Evaluation of Earth's Magnetic Field Anomalies over Sembalun Geothermal Prospect

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***Abstract*— This study uses geomagnetic data that has been taken around the Sembalun geothermal prospect, which was carried out separately in Sembalun Lawang and Sembalun Timba Gading Villages in 2019. Integration of the two data was carried out to obtain a combined map using Oasis Montaj Software, which can interpolate data and display the anomaly values between the two regions. Qualitative interpretation is carried out by analyzing the comparison of anomalous patterns obtained by reducing daily variations using two different data, i.e. data from the Nurul Bayan Station (NRB) in North Lombok and the Kakadu Observatory (KDU) in Northern Australia. The differences in anomalous patterns are shown, where the peak of positive anomaly is shifted about 250 meters. In addition, there are differences in the range of anomaly values, resulting from processing with NRB and KDU data. In this case, the reductions using data from NRB which is located closer to Sembalun is considered to give more valid results than using KDU data.**

Keywords—geomagnetic, geothermal, energy, interpretation, anomaly, Sembalun

I. Introduction

Geothermal energy is one of the sources of energy that is produced and stored in the Earth. The process of geothermal formation is triggered by tectonic activity in the bowels of the earth. The existence of geothermal resources in Indonesia is associated with volcanic activity as a heat source associated with the movement of these tectonic plates. The magnitude of volcanic activity creates a large geothermal potential [1]. Along the path of volcanoes, geothermal energy reserves are very large and one of the alternative energy sources that are environmentally sound [2].

This research has been carried out in Sembalun area which shows the existence of geothermal potential. One area that has geothermal potential is located in the south-western part of Sembalun. The existence of geothermal potential in this area is closely related to volcanic rocks, which are the most possible structure for a geothermal reservoir system [3].

Based on research [4] Sembalun is an area that shows indications of geothermal potential through manifestations in the form of Sebau hot springs, Orok springs, and Sembalun Lawang altered rocks. The research was conducted through geological, geochemical and geophysical investigations.

The geophysical method used in this research is the geomagnetic method. The geomagnetic method is the most appropriate method for interpreting the subsurface layer based on the measured magnetic field intensity. According to [5], the gomagnetic method is the recommended standard method and reference in geothermal exploration in international standards. The result of this method is an anomaly map that is used to determine variations in the magnetic field so that it can be associated with the geological structure of the existence of geothermal potential. In addition, the measurement accuracy of the geomagnetic method is relatively high and the field operations are relatively simple [6].

Previous research [7] identified that Lombok Island, especially in the Sembalun area, is a zone characterized by magnetic anomalies with very large intensity values. To find out the differences in magnetic anomalies for utilization of geothermal potential in Sembalun area, a systematic research is carried out that aims to identify the subsurface layer. In assisting the interpretation of geothermal potential, this study uses data from previous researches [8], [9]. Locations of previous studies are shown in Fig. 1.

Due to the limited amount of data available, the two data sets were combined to obtain a more comprehensive map. By using interpolation technique, it is expected that the two datasets can display anomaly values spreading between the two separated areas, with an accuracy range within a radius of 300 m. Based on [5], to distinguish between the anomaly value and the magnetic area in an area, the size of the survey area must exceed the expected size of the anomaly.

In addition, to identify differences in geomagnetic anomalies, one of the interesting objects to be investigated is comparing the results of data processing using two references (i.e. using data obtained from two different geomagnetic stations). This approach is useful to obtain a more accurate distribution of magnetic anomalies. In this research, we used data from Nurul Bayan Station (NRB) in North Lombok and Kakadu Observatory (KDU) in Northern Australia.

II. Methods

A. Magnetic Field Data Filtration

Data obtained from [8] and [9] researches in 2019 have been tested for data normality using the One Sample Kolmogorov Smirnov Test on SPSS Software. The basis for decision making is the significance value (Sig). If Sig $\geq 0.05^{o}$, then the total magnetic field data is normally distributed; whereas if Sig < 0.05°, then the total magnetic field data is not normally distributed.

B. Geomagnetic Data Correction

1. Daily corrections is corrections made due to deviations in the value of the Earth's magnetic field due to time differences and the effects of radiation from the sun in one day. In making daily corrections, it is necessary to pay attention to adjusting the time in the measurement data on the server to the time at the measurement point.
2. IGRF correction is to eliminate variations in the Earth's internal magnetic field so that an anomalous magnetic field is obtained.

C. Magnetic Anomaly Calculation

Magnetic data measured at a location is a resultant of Earth's internal magnetic fields (IGRF), the lithospheric field (produced by magnetized crustal rocks), the influence of external fields (known as daily variation), and the influence of slow change in the core magnetic fields (known as secular variation) [10].

The daily corrected value (F_u) is calculated as the difference between the measured magnetic field value [$F_u(t)$] and the magnetic field value measured at each station [$F_s(t)$] and the average baseline value for each station ($\overline{F}_s$), as formulated in (1).

$$F_u = F_u(t) - \left[F_s(t) - \overline{F}_s\right] \quad (1)$$

The average daily corrected value can be calculated by sum up all daily corrected values (obtained during measurement) and divided by the number of data, as formulated in (2).

$$\overline{F}_u = \frac{\sum_{i=1}^{n} F_u}{n} \quad (2)$$

Magnetic anomaly can be calculated by subtracting the average daily corrected value with IGRF value, as formulated in (3). The IGRF value, can be accessed at www.ngdc.noaa.gov.

$$Mag.Anomaly = \overline{F}_u - F_{IGRF} \quad (3)$$

III. Data And Analysis

A. Normalization of Data with SPSS Software

Table I shows the normalized result of the Kolmogorov Smirnov Test, which shows that point 13 magnetic field data in the Sembalun Lawang area is not normally distributed because the significance value of the total magnetic field intensity measurement data is 0.016°. To overcome the data that is not normally distributed, it can be done by eliminating outliers. Outliers are data whose nature can confuse statistical tests. Outlier data can be seen in the boxplot section. The output boxplot data can be seen in Fig. 2.

Fig. 2 indicate the data indicated as outliers. If the data is above, the box indicates extremely high data and if the data is below, the box indicates extremely low data. From the output above, it can be seen that subject numbers 1, 2, and 47 are indicated as outliers. We then deleted the data outliers, and the data is again tested for normality with the One Sample Kolomogorov Smirnov Test. The results of the new Kolmogorov Smirnov Test can be seen in Table II.

Table II shows the normality results of the Kolmogorov Smirnov Test after the outliers are removed. A significance value of 0.054° is obtained, therefore it is said that the data has been normally distributed. The total field data is measured at point 13 Sembalun Lawang; before removing the outliers, had a total of 47 data points with a significance value of 0.016°, while after removing the outliers, the number of data points is 44 with a significance value of 0.054°, and categorized as good quality data.

B. Correction Value

Following the normality testing of all total magnetic field data, the next process was carried out using Microsoft Excel Software, namely the daily variation correction process. The corrected values are obtained by using data from the NRB Station with a baseline value of (Fs) = 44840.28 nT and the KDU Observatory with a baseline value of (Fs) = 46196 nT.

Daily corrections are made at each time of data collection (per minute) at each measurement point. This daily correction aims to eliminate the influence of external magnetic field. Daily variation corrections show a difference between results obtained using NRB Station and KDU Observatory data. The measured value at NRB Station is lower than that at the KDU Observatory, due to the difference in local time between both locations. For example, when measurements were made in the field, the local time in Sembalun and NRB was at 08:24 a.m., while the local time in Kakadu was at 09:54 a.m. (1 hours and 30 minutes earlier). The difference in the local times causes a difference in the measured intensity of magnetic field at two locations, mostly due to the difference in the intensity of Sun irradiance at the two locations.

TABLE I. OUTPUT OF KOLMOGOROF SMIRNOV TEST NORMALITY BEFORE OUTLIERS REMOVAL

One-Sample Kolmogotov-Smirnov Test		
N		47
Normal Parameters[a.b]	Mean	45657.1513
	Std. Deviation	1.74358
Most Extreme Differences	Absolute	.144
	Positive	.144
	Negative	-.112
Test Statistic		.144
Asymp. Sig. (2-tailed)		.016°

TABLE II. OUTPUT OF KOLMOGOROF SMIRNOV TEST NORMALITY AFTER OUTLIERS REMOVAL

One-Sample Kolmogotov-Smirnov Test		
		V2
N		44
Normal Parameters[a.b]	Mean	45657.0823
	Std. Deviation	1.38460
Most Extreme Differences	Absolute	.131
	Positive	.131
	Negative	-.107
Test Statistic		.131
Asymp. Sig. (2-tailed)		.054°

The corrected value obtained using (1) at point 9 in Sembalun Lawang area at 09.04 (UTC) is 45165.9 nT with correction data from KDU, and 45162.49 nT with correction data from NRB. The average corrected value obtained using (2) at point 9 in Sembalun Lawang area is 45165.94 nT with KDU data, and 45161.6 nT with NRB data.

C. Magnetic Total Anomaly

The IGRF value at point 9 in Sembalun Lawang area is 44790.5 nT, as can be seen in Table III. From (3), it is found that the total magnetic anomaly at point 9 at 23:20 (UTC) with correction data from the KDU Observatory is 375,443 nT, while the total magnetic anomaly with correction data for NRB Station is 371,095 nT.

Magnetic field anomalies are often also referred to as local magnetic fields (crustal fields). Magnetic fields are generated by rocks containing magnetic minerals such as magnetite and titanomagnetite in the Earth's crust. Magnetic field anomalies are caused by remanent magnetic fields and induced magnetic fields. The remanent magnetic field has a major role in the magnetization of rocks, namely the magnitude and direction of magnetic fields associated with previous magnetic events. The anomalies obtained from this survey are the result of a combination of remanent and induced magnetic fields. The anomaly increases when the direction of the remanent magnetic field is the same as the direction of the induced magnetic field [11].

TABLE III. INTERNATIONAL GEOMAGNETIC REFERENCE FIELDS (IGRF) 2020 FOR SEMBALUN LAWANG

Magnetic Field							
Modul Used	IGRF2020						
Latitude	008.3623758° S						
Longitude	116.5429192° E						
Elevation	1149.0 m GPS						
Date	***Declination (+E | -W)***	***Inclination (+D | -U)***	***Horizontal Intensity***	***North Comp (+N | -S)***	***East Comp (+E | -W)***	***Vertical Comp (+D | -U)***	***Total Field***
7/2/2019	1.0200°	32.6649°	37,706.6 nT	37,700.6 nT	671.2 nT	24,174.5 nT	44,790.5 Nt
Change/Year	0.0604°/yr	0.0945°/yr	33.0 nT/yr	33.7 nT/yr	39.2 nT/yr	66.6 nT/yr	8.2 nT/yr

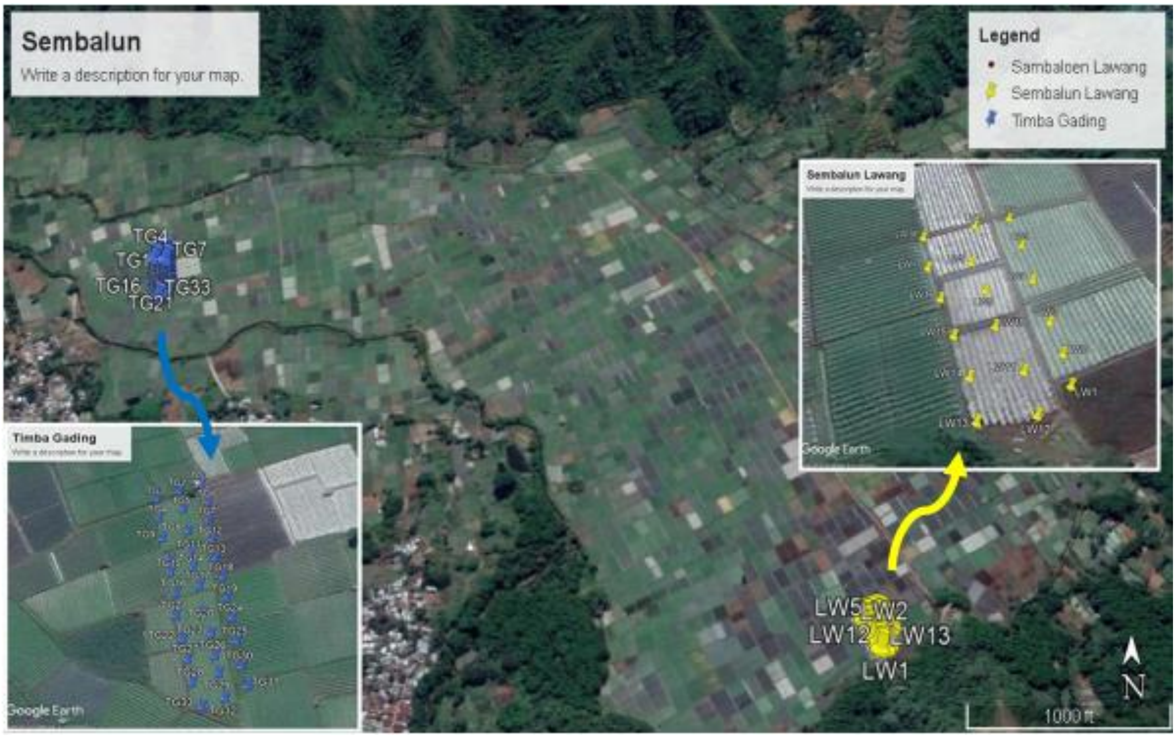

Fig. 1. Location of this study, which uses data from previous researches in 2019 [8], [9]. The data collections were carried out in Sembalun Lawang with an area of 1200 m^2 and Sembalun Timba Gading with an area of 2000 m^2, Sembalun District, East Lombok Regency.

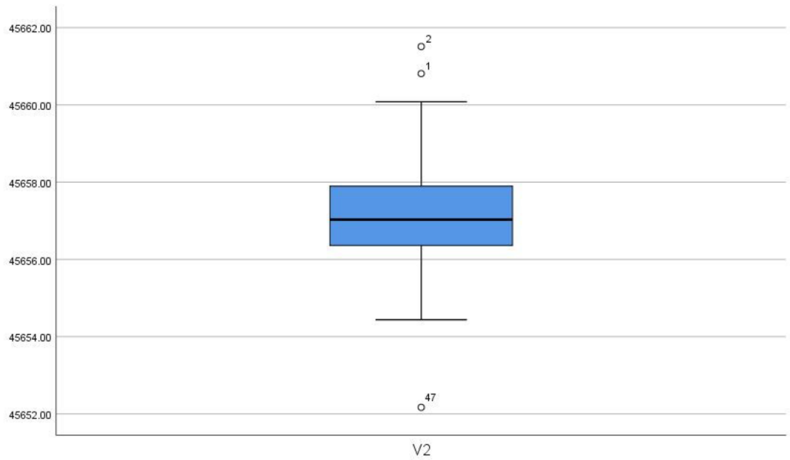

Fig. 2. The data indicated as outliers (subject numbers 1, 2, and 47).

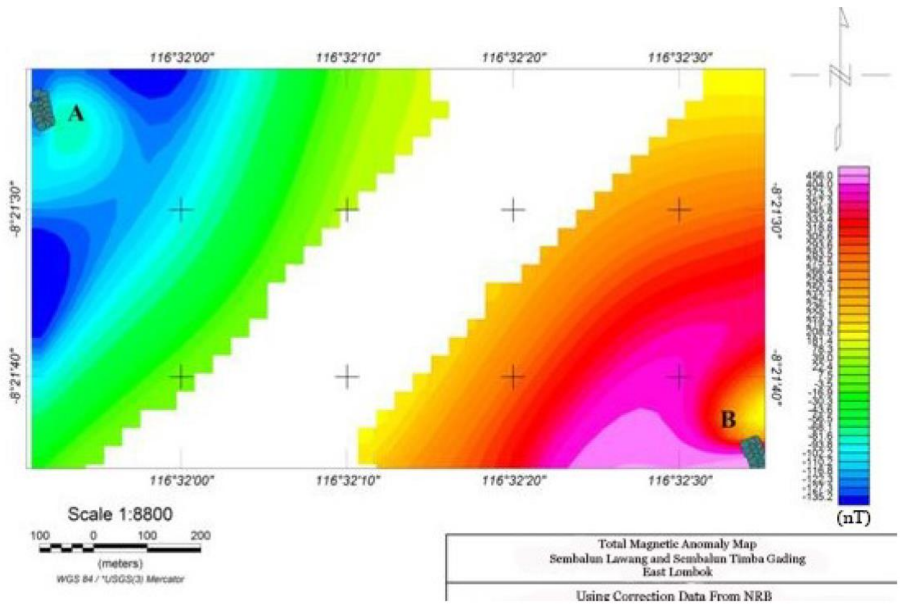

Fig. 3. Total Magnetic Anomaly Map for Sembalun Timba Gading (A) and Sembalun Lawang (B) using correction data from NRB Station.

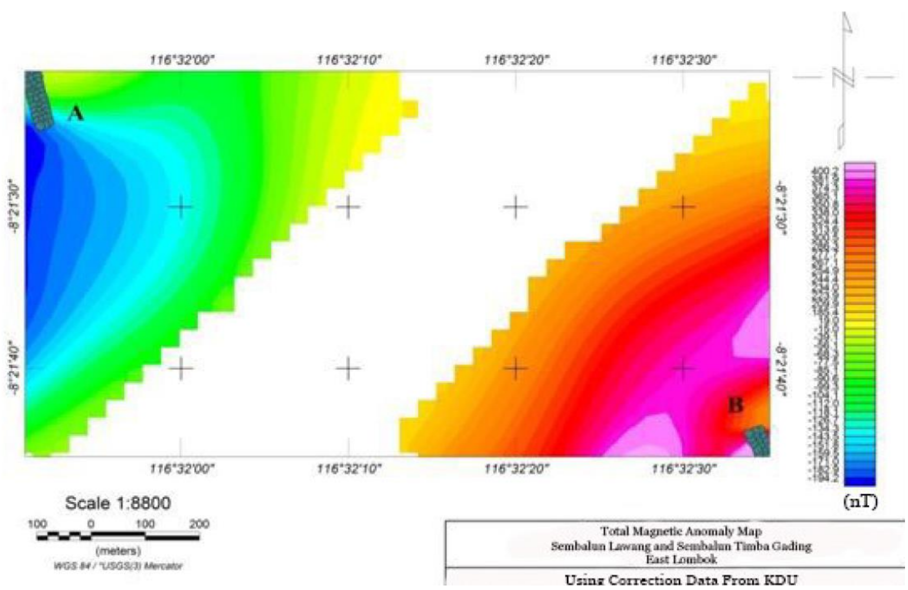

Fig. 4. Total Magnetic Anomaly Map for Sembalun Timba Gading (A) and Sembalun Lawang (B) using correction data from KDU Observatory

IV. Results and Discussions

From the results of data processing, by using Oasis Montaj Software, a map of the total magnetic anomaly is derived from regional and residual anomalies.

Fig. 3 shows the pattern of magnetic field anomalies in Sembalun Timba Gading (A) and Sembalun Lawang (B) areas, which were processed using data correction from NRB Station. The resulting total magnetic anomaly has a range of values between -135.2 nT to 456.0 nT. The negative anomaly is in the (A) research area, the high negative closure has a value range of -135.2 nT to -102.2 nT, located in the West to the North. The positive anomaly is in the (B) research area, the high positive closure has a value range of 456.0 nT to 181.4 nT, located in the South to the West.

Fig. 4 shows the distribution pattern of magnetic field anomalies processed using correction data from the KDU Observatory. The resulting total magnetic anomaly has a range of values between -194.2 nT to 400.2 nT. The negative anomaly is in the (A) research area, the high negative closure has a value range of -194.2 nT to -104.1 nT, located in the West. The positive anomaly is in the (B) research area, the high positive closure has a value range of 400.2 nT to 185.4 nT, located in the North and South-West.

A principal in magnetic data processing: the best station/observatory to be used for data correction is the closest one to the measurement point. According to this principal, because the measurement point is in Sembalun area, therefore the best one to be used for magnetic data correction is NRB Station. The use of data correction from KDU Observatory aims to compare the differences in anomalous patterns. In this case, after processing magnetic data, the distance of the anomalous body shift can be determined.

By comparing anomaly maps in Fig. 3 and Fig. 4, the positions of positive and negative anomaly pattern are the same, namely the positive anomaly is in (B) and the negative anomaly is in (A). The difference lies in the position of the maximum peaks of the anomalies. When using data correction from NRB Station, it is found that one maximum peak of positive anomaly is in the South to the West and the maximum peak position of negative anomaly is in the West to the North. Meanwhile, when using data correction from KDU Observatory, it is found that the two maximum peaks of positive anomalies are in the North and West, while the maximum peaks of negative anomalies are in the West.

The difference in the results obtained by using data from the two station/observatory greatly affects the position of the maximum peaks of positive and negative anomalies. The significant difference lies in the positive anomaly, which a difference in the maximum peak position is of ± 250 meters.

These results should be considered in geothermal exploration in Lombok Island. KDU Observatory data can be used as replacement correction data (when NRB Station data is unavailable) provided if only the geothermal survey is carried out on the island of Lombok in an area that has a homogeneous landscape within a radius of > 250 meters. If the local landscape is quite complex (such as in some parts of Sembalun area), then KDU Observatory data cannot be used as replacement correction data on the island of Lombok.

The second difference lies in the anomalous values obtained. By using correction data from NRB Station, the range of total anomaly values obtained is between -135.2 nT to 456.0 nT, while using data from KDU Observatory is between -194.2 nT to 400.2 nT. The total anomaly value obtained using correction data from NRB Station has a greater value than using KDU Observatory, because the distance from NRB Station is closer to the measurement point.

V. Conclusion

Result obtained from data processing is the difference in anomalous patterns in Sembalun Lawang and Sembalun Timba Gading areas using correction data from the NRB Station and the KDU Observatory. The difference lies in the position of the maximum positive anomaly with a distance of ± 250 meters. Considering geomagnetic surveys for geothermal explorations carried out on the island of Lombok, Kakadu (KDU) observatory data can be used as replacement correction data if Nurul Bayan (NRB) or other local station/observatory data is unavailable; with a special note: if only the survey carried out in an area that has a homogeneous landscape within a radius of > 250 meters.

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