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Recharge Calculation of Lahendong Geothermal Field in North Sulawesi-Indonesia

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ABSTRACT

The research site is located 30 km south of Manado city or west of Tondano lake at an altitude of ± 850 meters above the sea level.

The geology of the research site is represented within a geological map by Ganda and Sunaryo (1982). Based on the current geological map, it may be pointed out that the research site is defined as high terrains situated in a small Pangolombian caldera which has collapsed in its center area resulting in the formation of a volcanic group called Tampusu-Linau. The stratigraphy of the area is comprised of young volcanic sediments, which in an older to younger sequence are: Lengkoan, Pangolombian, Kasuratan, Kasuan and Kolovium Formation sediments.

The conceptual model of Lahendong geothermal field consists of two reservoirs, that is a shallow reservoir having a depth of 500 – 700 meters and a deep reservoir having a depth above 1500 meters. From such a conceptual model can be observed that the recharge factor holds an important role as a mass supplier to the reservoir.

The objective of the research is to determine the amount of recharge into the reservoir by means of an overlay of geologic map, fracture density map, and fluid dynamic map. From the overlay of the various maps, it enables the determination of the cross sectional boundary of the recharge area to obtain the area of research. The amount of recharge from rainfall which infiltrates into the recharge area can be determine by the infiltration amount of rainfall into the area, rainfall data and infiltration coefficient.

Based on calculations, it is determined that the amount of recharge in the Lahendong Geothermal Field is 10.3 x 10^6 m^3/year.

1. INTRODUCTION

Lahendong geothermal field is located about 30 km to the south of Manado city, district of Tomohon, Minahasa, North Sulawesi province (Figure 1). Generally, the field is located between 600 – 900 m above the sea level. The main objective of this study is to predict the amount of natural “recharge” within the given area by means of an overlay of the geological map, fracture density map, fluid dynamics map and climatologic data of the investigated area. There have been seven wells drilled by Pertamina (Indonesian Oil and Gas Company) that is LHD-1 until LHD-7. Around LHD-4 to LHD-16 is being developed a cluster drilling. This program is run to develop a power generator with a capacity of 20 MWe owned by PLN (Indonesian Electric Energy Company). In order to maintain a mass balance within the reservoir, it is necessary to conduct a “recharge” study in the current geothermal field.

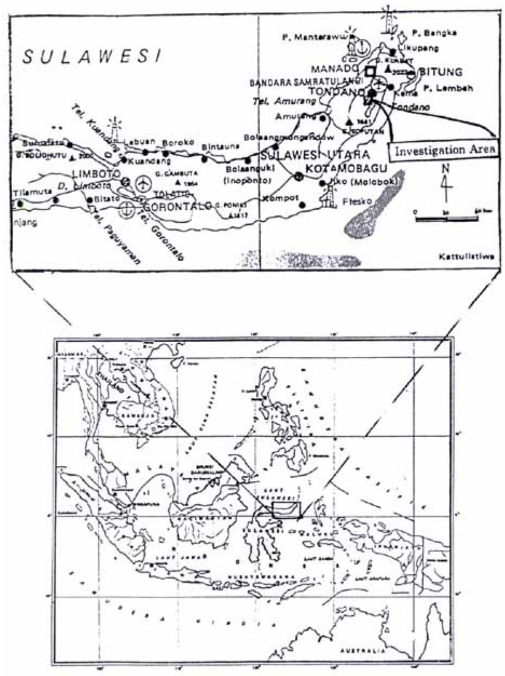

Figure 1: Location of Lahendong Field Map

2. GEOLOGICAL SETTING

The regional geology of the Lahendong Geothermal Field is shown in Figure 2. It shows clearly that the structure is located within a big caldera, with wide elongation of 3 km encircling the Linau crater.

There are six tectonic components in the Lahendong Geothermal Field :

- Pangolombian structure, edge side of Caldera.
- NE-SW fault, correlates with the Tondano volcanic depression boundary limit.
- E-W fault, indicated as lateral fault and as pivot of secondary magmatic intrusion.
- NW-SE fault, tensional type, formed big Lahendong graben.
- N-S fault, young tectonic activity.
- Circular structure, interpreted as deep plutonic intrusion.

The geothermal field is mainly covered by pre-caldera formation (before the Pangolombian formation collapse) and post-caldera formation. Post-caldera formation is divided into three sub-groups.

- Tampusu sub-group, in the eastern part of geothermal field is indicated as a center of young volcanics.
- Kasuratan sub-group, between Linau lake and Kasuratan village, is indicated as a central volcanic.

They are correlated with the viscous extrusion of magmatic activity.
- Linau sub-group, located in central geothermal field, consists of volcanic breccias and pyroclastic which resulted from a recent phreatic eruption (Linau lake).

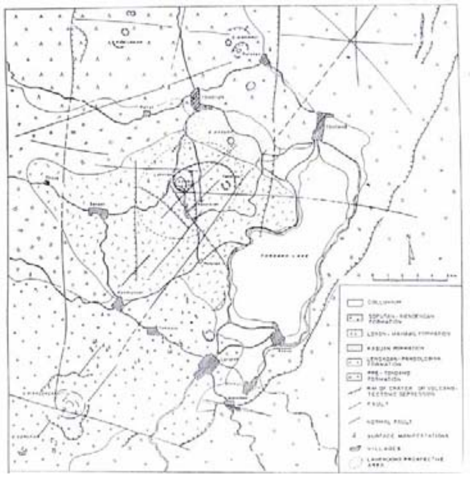

Figure 2: Geological Map of Tondano Area

In general, the stratigraphy of older-younger sequence within the studied area is:

- Pre Tondano, andesite, megaloclastics with sediment intercolation.
- Tondano unit, tuff and ignimbrite.
- Pre Pangolombian formation (Post Tondano Unit), basaltic, andesitic.
- Post Pangolombian formation, tuff and breccia.

3. FRACTURE DENSITY

Fracture density analysis of Lahendong geothermal field is conducted based on linearment analysis of the geologic structure from aerial photograph (Figure 3).

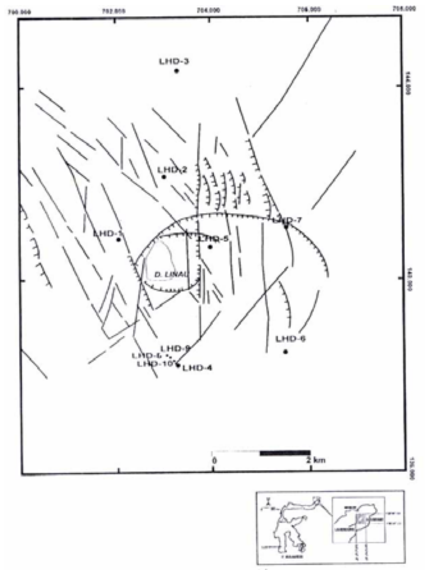

Figure 3: Geological Structure Linearment Analysis Map Based on Aerial Photograph of Lahendong Geothermal Field

From measurement and calculation of fracture/fault on a grid (1 km^2) a density fracture/grid is obtained with a dimension of (m/km^2). Based on numbers on each grid, then a fracture density contour map is produced. This map is produced with an assumption that through this fracture density rain water infiltrates into the reservoir as recharge water. The fracture density map obtained is presented in Figure 4.

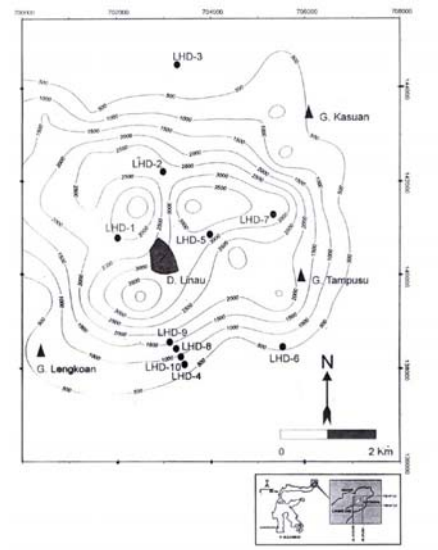

Figure 4: Fracture Density Map of LahendongGeothermal Field (m/km^2)

4. FLUID DYNAMIC

A fluid dynamic map of the Lahendong geothermal field is derived by defining the amount of departure pressure of each well.

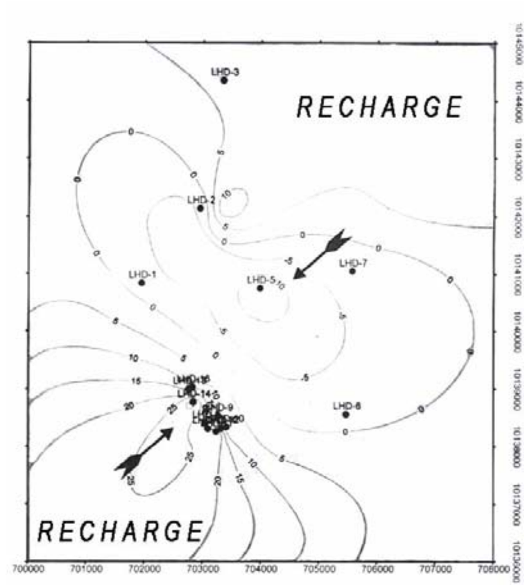

Figure 5: Fluid Dynamic Map Based on Pressure Departure Concept of Lahendong Geothermal Field

5. RECHARGE AREA

The definition of the recharge area is carried out by means of an overlay of the geologic map, the fracture density map, and the fluid dynamic map. The overlay of the various maps produces a recharge area boundary taken from the intersection of zero contour (fluid dynamic map) with the 500 contour (fracture density map) and the Pangolombian and Kasuan formation which also forms the Lahendong reservoir. From the intersection, it is then possible to calculate the area of recharge which gives a total of 20 km^2 (Figure 6).

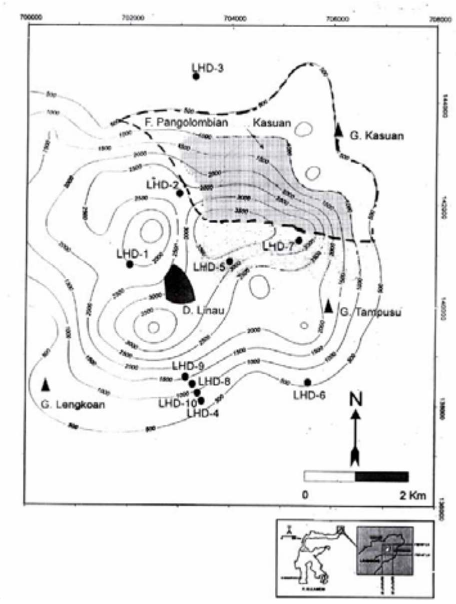

Figure 6: Recharge Area Map of Lahendong Geothermal Field (m/km^2)

6. CLIMATOLOGIC DATA

The climatologic data required is the annual rainfall data from observation posts located within the Lahendong geothermal field. There are three rainfall observation posts currently providing data within the calculation, that is: the Kaskas station = 1948 mm/year situated in the eastern part of the field, the Kawangkoan station = 2479 mm/year situated in the southeast of the field, and the Noongan station = 1755 mm/year situated in the south of the field. From the calculation of the three rainfall observation posts a rainfall average of 2060 mm/year is obtained.

7. RECHARGE POTENTIAL ESTIMATE

In order to predict an annual recharge potential of the Lahendong geothermal field, the following equation is applied:

$$R = A \, x \, P_A \, x \, c$$

R = mean annual groundwater recharge (m^3/year)
A = surface area of recharge zone (km^2)
P_A = mean annual precipitation recharge zone (mm/year)
c = recharge coefficient for the area (%)

The recharge coefficient value normally is determined by conducting an analogy to the research of McDonald (1989) on young volcanic sediments which have similar formations to those of the Lahendong geothermal field. They classify the young volcanic sediments into three zones :

- Top slope (slope = 50%), recharge coefficient = 25% - 50%
- Middle slope (slope = 20% - 30%), recharge coefficient = 25%
- Lower slope and foothills elevation < 800 m (slope = 5% - 10%), recharge coefficient = 20% - 25%.

The research area is located at the middle – lower slope zone which is formed mainly of andesite, basalt and some pyroclastic in which all has developed fractures. In the calculation, the applied recharge coefficient is 25%, therefore the recharge potential of the area of research is calculated:

$$R = A \, x \, P_A \, x \, c$$

A =20 km^2
P_A =2060 mm/year
≈65.3 ltr/sec/km^2 ≈2059301 m^3/year/km^2
c =25%

$$R = 20 km^2 \, x \, 2059301 m^3 / year / km^2 \, x \, 0.25$$
$$= 10.3 x 10^6 \, m^3 / year$$

8. DISCUSSION AND CONCLUSIONS

- The rocks of the Pangolombian and Kasuan formation consist of andesitic lava, basaltic and some pyroclastics which have developed fractures and act as a reservoir in the Lahendong geothermal field.

- Based on geologic structure map analysis of aerial photography, a fracture density map is constructed based on values between 500 – 3500 m/km^2. From the dynamic fluid map, it is shown a fluid dynamic from positive 5 to negative 5 (high to low potential).

- From the overlay of the geologic map, fracture density map and fluid dynamic map, a recharge area of 20 km^2 is obtained. Mean annual rainfall obtained by rainfall observation posts around the Lahendong geothermal field reach an amount of 2060 mm/year.

- Based on the calculation, the recharge potential for an area of 20 km^2 is 10.3 x 10^6 m^3/year.

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