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Estimation of Potential of Iron Sand in The Eastern Coastal Area of Cilacap Regency Based on The Local Magnetic Anomalies Data

Estimation of Potential of Iron Sand in The Eastern Coastal Area of Cilacap Regency Based on The Local Magnetic Anomalies Data

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Abstract. Estimation of potential of iron sand in the Eastern Coastal Area of Cilacap Regency, Central Java Indonesia based on the magnetic anomalies data has been carried out in March 2016 – October 2018. The research area covers five coastal areas, i.e. Widarapayung, Western Binangun, Eastern Binangun, Western Nusawungu, and Eastern Nusawungu. The results of the research which are acquired show that iron sand deposits are estimated to be discovered in all coastal areas, where the greatest potential is the Western Nusawungu Coastal and the smallest potential is the Eastern Nusawungu Coastal. The range of the local magnetic anomalies data of the Western Nusawungu Coastal area is -711,38 – 1701,84 nT, whereas the range of the local magnetic anomalies data of the Eastern Nusawungu Coastal area is -498,66 – 201,73 nT. The potential of iron sand is based on the range value of the local magnetic anomalies data of each research area, because the local magnetic anomalies data are directly assosiated to the magnetic properties of iron minerals.

1. Introduction

One of area in the Cilacap Regency, Central Java, Indonesia which is estimated to still have iron sand potential is the eastern coastal area of Cilacap Regency, covering Binangun and Nusawungu Coastal. The iron sand reserves in these areas are reserves that have not been mined formally with an area of more than 500 hectares, a magnetic degree of 12.2%, and iron (Fe) content of more than 53%. Iron sand reserves in the eastern coastal area of Cilacap Regency are estimated to be spread from Welahan Wetan Coastal in Binangun District to Jetis Coastal in Nusawungu District with an estimation of about 744,678.85 tons [1]. Whereas iron sand reserves in other coastal areas in Cilacap Regency have been mined by a mining companies, as shown in Figure 1, so that are exhausted.

The dominant iron ore in the Cilacap Regency coastal area is magnetite mineral (Fe_2O_4) which is the basic material of ferrous metals [2]. Iron is an important raw material which has been used by almost all industries for hundred years as a basic material for steel industry, construction of concrete and bridge, transportation tools such as airplanes, cars, motorcycles, trains, etc. Moreover, nano-sized iron sand have been used for cement admixture, basic ingredients for dry ink, laser printer, and various

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electronic sensors. Iron sand containing Fe_2O_3, SiO_2, MgO with grains size of about 80-100 mesh have the potential to be expanded and used as a substitute for cement materials in the high-performance concrete production [3].

Figure 1. One of the iron sand mining area in the Cilacap Coastal, Central Java (source: http://denisugandi.com).

To investigate the potential and distribution of iron sand in the eastern coastal area of Cilacap Regency Central Java, then a geophysical survey can be applied. The geophysical survey is a survey which aims to investigate the geological structures or subsurface rocks or other natural resources in the subsurface through measurement of the physical quantities on the earth's surface. Geophysical survey suitable for investigation of iron sand in the subsurface is magnetic survey, because this method is very responsive to magnetic properties of iron minerals. A magnetic survey is based on the variation of magnetic field measured on the surface due to the distribution of magnetized rocks or minerals in the subsurface in homogeneous [4].

Basic Theory

Magnetic survey is one of the exploration methods in the geophysics which is based on measuring magnetic field on the earth′s surface. The total magnetic field measured on the earth′s surface is a combination of the earth′s main magnetic field, external magnetic field, and magnetic anomalous field originating from distribution of several magnetized rocks or minerals in the subsurface. Therefore to get the magnetic anomalies data (ΔB), then the total magnetic field data (B_T) acquired from measuring in the fields must be corrected from the earth's main magnetic field (B_0) and external magnetic field (B_H), as stated in equation [4]

$$\Delta B = B_T - B_0 - B_H \tag{1}$$

Magnetic anomaly is a magnetic field originating from several magnetized minerals and rocks which are distributed in the subsurface. A volume consisting of magnetic materials can be assumed to be a magnetic dipole as can be seen in Figure 2. The magnetization that occurs in magnetic materials depends on the amount of magnetic induction received while they are in the earth main magnetic field. Based on Figure 2, the value of magnetic potential for overall rock volume can be stated by equation

$$V(\vec{r}_o) = -C_m M \frac{\partial}{\partial \alpha} \int \left[\frac{dV}{|\vec{r}_o - \vec{r}|} \right] \tag{2}$$

where M is the magnetic dipole moment per unit volume and Cm is a constant. The total magnetic induction of the rock can be formulated [5]

$$\vec{B}(\vec{r}_o) = C_m \nabla \int_V \vec{M}(\vec{r}) \bullet \nabla \left[\frac{1}{|\vec{r}_o - \vec{r}|} \right] dV \tag{3}$$

The magnetic induction in equation (3) is called the magnetic anomaly which is superposed with the earth's main magnetic field (B_0) at all points of the acquisition location. Thus, the actual total magnetic field data measured using the equipment at a location point on the earth's surface is a combination of the earth's main magnetic field and magnetic anomaly field with assumption that the external magnetic field can be ignored. If the external magnetic field can not ignored, then the magnetic anomalies value measured at a location point on the earth's surface can be stated as in Equation (1).

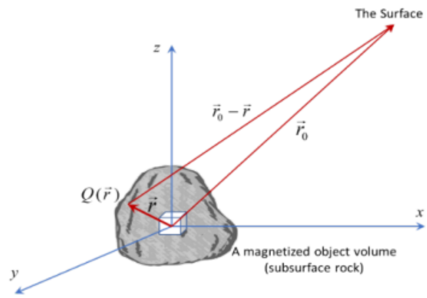

Figure 2. Description of magnetic anomaly from magnetized object or subsurface rock volume [5].

Geological Review
Generally all the eastern coastal area of Cilacap Regency is covered by alluvium and coastal deposits. The alluvium deposits are located in the northern, containing silt, clay, sand, gravel, large gravel, and erosion material from around the Karangbolong mountain in Kebumen Regency deposited through several rivers flow in this area. The erosion material is estimated to be rich in iron ore, because many igneous rocks intrusions are found in this mountain area [6]. Whereas the coastal deposits consist of sand separated in well-to-moderate, which show a layered shape; where natural resources of iron sand are found in the coastal surface of Cilacap Regency [7]. In several locations of the research area, iron sand granules are often found on the surface as shown in Figure 3.

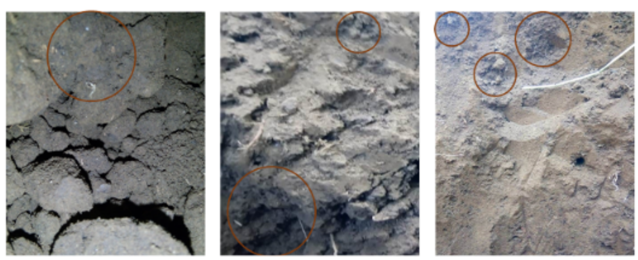

Figure 3. Iron ore grains are often found in some locations of the Binangun and Nusawungu coastal areas, Cilacap Regency.

Iron sand is sand containing iron minerals (especially magnetite) and generally deposited along the coastal. The iron sand are formed from the destruction process due to weather, surface water, and sea wave to the host rocks containing iron minerals such as magnetite, ilmenite, and other iron oxides. These materials are accumulated and washed by ocean waves. Iron sand is thought to originate from volcano materials (i.e. Slamet volcano and Karangbolong ancient volcano) which flow through several rivers. These materials accumulate along river valleys or river curves, then are carried by river flow and settle downstream and estuary areas. Sea waves which sweep along coast resulted these materials being separated continously becomes granules, that are naturally enriched by iron minerals into iron sand. The iron sand which have a high specific gravity value will settle, and which have a low specific gravity value will be decomposed and dumped into the sea. This natural process occurs repeatedly and continously for hundreds or thousands years, thus forming the iron sand deposits [7].

2. Experimental Methods

Location dan Time

The estimation of the potential of iron sand in the eastern coastal of Cilacap Regency has been done in March 2016 – October 2018. Data acquisition of the total magnetic field has been carried out in the research area, spreaded from the Widarapayung Coastal in Binangun District to the Jetis Coastal in Nusawungu District, Cilacap Regency, Central Java as shown in Figure 4. The geographical position of all research area can be seen in Table 1. Then data processing and modeling have been conducted at the Laboratory of Electronic, Intrumentation, and Geophysics; Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University, Purwokerto, Central Java.

Figure 4. Location of data acquisition in the magnetic survey; the eastern coastal area of Cilacap Regency (source: google map).

Table 1. The geographical position for each research area

No.	Research Area	Geographical Position	
1	Widarapayung Coastal	109.2501 – 109.2702 °E	7.6781 – 7.6986 °S
2	Western Binangun Coastal	109.2699 – 109.2982 °E	7.6851 – 7.7019 °S
3	Eastern Binangun Coastal	109.2988 – 109.3189 °E	7.6843 – 7.7040 °S
4	Western Nusawungu Coastal	109.3143 – 109.3445 °E	7.6908 – 7.7091 °S
5	Eastern Nusawungu Coastal	109.3462 – 109.3718 °E	7.6958 – 7.7098 °S

Equipment and Materials

Several equipment used in the magnetic survey consists of Google Earth application for plotting all data points in the field, Proton Precession Magnetometer (PPM) to measure the total magnetic field strength values at all points, Global Positioning System (GPS) to measure the geographical position of all measured point, compass to direct the PPM sensor to the north, and other supporting tools. While the equipment used in the laboratory is a personal computer equipped with various necessary software. Several softwares are microsoft excel 2010 for processing raw magnetic data to obtain the magnetic anomalies data, Fortran 77 for processing magnetic anomalies data; such as reduction to the horizontal surface and upward continuation, and Surfer 7 for depiction magnetic anomalous contour map for each stage of data processing.

Procedure of Research

The research begin with data acquisition, so the total magnetic field strength data are acquired. Then, several corrections including daily and IGRF corrections are applied as have shown in Equation (1) so the total magnetic anomalies data can be acquired. The anomalies data acquired are still distributed on the topographic, so that must be reduced to a horizontal surface; because the data can be processed in the next, if have distributed on the horizontal surface [8]. One of method which can be used to reduce anomalies data to a horizontal surface is Taylor series approximation which can be stated as Equation (4). If the total magnetic anomalies data can be written as ΔB, then [8]

$$\Delta B(x,y,h_0)^{[i+1]} = \Delta B(x,y,h) - \sum_{n=0}^{\infty} \frac{(h-h_0)^n}{n!} \frac{\partial^n}{\partial z^n} \Delta B(x,y,h_0)^{[i]} \qquad (4)$$

The Equation (4) is stated in the form of iteration; where $\Delta B(x,y,h_0)$ value are magnetic anomalies data which are distributed on a horizontal surface. The data can be estimated through an approximation; i.e. $\Delta B(x,y,h_0)$ values acquired from i-th iteration can be used to acquire $\Delta B(x,y,h_0)$ values in the $(i+1)$-th iteration. The iteration is done sufficiently to reach a convergent value. For the initial values before iteration process, the $\Delta B(x,y,h_0)$ values on the right of equation can be filled by $\Delta B(x,y,h)$ which are the magnetic anomalies data distributed on the topographic surface [8].

The anomalies data acquired from Equation (4) are still affected by magnetic effects originating from the deep and wide anomalous sources, which are generally called as regional magnetic anomaly. The regional anomalies effect must be reduced, because the target of the research is the distribution of iron sand near surface. Generally the regional magnetic anomalies data can be acquired through the upward continuation using the equation of the 2nd-Green identity [5,9]

$$\Delta B(x',y',h_0+\Delta h) = \frac{\Delta h}{2\pi} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta B(x,y,h_0)}{\sqrt{\left((x'-x)^2+(y'-y)^2+\Delta h^2\right)^{3/2}}}\,dx\,dy \qquad (5)$$

where $\Delta B(x',y',h_0+\Delta h)$ are the regional magnetic anomalies data. Then, the data are corrected to the the total magnetic anomalies data which have been distributed on the horizontal surface, so that the local magnetic anomalies data are acquired, as the equation [10]

$$\Delta B(x,y,h_0)_{Local} = \Delta B(x,y,h_0) - \Delta B(x',y',h_0+\Delta h) \qquad (6)$$

The local magnetic anomalous map acquired is the map that represent shallow subsurface rocks in the research area. Generally, the iron sand are estimated to occur in the alluvium deposits which are near surface [11]. Therefore the local magnetic anomalous map can be used as a tool to carry out qualitative interpretation of the potential and distribution of the iron sand in the research area. Moreover, based on the geological information, the type of minerals that dominate in the research area is only iron ore [7]. Thus the iron ore can be assumed to be the only subsurface anomalous source which have contribution to the local magnetic anomalies data.

3. Results and Discussion

Results of Data Acquisition and Corrections

Data acquisition of total magnetic field strengh has been done in five locations with the geographical positions as has shown in Table 1. Then to acquire the total magnetic anomalies data, so the daily and IGRF corrections can be applied as have explained in the Method. The daily correction is conducted to eliminate the external magnetic field variation due to the radiation from the solar [4]. While the IGRF correction is conducted to eliminate the value of the earth's main magnetic field from the measured data in the field. The Earth's main magnetic field value has been set in the form of the International Geomagnetic Reference Field (IGRF) value according to the latitude and time [12]. The IGRF value has acquired online from website provided by The Meteorology Climatology and Geophysics Agency (BMKG) Republic of Indonesia. The total magnetic field strength data of each research area and the total magnetic anomalies data are shown in Table 2. Whereas the total magnetic anomalous map of one of research area i.e. Western Nusawungu coastal is shown in Figure 5.

Table 2. The total magnetic field strength data and the total magnetic anomalies data for each research area

No.	Research Area	Total Magnetic Field Strength (nT)	Total Magnetic Anomalies (nT)
1	Widarapayung Coastal	44332.06 – 45586.37	-685.58 – 578.78
2	Western Binangun Coastal	44621.42 – 45537.00	-374.34 – 552.82

3	Eastern Binangun Coastal	44104.34 – 46387.65	-861.99 – 1421.85
4	Western Nusawungu Coastal	44297.50 – 46960.12	-694.32 – 1961.62
5	Eastern Nusawungu Coastal	44384.28 – 45291.84	-612.55 – 296.29

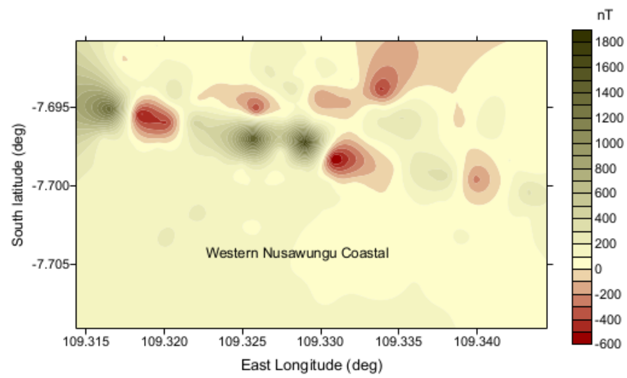

Figure 5. The total magnetic anomalous contour map of the Western Nusawungu Coastal area.

Results of Data Reductions

The total magnetic anomalies data acquired are still distributed on the topographic, so the data must be reduced to the horizontal surface using Taylor series approximation as have explained in the Method. The principle of Taylor series is to use a derivative function at a point to extrapolate that function to around that point. Therefore this formula can be used to estimate the magnetic anomalies value at data points outside the observation field. The total magnetic anomalies data obtained are anomalies data which have distributed on a horizontal surface. The horizontal surface can be taken at the average the topographic height of each research area, so that the iteration process of Equation (4) reach convergent quickly [5]. Anomalies data which have distributed on a horizontal surface or have reached convergent generally have a smaller values range than anomalies data which are still spread on the topographic, as shown in Table 3. The total magnetic anomalous map which have distributed on a horizontal surface of one research area is shown in Figure 6.

Table 3. The total magnetic anomalies data which are distributed on a horizontal surface of each research area

No.	Research Area	Total Magnetic Anomalies (nT)	Description
1	Widarapayung Coastal	-582.71 – 452.46	convergent
2	Western Binangun Coastal	-274.44 – 396.07	convergent
3	Eastern Binangun Coastal	-570,62 – 1330.61	convergent
4	Western Nusawungu Coastal	-589.62 – 1.823.61	convergent
5	Eastern Nusawungu Coastal	-478.77 – 221.62	convergent

The total magnetic anomalies data that have distributed on a horizontal surfaces are still affected by magnetic anomalies associated with very deep and wide anomalous sources, which are referred to the regional magnetic anomaly. The regional magnetic anomaly effects must be eliminated from the total magnetic anomalies data as have explained in the Method. The regional anomalies data can be acquired through upward continuation process, so the obtained anomalous contour map has a smooth pattern with very small anomalies range as can be seen in Table 4 [13,14]. The upward continuation results leads to anomalous sources derived from very deep structures, so can indicate the valid regional magnetic field [15]. The magnetic anomalies data acquired after regional magnetic correction as stated in Equation (6) are called the local magnetic anomalies data, with the anomalies data range are shown in Table 4 and the contour map of one of the research area is shown in Figure 7.

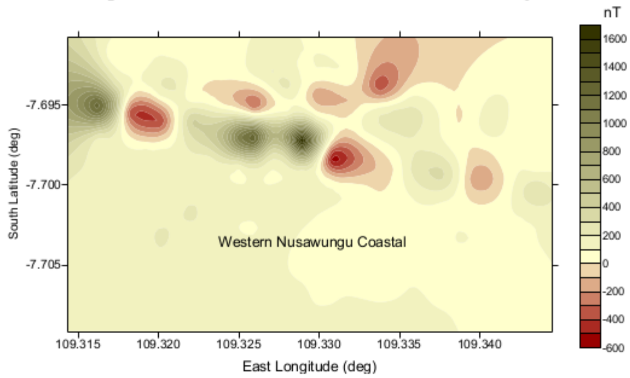

Figure 6. The total magnetic anomalous contour map of the Western Nusawungu Coastal area which has distributed on a horizontal surface.

Table 4. The regional magnetic and local magnetic anomalies data of each research area

No.	Research Area	Regional Magnetic Anomalies (nT)	Local Magnetic Anomalies (nT)
1	Widarapayung Coastal	-42.942 – -42.335	-541.40 – 494.34
2	Western Binangun Coastal	39.612 – 39.680	-314.08 – 356.42
3	Eastern Binangun Coastal	145.164 – 145.268	-715,80 – 1185,37
4	Western Nusawungu Coastal	121.680 – 121.830	-711,38 – 1701,84
5	Eastern Nusawungu Coastal	19.839 – 19.960	-498,66 – 201,73

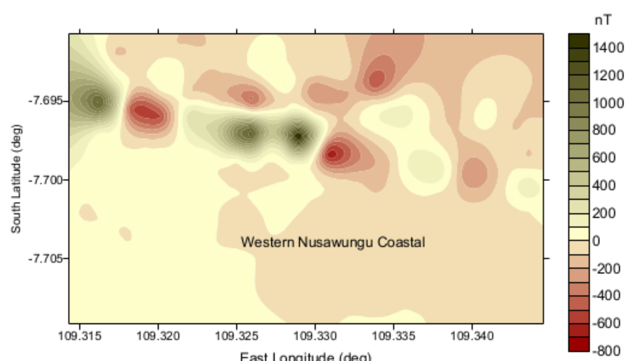

Figure 7. The local magnetic anomalous contour map of the Western Nusawungu Coastal area.

Results of Qualitative Interpretation

Based on the geological information, iron sand is the only type of metal ore which is discovered in the eastern coastal area of Cilacap Regency [7]. Therefore the local magnetic anomalous are directly associated with the iron sand content. This can be understood, because the magnetic properties of iron minerals are more dominant than sedimentary rocks in the around. Thus, the local magnetic anomalous contours of the all research area as shown in Figure 8 indicate the content of iron sand qualitatively.

The local magnetic anomalous maps are equipped with interval value of local magnetic anomalies for each research area, so that the potential of iron sand content in the all research areas can be estimated easily. Moreover, the area that have high iron sand content can be shown visually through the density of anomalous contour patterns. It is supported by the recognition of the communities that they often find iron sand granules when digging wells with a depth of less than 5 m. Even based on the results of chemical analysis of the sand samples taken along the coastline at a depth of 0.8 – 1.6 m acquired iron content (Fe) of 9.56% [11]. Although the magnetic data were obtained in 2016 – 2018, generally these data can still be used; unless there is a large geological process that changes the subsurface structure.

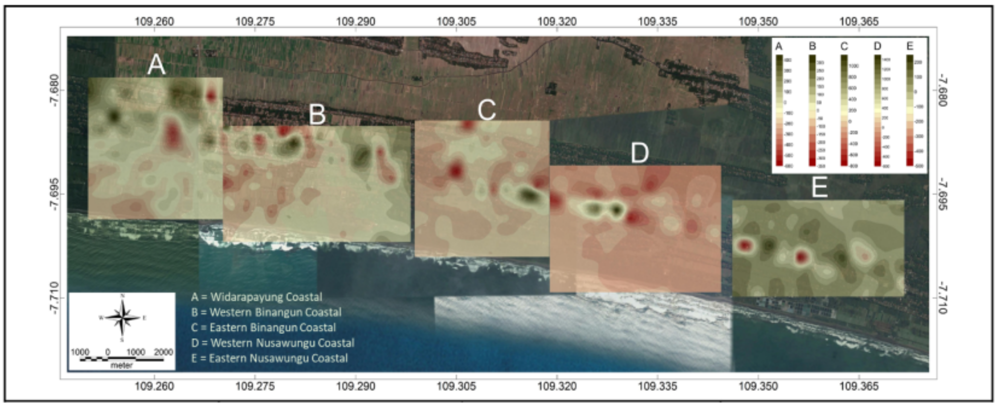

Figure 8. The local magnetic anomalous contours maps of all research area; the Eastern Cilacap Coastal area.

Based on the local magnetic anomalous maps of the all research areas, the Western Nusawungu Coastal area is an area estimated to have greatest potential of iron sand. It is related to the large range of the local magnetic anomalies data, i.e. -711.38 – 1701.84 nT, although the highest anomaly is only located in the around middle of the contour map [16]. Then the Eastern Binangun Coastal area is also estimated to have large potential of iron sand content [17]. This area has the local magnetic anomalies values with ranging of -715.80 – 1185.37 nT. Both these areas are close together, then the geological processes which make up iron sand are also assumed the same. These areas have relatively sloping and low morphology, so the iron sand grainules tend to settle in these areas. Therefore, the local magnetic anomalies range value in these areas to be relatively high. Otherwise, the Eastern Nusawungu Coastal area is estimated to have smallest potential of iron sand content. It is related to the small range of the local magnetic anomalies values, i.e. -498.66 – 201.73 nT [18].

The estimation of the potential of iron sand in the all research areas as Figure 8 is only based on the range of the local magnetic anomalies values; where the greater of the range between positive and negative anomalies data, then the potential of iron sand content is greater. Because the local magnetic anomalies data are associated with magnetic properties of iron minerals, i.e. magnetic susceptibility. Moreover, iron sand is assumed to be the only natural resources of metal ore in the research area. Then if based on the total area, Widarapayung Coastal is the most extensive area of iron sand [19]. The next areas are Western Binangun [20], Eastern Binangun [17], and Western Nusawungu [21]. Whereas the Eastern Nusawungu Coastal is estimated to have the lowest potential of iron sand. This indicate that increasingly to the eastern, the areas which have the iron sand content are decreasingly. In the eastern of Widarapayung Coastal area, iron sand mining has been carried out by several local companies since 2008, but now all iron sand mining have been closed. The facts are estimated to cause the iron sand reserves in the Widarapayung Coastal to be relativity lower than the Eastern Binangun and Western Nusawungu coastal areas.

The natural resources of iron sand in the eastern coastal area of Cilacap Regency have triggered various companies to exploit. If exploitation is done on a massive scale without considering the nature conservation, then the activities can damage the coastal environment; one of them is a coastal aquifer. Sand materials as the main media of coastal aquifers to be lost or reduced, so the function of aquifer in storing groundwater in the coastal area to be decreased. Before mining, the eastern coastal of Cilacap Regency has never experienced a drought even though during the long dry season. But the drought has been experienced by coastal communities in Widarapayung Kulon, Binangun District. This drought is estimated to be caused by iron sand mining activities along the coast of this village, so it can damage the shallow aquifer that resulted in reduced well water discharge. Even though it has entered the rainy season, the discharge of well water is relative still small [22].

4. Conclusion

The estimation of the potential of iron sand in the eastern coastal area of Cilacap Regency Central Java Indonesia has been carried out in March 2016 – October 2018 based on the local magnetic anomalies data. The research location covers five coastal areas i.e. Widarapayung, Western Binangun, Eastern Binangun, Western Nusawungu, and Eastern Nusawungu in Cilacap Regency, Central Java, Indonesia. This research has been resulted that the all research areas have the potential of iron sand content, with the largest potential is Western Nusawungu Coastal and the smallest potential is Eastern Nusawungu Coastal. The estimation of the potential of iron sand is only based on the range of the local magnetic anomalies values. Because the local magnetic anomalies values are directly associated with magnetic properties of iron minerals contained in iron sand, i.e. magnetic susceptibility. Moreover, iron sand is the only type of metal ore discovered in the eastern coastal of Cilacap Regency. Based on the results of the research, the Western Nusawungu Coastal has the local magnetic anomalies data with ranging of -711.38 – 1701.84 nT, whereas the Eastern Nusawungu Coastal has the local magnetic anomalies data with ranging of -498.66 – 201.73 nT.

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