer. The characteristics were identified from the type of manifestations and the result of water analysis. Water samples were analyzed at laboratory of Center for Mineral, Coal, and Geothermal Resources. The cation-anion analysis was determined by volumetric method, UV-VIS spectrophotometry, Atomic Absorption Spectrophotometry, and ion chromatography. Analysis of stable isotopes (^{18}O and ^{2}H) used PICCARO L2130-i laser spectrometer. This interpretation also combines secondary data from several literatures.

3. A BRIEF OF REGIONAL GEOLOGY

Geologically, southeast Sulawesi is associated with non-volcanic environment with metamorphic and sedimentary rocks mostly. South East Sulawesi leg is having metamorphic rock as the basement (Hermawan, D., Sugianto, A., Yushantarti, A., Dahlan, Munandar, A., Widodo, S, 2011). The movement of Australia continent to the west which is collision with Asia continent at east side and Pacific continent resulting tectonic movement which is tend to northwest-southeast. This tectonic activity resulting new basins which is filled with sedimentary deposition especially tertiary sedimentary carbonate rocks. The next phase is exogenous process, resulted sedimentation product from metamorphic rock and sedimentary rock which is grouped into conglomerate rock of pre quaternary. Sedimentation activity is still formed until now formed surface deposition: river alluvium and coastal alluvium.

Structure geology patterns at land of south east Sulawesi is dominated with the same pattern with Palu-Koro structure which is northwest-southeast. This pattern because of the moving of Banggai Sula continent to the west. The big structures type of strike slip sinistral fault which is still correlated with Palu-Koro structure are Kolaka, Matano, and Lawanopo fault. They are locally Normal faults which have possibility formed of depression zone which could be formed the secondary permeability at depth. This permeability may form geothermal reservoir at south east Sulawesi arm. The thermal surface features are commonly controlled by this northwest-southeast structures.

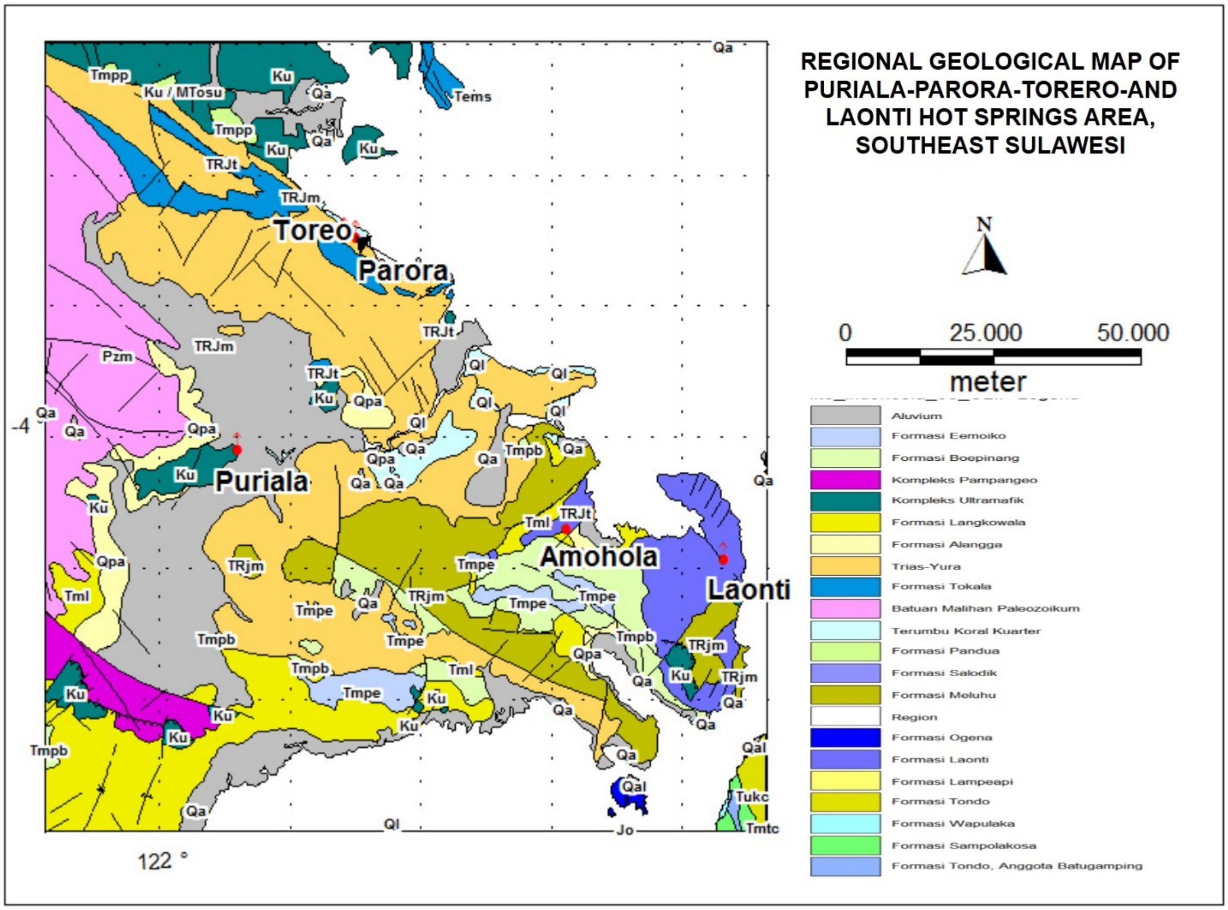

Figure 2: Regional Geology of South East Sulawesi Arm, compiled with several thermal geothermal surfaces area (modified from Rusmana et al, 1993)

4. SURFACE GEOTHERMAL FEATURES

Geothermal manifestations that are still active in the several areas in southeast sulawesi are only in the form as hot springs, the identifying of the active geothermal surface features at Puriala, Parora, Toreo, and Laonti Hot Springs was conducted in 2011.

4.1 Puriala hot springs

Puriala hot springs is located at coordinates 4°1'16.4" S and 122° 7' 19.8" E, altitude of 29 m above sea level, Sonai village, Puriala District, Konawe Regency, Southeast Sulawesi Province. It has temperature of 44°C at air temperature 29°C, electrical conductivity of 382 µS/cm, pH 8.72, flow rate of 5 l/s, area 50x30 m, clearly color, tasteless, air bubbles, and bicarbonate type. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi (Rusmana et al., 1993), it is in alluvium rocks, which consist of gravel, gluttony, sand, and clay, which are Holocene aged.

Figure 6: Puriala hot springs

4.2 Parora hot spring

Parora hot springs is located at 3°41'49" S and 122°37' 31.5" E, altitude of 11 m above sea level, Woi Makula village, Lasola District, North Konawe Regency, Southeast Sulawesi Province. It has temperature of 50.6 °C at air temperature of 27.5 °C, electrical conductivity of 2,650 µS/cm, pH 6.13, flow rate of 5 l/s, area of 50x50 m, clearly color, salty, air bubbles, H_2S odor, thick and terraced carbonate sinter, located near the sea, and chloride type. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi (Rusmana et al., 1993), it is in the Meluhu Formation which consists of Sandstone, quartzite, black shale, red shale, phylite, coconut shells, limestone and siltstone, which Trias-Jura age.

Figure 6: Parora hot springs

4.2 Torero hot spring

Toreo hot springs is located at 3° 41' 33.5" S and 122° 17' 5.8" E, altitude of 25 m above sea level, Toreo village, Losalo sub-district, North Konawe regency, Southeast Sulawesi province. It has temperature of 49.9°C at air temperature of 25.7°C, electrical conductivity of 1,256 µS/cm, pH of 7.42, flow rate of 5 l/s, area of 5 x 5 m, appeared at two points, clearly color, salty, air bubbles, coming out on alluvium rocks, and chloride type. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi (Rusmana et al., 1993), it is in the Meluhu Formation which consists of Sandstone, quartzite, black shale, red shale, filit, batusabak, limestone and siltstone, which aged Trias-Jura.

Figure 6: Torero hot springs

4.2 Laonti hot spring

Laonti hot springs is located at 4° 11'16.4"S and 122° 51' 51" E, altitude of 14 m above sea level, Pondirangga village, Laonti District, South Konawe District, Southeast Sulawesi Province. It has a temperature of 33° C at air temperature of 25.7 ° C, electrical conductivity of 942 µS/cm, pH 7.42, flow rate of 0.5 l/s, area 3X3 m, clearly color, tasteless, air bubbles, oxides iron deposition, bicarbonate type. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi (Rusmana et al., 1993), it is on the Laonti Formation rocks, which consist of Malih, marble and filite limestones, which are Trias-Jura.

Table 2: Table of Geothermal Surface Features Description at Puriala, Parora, Toreo, and Laonti Southeast Sulawesi

No.	Name	Coordinate		Elevasi (m)	Temperatur (°C)		pH	Conductivity (µS/cm)	Flow Rate (l/sec)	Brief Explanation
		Latitude	Longitude		Water (°C)	Ambient/ Air (°C)				
1.	PURIALA hot springs, Sonai village, Puriala district, Konawe Regency	4^0 1' 16,4" S	122^0 7' 19,8" E	29	44	29	8.72	382	5	area 50x30 m, clear, tasteless, air bubbles
2.	PARORA hot springs, Woi Makula village, Lasola district, North Konawe Regency	3^0 41' 49," S	122^0 18' 8,6" E	11	50.6	27.5	6.82	2,650	5	Size about 50x50m, clear, salty, bubble, H_2S odour, sinter carbonate thick and terrace, near the sea, based on Regional Geology map of Lasusua-Kendari, Sulawesi (E.Rusmana, et al, 1993), it is manifested at Meluhu Formation
3.	TOREO hot springs, Toreo village, Losalo District, North Konawe Regency	3^0 41' 33,5" S	122^0 17' 5,8" E	25	49.9	25.7	7.42	1,256	5	Size of 5m x 5 m, there are two hotsprings in this area, clear, salty, buble, manifested at alluvial which is consisted of sandstone, etc Trias-Yura age
4.	LAONTI hot springs Pondirangga village, Laonti district, South Konawe regency	4^0 11' 16,4" S	122^0 51' 51" E	14	33	25.7	7.42	942	0,5	dimension of 3X3 m, clearly color, tasteless, air bubbles, oxides iron deposition. Based on the regional geological map of Lembar Lasusua-Kendari, Sulawesi (E. Rusmana, et al., 1993), it is on the Laonti Formation rocks, which consist of Malih, marble and filite limestones, which are Trias-Jura

5. RESULT AND DISCUSSION

Geothermal manifestations that are still active in the several areas in southeast sulawesi are only in the form as hot springs, the identifying of the active geothermal surface features at Puriala, Parora, Toreo, and Laonti Hot Springs was conducted in 2011. The result of water analysis is in the table 2.

Table 2: Laboratory Result of Water Analysis at Puriala, Parora, Toreo, and Laonti Hot Springs

No	Thermal Features/ Name	pH	Temperature	Conductivity	SiO_2	B	Al^{3+}	Fe^{3+}	Ca^{2+}	Mg^{2+}	Na^+	K^+	Li^+	As^{3+}	NH_4^+	F^-	Cl^-	SO_4^{2-}	HCO3	CO_3^*	ion balance
			(^oC)	µS/cm	mg/l																
1	Puriala	8.72	44.0	382	1.36	0.00	0.04	0.02	0.84	10.99	47.40	3.07	0.00	0.00	0.73	0.00	34.79	0.00	97.01	15.50	0.16
2	Parora	6.82	50.6	2,650	23.29	2.36	0.04	0.11	923.65	388.50	5469.00	199.50	0.06	0.50	0.00	4.70	9028.01	1399.10	760.44	0.00	3.84
3	Toreo	7.42	49.9	1,256	22.83	2.03	0.00	0.04	891.00	385.20	5283.00	192.00	0.06	0.00	0.00	3.92	8836.66	1335.73	704.02	0.00	3.53
4	Laonti	7.42	33.0	942	33.82	0.41	0.12	0.15	72.12	10.66	79.20	4.54	0.05	0.00	0.73	0.70	150.03	2.00	240.25	0.00	-1.05

5.1 Classification of the Fluids

During the geothermal fluid rises from the reservoir to the surface and appears as hot springs or warm springs, the fluids can undergo a cooling process as a result heat conduction process to surrounding rock, boilling process, mixing process with cold water, or the result of a combination of the three processes. Substances dissolved in the fluid can be a function as tracer components (tracers) and geo-indicators (Giggenbach, 1991). Giggenbach (1991) divides solutes into two categories, namely: 1) tracers, namely solutes that are chemically inert/non-reactive where when these components are in a fluid, they do not change and can be traced back to the origin. them (eg Cl, B, Li, and N_2); 2) geoindicator, which is a solute component that is reactive and reflects a specific equilibrium in a particular environment (eg Na, K, Mg, Ca, and SiO_2, which play a role in temperature-dependent interactions of the geothermal system with the source rock). The concentrations of these components are used as tracers and geoindicators by plotting on the Giggenbach triangle diagram (1991). Using the concentration of these components as tracer and geoindicator can be done with how to plot the concentration of its components in the Giggenbach triangle diagram (1991).

The hot springs, based on the results of hot springs analysis and plotted in the relative of Cl-SO_4-HCO_3 triangle diagram (figure 7), generally characterizes the study area of Puriala, Parora, Toreo, and Laonti, Southeast Sulawesi showing a bicarbonate fluid type (Puriala and Laonti), the presence of bicarbonate is thought to be associated with the rise of geothermal fluid containing gases, especially CO_2, then Condensing in shallow aquifers, bicarbonate water is formed below the groundwater zone where the water is initially acidic but then loses CO_2 in the fluid released to the surface which will increase the pH value to neutral to slightly alkaline. There are 2 manifestations of hot springs with the chloride type, namely the Toreo and Parora, this indicates that these waters may be related to deep water. The absence of sulfate-type hot springs manifestations in the study area is possible because of the insignificance of gases such as H_2S and CO_2 (which are often called magmatic gases in volcanic areas) in the geothermal system in the non-volcanic area of Southeast Sulawesi.

Based on the Na-K-Mg triangle diagram (figure 8), the hot springs in the study area are located in immature water (Puriala and Laonti), this is an indication that the hot springs that appears on the surface is predominantly mixed with surface water (meteoric water), after previously interacting with hot rocks. However, there are 2 hot springs that are in the partial equilibrium zone (Parora and Toreo) which when drawn to Na-K and K-Mg are in a straight line and fall at almost the same point at moderate temperatures (around 160 ^oC), this indicates that the hot springs has been mixed with surface water (meteoric water), after previously undergoing an interaction process with hot rocks.

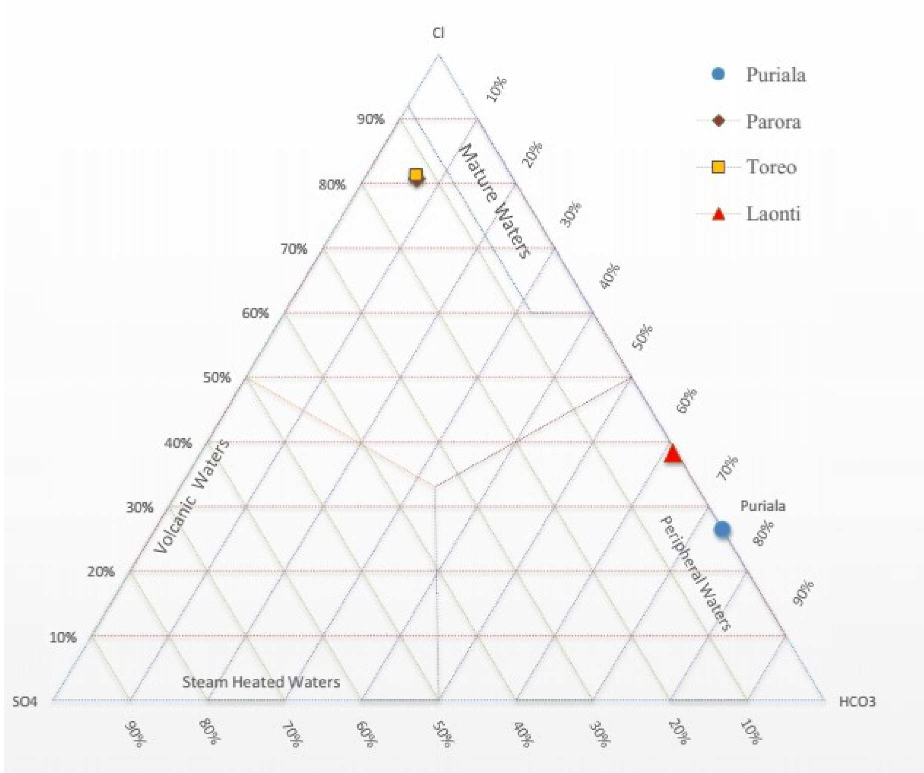

Figure 7: Cl-SO_4-HCO_3 Ternary Diagram

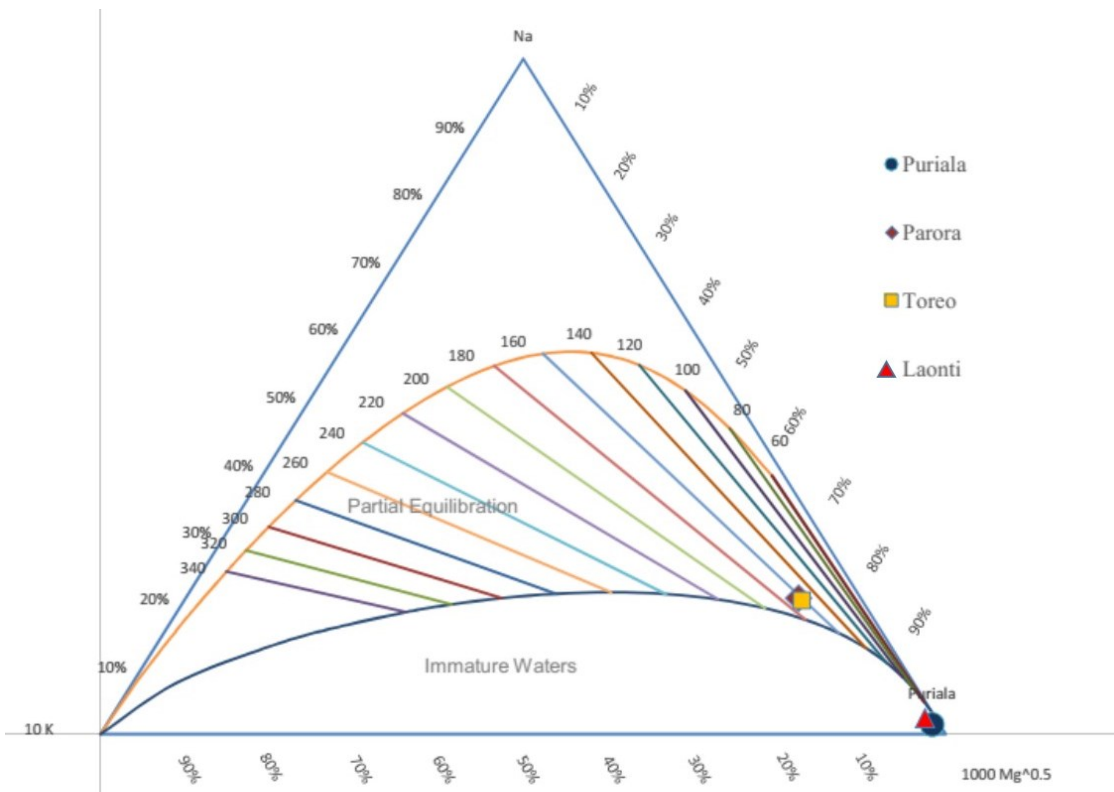

Figure 8: Na-K-Mg Ternary Diagram

5.2 Isotope

In general, geothermal fluids will undergo the process of adding the oxygen-18 isotope from water origin, in this case is meteoric water (Craig, 1963 in Nicholson, 1993). The data is plotted into the diagram relationship between oxygen-18 isotope ($\delta^{18}O$) versus deuterium ($\delta^{2}H$) and compared with the line of Indonesia's local meteoric water (BAFI-BATAN, 1984 in Sidauruk et al, 2000). It shows that Puriala, Parora, Toreo, and Laonti Hot Springs are relative close from the meteoric water line (not significant of adding the oxygen-18 isotope from water origin) and could be concluded that there could be a mixing process and the intensity of water and rock interactions in the reservoir is not significant. While deuterium isotope changes will not occur because rocks generally have a concentration low hydrogen.

Table 3: Laboratory Result of Isotope Water Analysis at Puriala, Parora, Toreo, and Laonti Hot Springs

No.	Sample	$\delta^{18}O$ (°/oo)	$\delta^{2}H$ (°/oo)
1	Puriala	-5,96	-35,0
2	Toreo	-3,92	-24,4
3	Parora	-3,99	-24,1
4	Laonti	-5,93	-34,0
5	Sea water of kendari	0,07	0,4

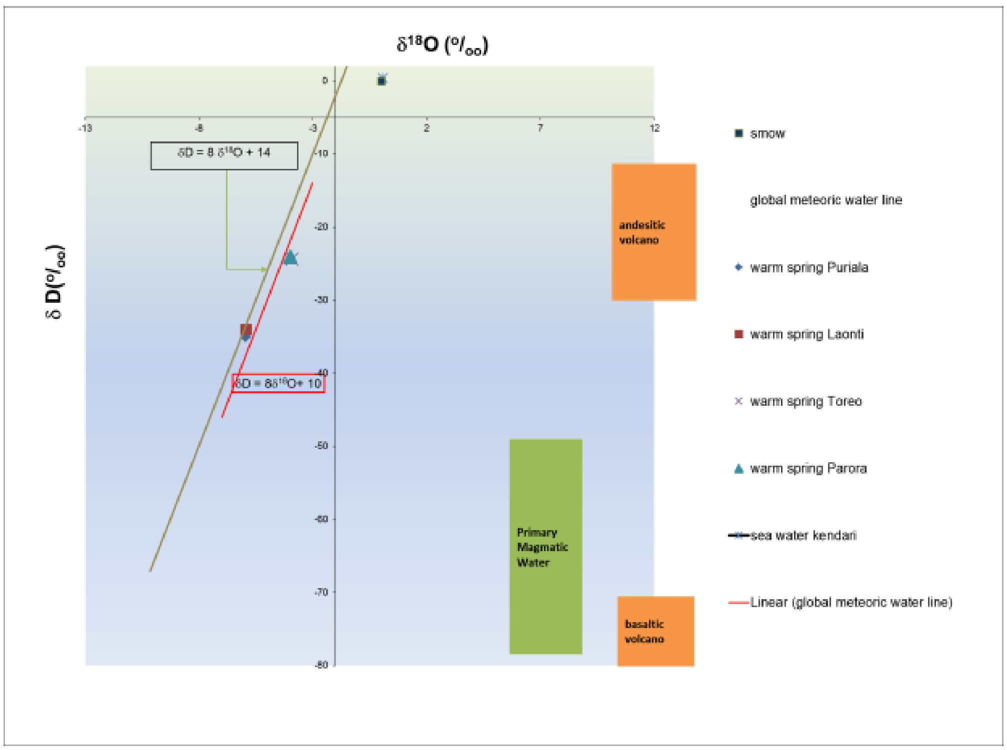

Figure 9: Water Isotopes Diagram of Puriala, Parora, Toreo, and Laonti Hot Springs

5.3 Geothermometry

Estimating reservoir temperature is the main objective in the chemical characteristics of hotsprings. Some of the approaches used to determine a geothermometer can be through the concentration of solutes in water, isotopes, or with a gas geothermometer. The solute geothermometer is based on fluid-mineral equilibrium that depends on temperature with several assumptions (Ellis, 1979; Fournier, 1977; Fournier et al, 1974; Truesdell, 1976; and White, 1970, in Nicholson, 1993). In other words, the reaction must be fast enough to maintain the conditions equilibrium that has occurred in the reservoir.

All manifestation in the Puriala, Parora, Toreo, and Laonti tend to have a pH that tends to be neutral to alkaline so that it could be considered in geothermometer calculations, Reservoir temperature calculations related to the these hot springs are listed in Table 3. In the Parora and Toreo hotsprings, the reservoir temperature calculation uses the considering the following: the type of the Parora and Toreo is chloride type (could be indicated the fluid from reservoir), in a partial zone equilibrium, indicating these hot springs mixed with cold water and still can be a consideration for calculating the reservoir temperature. The calculation results for reservoir temperatures are around 143-163 ^{o}C with Na-K calculations (Fournier and Giggenbach).

In the Puriala and Laonti hotsprings, the reservoir temperature calculation uses the results of the analysis of the considering the following: the type of hot springs is in the chloride-bicarbonate zone, immature waters in the Mg corner, indicating the Puriala and Laonti are not a fluid that reflects the reservoir fluid from the reservoir geothermal system or a lot of mixing with surface water, and HCO_3 waters is doubtful to be used as geothermometer (Nicholson, 1993), so the uncertainty of the calculation should be only considered that the result of the temperature reservoir only happen at the shallow level of the system.and later the calculation results of the reservoir temperature only reflect the temperature at very shallow depths. The calculation results for the reservoir temperature are around 200 ^{o}C Na-K (Giggenbach, 1991). However, the temperature of Na-K cannot be used because it is in the Mg zone and does not represent the fluid originating from the reservoir. the chloride concentration tends to very low, it could indicate that the warm water in the Puriala and Laonti is a geothermal fluid that has been diluted with quite a lot of surface water, and the results of the reservoir temperature calculation only reflect the temperature at very shallow depths.

Table 4: Consideration of temperature Reservoir in Puriala, Parora, Toreo, and Laonti Hot Springs (using Tom Powell spreadsheet)

Name	Quartz cond	Quartz adiabatic	Na-K-Ca	Na/K Fournier	Na/K Truesdell	Na/K (Giggenbach)	K/Mg (Giggenbach)
Puriala	-32	-2	127	182	145	200	41
Parora	70	74	155	143	100	163	96
Toreo	69	73	155	143	99	163	95
Laonti	85	87	46	174	134	191	50

6. CONCLUSION

Surface geothermal appearance in the southeast Sulawesi is identified at Puriala, Parora, Toreo, and Laonti hotsprings, with a manifestation temperature ranging from 33-50^{o}C, appears in mostly limestone lithology. In the area of the Puriala, Parora, Toreo, and Laonti non volcanic area, the geothermal features on the surface are identified in the form of hot springs, namely in Puriala, Parora, Toreo, and Laonti (manifestation temperatures ranging from 33-50^{o}C). The types of Parora and Toreo is in the zone of the chloride, are located in the zone of partial equilibrium, isotope values reflection is not very significant of water and rocks interaction. The types of Puriala and Laonti is in the zone of the bicarbonate zone, are located in the zone of Mg corner, isotope values reflection is not very significant of water and rocks interaction. The reservoir temperature is clearly only from Parora and Toreo (143-163 ^{o}C). To find out the geothermal resources in this area, it is necessary to do other methods such as geology, geochemistry, and geophysics in more detail.

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