

Depicting the Underground River Systems in Karst Mountains of Buayan and Ayah Subdistricts Using GGMPlus Data and Springs Distribution

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ABSTRACT

The karst mountain area in Buayan and Ayah subdistricts is a mountainous area that stretches from North to South and ends in the South coast region. In this area, many springs are found which are a source of clean water for residents. The existence of springs in the area is an indicator of the existence of underground rivers flowing under the mountainous area, this is also reinforced by the presence of interconnected caves and the existence of river flows in these caves. Analysis the presence of underground river flows in the Karst mountain area in the study area can be identified by looking at the type of rock formations that dominate the area. The density contrast shown through the residual gravity data also shows changes in rock formations related to the presence of water sources in the study area. GGMPlus data was obtained from forward modeling in order to get a residual map. This study shows that rock formations in the Karst area in the study area conform to the topographical shape.

1. Introduction

The karst mountains scattered in the southern region of the Kebumen district are natural resources that have great potential. The nature of the karst rocks in this area, especially in the Buayan and Ayah sub-districts, is a type of porous limestone with a large level of porosity that allows easy seep down of rainwater, but difficult accommodation at surface water depths. During the dry season, some areas in the Karst Mountains experience water shortages because people's wells dry up and water sources become difficult to obtain [4]. Meanwhile, at some points, springs appear and they never seem dry up. These springs come from underground river flows which until now have not been completely mapped. Several tourist attractions in the sub-districts have been opened for underground cave tours, and some tourists have explored the depths of the cave to more than 2 km.

GGM Plus data, which is BGI satellite gravity data reprocessed using the latest terrain correction by Curtin University using the ETOPO EGM2008 topography model, allows gravity disturbance data and anomaly residual data to be generated from forward modeling with a resolution of ~200 m. These data can be used to analyze anomalies that are shallower (<10 km) and those with small residual gravity values. Utilizing gravity anomaly data from GGMPlus and analyzing them using geological maps reveals the distribution of rock formations in an area and its relationship to the topography of the area.

This study found a match between the distribution of rock formations and the geological map of the research area. In addition, because the Karst area is a type of middle-aged karst mountain, the topography of the research area conforms to the map of the distribution of formations as described in the geological map. Figure 1 shows the karst mountain area the which includes Buayan and Ayah sub-districts, along with the location of water sources. Figure 1.2 is a description of the geological map of the research area.

2. Literature Study

The karst mountain region of this research is located in the Buayan and Ayah sub-districts of the Kebumen district. The karst mountains in the selected research area are an area of the Southern-mountain range that forms rocky hills and have many cavities that, in turn, indicate the large pore size and porosity of the region. In several areas, limestone cliffs are also found which are the former ruins of its main dome/cave [2]. The caves in the area serve as tourist destinations, especially for local tourists who want to enjoy the exotic natural scenery of such caves. The caves that become tourist destinations include Jatijajar Cave, West Cave, and Petruk Cave. These three caves are caves below the surface with views of stalactites and stalagmites that are hundreds of millions of years old. These caves also have natural springs which are underground rivers with clear water and they continue to flow even during the dry season [3].

However, not much is known about the area of the cave as a whole, and neither are the creatures dwelling in them.

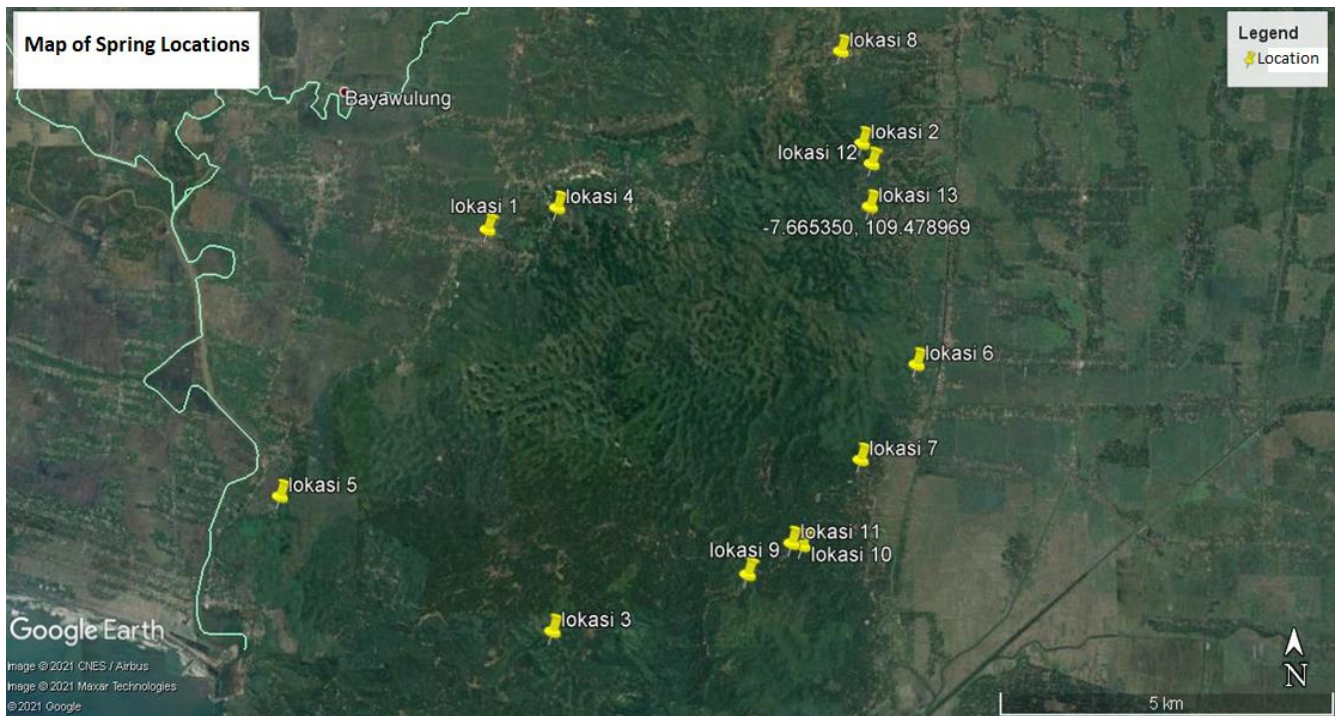


Fig.1: Springs distribution in Buayan and Ayah subdistricts (Google Inc, 2000).

Underground Water Mapping

Studies of underground river mapping have been carried out using electrical methods, such as geoelectric and VLF. The research was carried out in the Praciwantoro area, Wonogiri district, and mapped the karst area using the VLF method with a track length of 200 m [1].

Aquifer mapping in the Buayan sub-district has also been carried out previously by Sinta Maumena using the geoelectric method of the Schlumberger configuration and results in conclusions about the types of limestone in the area to the limits of the presence of an impermeable layer that indicates the depth of the underground cave/river floor in the area [2].

Chusni Ansori et al. wrote about the potential for karst areas in the Buayan and Ayah sub-districts by dividing the area into 3 categories of karst I, II, and III [3]. Karst area I relates to 75% karst area and is free from the mining of limestone, andesite, and phosphate which is related to the importance of protecting the resources around the area so as not to be damaged.

He showed that 8 types of minerals exist in the karst mountains in the Ayah, Buayan, and Gombong sub-districts. These minerals are shown in Table 1.

Table 1. Mining potentials in the karst area of Buayan, Ayah, and Gombong subdistricts.

Type of Material	Location	Description
Andesite	Mangunweni and Candirenggo villages, Ayah subdistrict Kalipoh village (M. Poleng), Ayah subdistrict Srati village (M. Gadung), Ayah subdistrict Jintung village, Ayah subdistrict Adiwarno village (M. Kukusan), Buayan subdistrict	Some already mined. have been
Crystalline and fossilized limestone	Karst area of South Gombong	Some already mined. have been
Kephrus limestone	Kalisari and Redisari villages, Ayah subdistrict	Already mined. been
Phosphate	Banteng Cave, Buayan subdistrict	Already mined. been
Bentonite	Argopeni village, Ayah subdistrict	Has not been mined.
Trass	Jintung village, Ayah subdistrict	Has not been mined.
Mangan	Mangunweni and Adewerna villages, Buayan subdistrict	Some already mined. have been
Gold	Jladri village, Buayan subdistrict	Early indication.

Gravity Method

Theoretical Foundation of Gravity Method

It is a theory that describes the interaction of two or more masses separated by distance r . The equation of gravity that we know as Newton's Law of Gravity states that the interaction between 2 masses m_1 and m_0 that is separated by distance in r comes with a force equal to:

$$F = -\gamma \frac{m_0 m_1}{r^2} \hat{r} \quad (1)$$

where $\vec{F}(r)$ is the magnitude of the gravitational force which is directly proportional to the mass of the object and inversely proportional to $r^2 = |-r_0 + r_1|^2$ which is the square of the distance between the two masses. The direction of the force is given a negative sign because it is opposite to the direction of the unit

vector, whereas γ is the general gravitational constant – the symbol often used is G_- which has a value of $6,67 \times 10^{-11} \text{m}^3 / \text{kg s}^2$.

Gravity Anomaly

The measured gravitational field is a combination of the earth's gravitational field and the field caused by anomalous objects. The first step to getting the gravitational anomaly field is to separate the residual anomaly field from the regional anomaly field. An example is the anomaly of an object that is close to the surface which is still mixed with anomaly due to variations in the density of the crust with the upper part of the earth's mantle. Figure 2 illustrates this explanation very well.

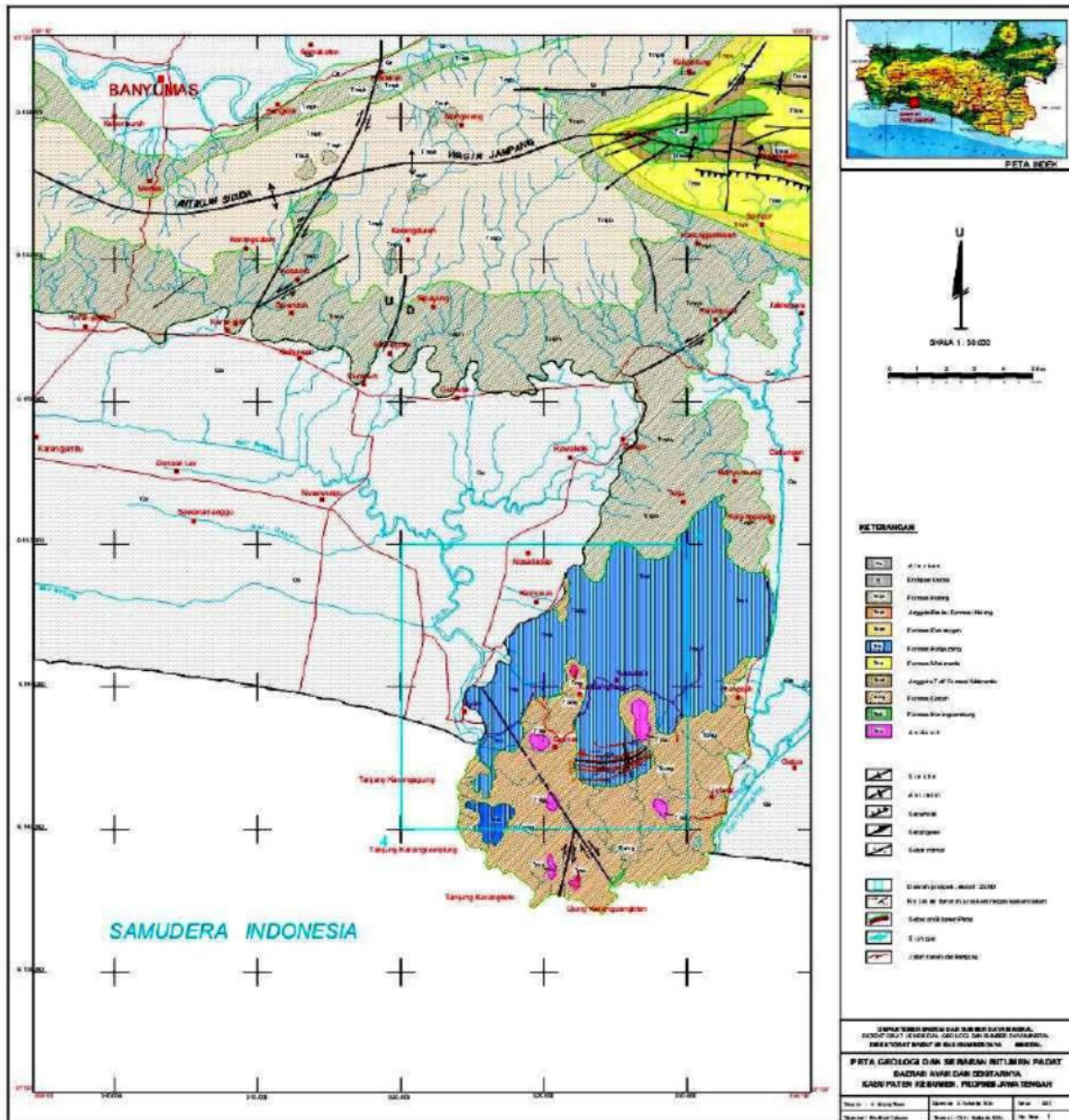


Fig.2: Geological map of Buayan and Ayah subdistricts (Asikin, 1992).

The size of the anomaly that is detected depends on the mass, shape, and normal spin of the earth, the height of the tool to sea level, the effect of the field

around the tool when data collection, and the isostasy effect.

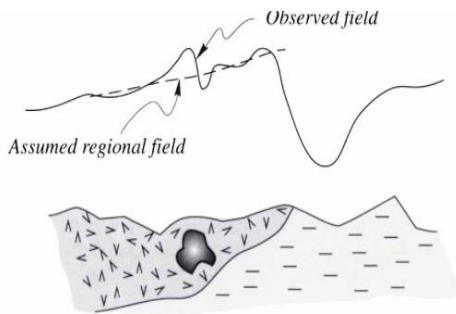


Fig.3: Definition of regional field that depends on the scale of the issue (Blakely, 1995).

If the gravitational field has gone through various reduction processes, the remaining anomalous field is a gravitational field caused by objects causing density variations in the crust. Gravity anomaly Δg can be obtained by finding the difference between the observed gravity values g_{obs} which has undergone a reduction process with theoretical gravity $g_{teoritis}$ [5-7].

$$\Delta g(x, y, z) = g_{observasi}(x, y, z) - g_{teoritis}(x, y, z) \quad (2)$$

Gravity Data Reduction

The data obtained is data that has been reduced to obtain a complete Bouguer anomaly with the following basic formulation:

$$\Delta TC = \gamma \rho (\Delta \theta) \left((r_1^2 + \Delta h_s^2)^{1/2} - (r_2^2 + \Delta h_s^2)^{1/2} + (r_2 - r_1) \right) \quad (3)$$

2. Methods

Research Location and Period

This research covers the area of Ayah and Buayan sub-districts of the Kebumen district, at E 103°23'24" to E 109°29'24.46" latitude and S 7°37'28" to S 7°46'24" longitude (Figure 2).

Data Collection and Analysis Methods

The data collection process is divided into stages of data collection by downloading GGMPlus satellite data from: <https://bgi.obs-mip.fr/data-products/grids-and-models/modele-global-ggmplus2013/>. The next step is selecting the position/coordinates to be inverted. Data sorting needs to be performed because downloaded data cover a very large area, while the data needed for research only covers a small part of such data. This sorting and cutting employ Matlab. Selected location is then mapped and analyzed based on geological information of the research area and existing underground river traceability.

Afterward, residual gravity data from GGMPlus are displayed as an anomaly map distribution using Surfer. The distribution map is then analyzed by comparing the residual distribution map with the topographic map, and then overlaying the position of the springs and their altitude on the map.

Residual map, along with topographic and geological maps, is analyzed and results in information on the distribution of rock formations of the springs. From here on, further analysis is carried out related to the possibility of the existence of

underground rivers by taking the type of formation and the altitude of the observed springs into account.

3. Results and Discussion

Results from this study show a match between the location of springs and probable underground river flow. Figure 4 shows the value of satellite gravity in the research area and its residual anomaly, which is the result of forward modeling from gravity data reprocessed using a 90 m resolution topographic map taken from ETOPO EGM 2008. Forward modeling of residual anomaly results in a relationship between residual anomalies and topography, topography distribution of the study area, as well as the distribution of rock formations. This is made possible as the forward modeling process provides a very good initial picture of the contrasting residual anomalies associated with changes in rock formations.

Nonetheless, the initial assumption for such a forward is anomaly data deviation in the range of 0.02 mGal, which is comparable to an anomalous wavelength of close to ~200 m. Considering that the research area is 6 km × 10 km wide, and the topographical altitude of the highest water source of 330 m, the thickness of the rock formation boundary is difficult to predict. Furthermore, very high data ambiguity and limited additional information do not allow for the inversion of gravitational residuals using Grablox. Such an attempt would require additional reliable data, such as formation thickness and density values. However, plotting of water source spots on the residual map shows a relationship between the residual value of gravity and the type of formation of these water sources.

As can be seen in Figure 5 and Figure 2, the area marked with a blue box is an area with a match between gravitational anomaly and residual gravity anomaly and the Kali Pucang formation. The Kali Pucang formation seems to have a lower gravity value compared to the surrounding area. However, from residual anomaly modeling, this formation has a high residual gravity anomaly. This is because the lithology of such formation is a porous rock with many cavities and lower density compared to surrounding rock formations that are younger, but with more compact. Meanwhile, the residual value of gravity in the formation appears to be high because, after altitude correction, this formation shows a fairly large density contrast to the surrounding area. Although underground rivers are found in this formation, many caves are that are not mapped, hence, it is difficult to be assured of their associations.

The difference between water sources in the Kali Pucang formation and those of the Halang formation is mainly observed from the location where the springs and rivers appear. The river system in the Karst mountains in this research area has various altitudes, but using the simple fact that water flows from the ground to its lower counterpart, it is assumed that each of those different springs in these two formations is not directly connected. Meanwhile, the springs in the same formation are possibly connected via an underground river system. A good example is the spring system in Sikayu Village from the north to Sendang Pelus. This spring is located at an altitude of about 30 meters above sea level with underground river flows that are recognizable

through bare ears at several points. This strengthens the assumption that there is a deeper underground river system, which does not appear on the surface directly.

Figure 6 shows 3 river systems that are observable based on the analysis of their altitudes. All three indicate a river system flowing from the North to the

South with a tendency for the position of the springs in the North to be higher than that of the South. Thus, this study shows three types of large subsurface river flows in the research area and that they are of different rock formations, i.e., the Kali Pucang formation and the Halang formation.

Plotting of Springs on the Residual Gravity Anomaly Map

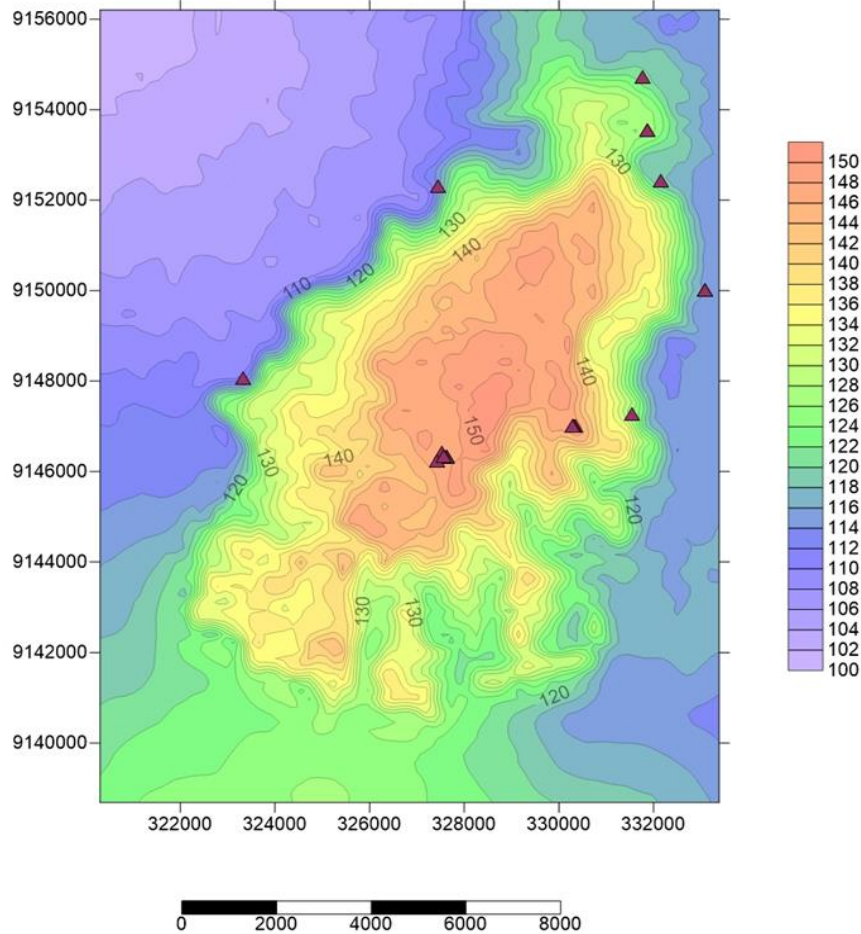


Fig.4: Residual gravity anomaly map in the study area and the plot of the location of the springs

Map of Gravity Anomaly vs Map of Residual Gravity Anomaly

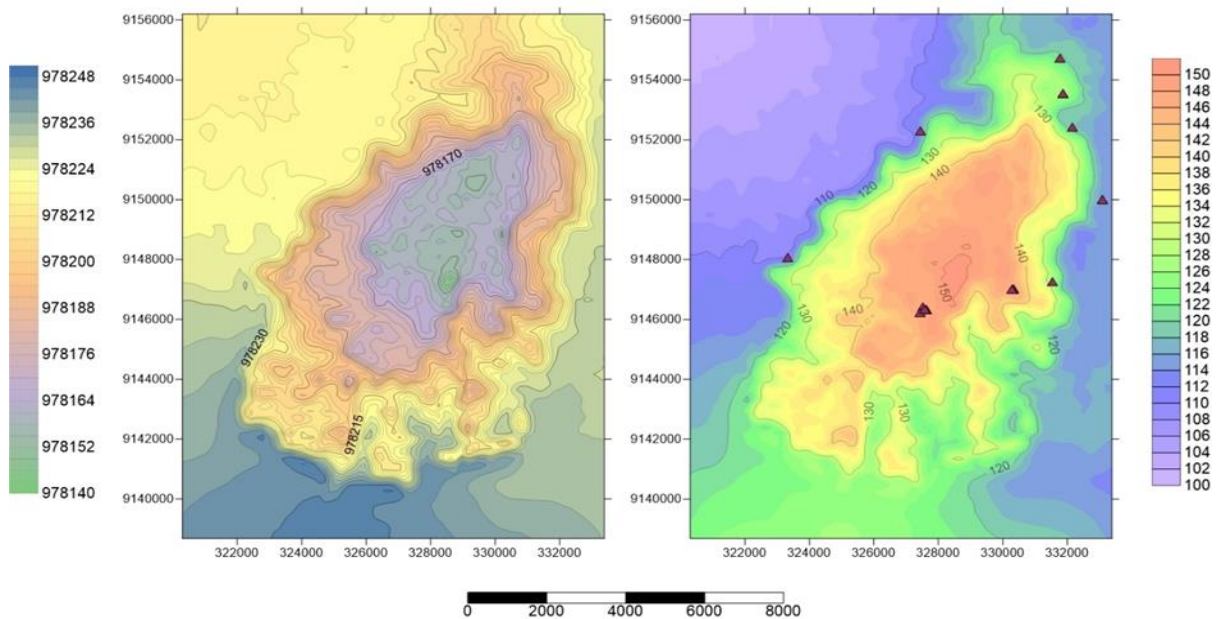


Fig.5: Correspondence between the gravity value and the residual gravity anomaly resulting from the forward modeling of the GGPlus data

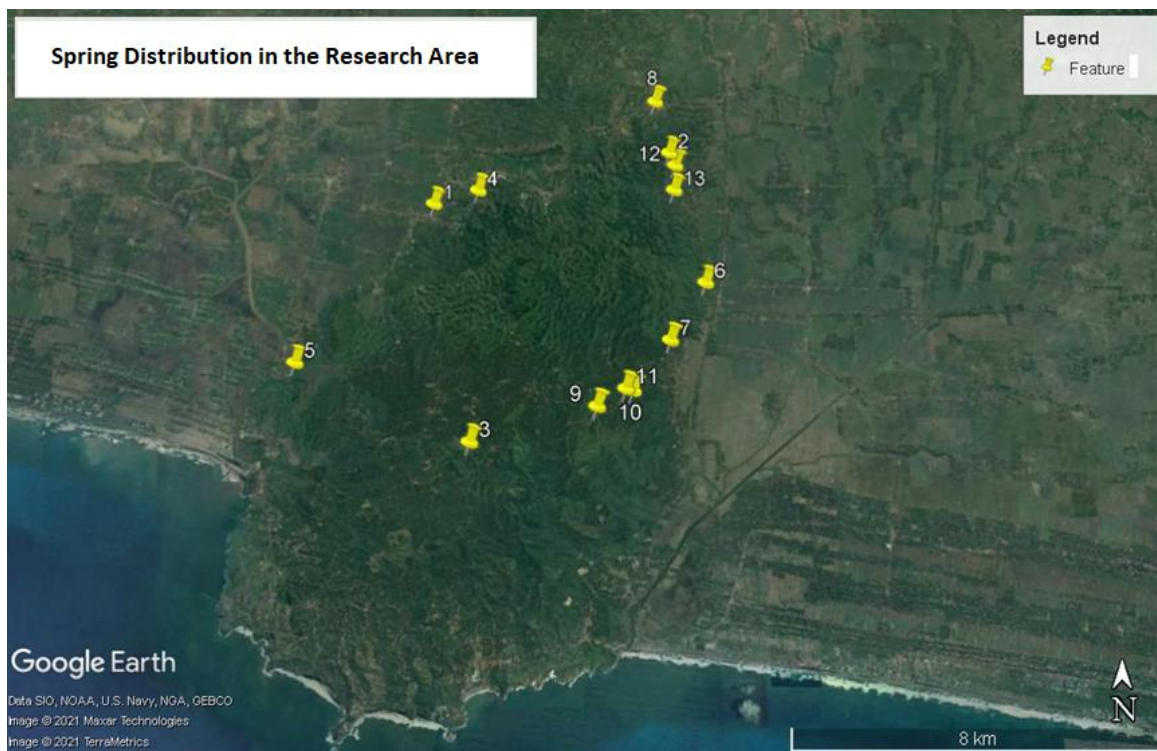


Fig.6: Location of the springs in the village of Banyumudal to Sendang Pelus and the possibility of underground river flows in the area.

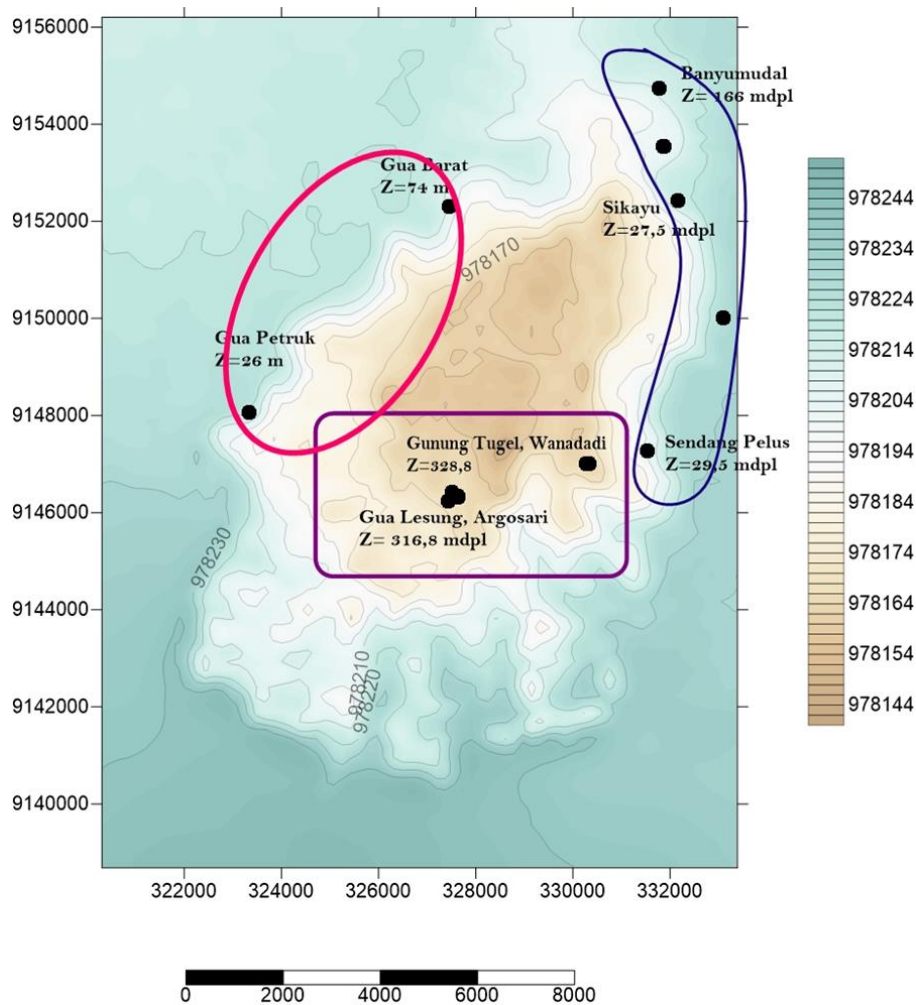


Fig.7: Possibility of an underground river system in the research area based on an analysis of the position of the springs and the type of rock formation.

It can be seen in Table 2 that the Kalipucang formation is older than the Halang formation. This earlier formation shows the characteristics of porous rock and high permeability that can accommodate and drain rainwater below the surface so that it forms a cave system and develops into an underground

river. A gravitational anomaly point of view, this formation also has a lower anomaly value because of its porous character. Meanwhile, the Halang formation has a higher density than the Kalipucang formation and is younger because it contains more shale and smaller deposits than its older counterpart.

Table 2. Regional stratigraphy of the study area (S. Asikin, et al. 1992).

ERA	AGE	FORMATION	
QUATERNARY	HOLOCENE	Alluvium and Coastal Sediments	THRUST ROCKS
	PLEISTOCENE	Terrace Deposit	
	PLIOCENE	Tapak Formation	
TERTIARY	Early	Halang Formation	
		Breccia Family	
	Middle	Halang Formation	
	Early	Panosongan Formation	
		Kalipucang Formation	
OLIGOCENE	Gabon Formation		
EOCENE	Karang Sambung Formation		

4. Conclusion

Data processing and its subsequent analysis in this study show that: GGMPlus data, which is the result of forward modeling of satellite gravity data using the 2008 ETOPO EGM model can be used to show residual anomalies associated with the presence of underground rivers. Residual anomaly of GGMPlus data in the Buayan and Ayah sub-districts shows a density contrast associated with rock formations in these areas. The existence of an underground river in the Buayan and Ayah sub-districts is indicated by the traceability of the position of the springs in the area and the type of rock formation indicating the presence of an underground river in the Kalipucang formation. There are 3 underground river systems identified in the research area; an underground river located in Argosari Village (Lesung Cave and Wanadadi) with the highest spring altitude of 326 meters above sea level; an underground river that flows in the West cave to the Petruk cave with the highest spring altitude of 74 meters above sea level, and an underground river in the eastern part of the Karst mountains which runs from Banyumudal to Sendang Pelus with the highest spring altitude being in the northernmost part (Banyumudal), which is 166 meters above sea level.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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References

- [1] S. Asikin, A. Handoyo, B. Prastistho, and S. Gafoer, Geology Lembar Banyumas, Jawa, (Pusat Penelitian dan Pengembangan Geologi., 1992).
- [2] S. Maemuna, D. Darsono, B. Legowo, "Identifikasi Akuifer di Sekitar Wilayah Karst Gombong Selatan Kecamatan Buayan Kabupaten Kebumen dengan Metode Geolistrik Konfigurasi Scumberger," Jurnal Fisika dan Aplikasinya: ITS, (2017).
- [3] Indriyani, D. Dewi dan Supriyadi, "Pemetaan Distribusi Aliran Sungai Bawah Tanah Menggunakan Metode Geofisika VLF (Very Low Frekuensi) Daerah Karst Pracimantoro Kabupaten Wonogiri," UNNES Physical Journal, 3, 2, (2014).
- [4] C. Ansori et al., "Potensi Sumber Daya Mineral Kawasan Karst Gombong Selatan Serta Implikasinya terhadap Pengelolaan Kawasan Lindung," Prosiding Pemaparan Hasil Penelitian Pusat Geoteknologi: ISBN: 978-979-8636-15-8, LIPI Bandung, (2008).
- [5] R. Blakely, "Potential Theory in Gravity and Magnetic Application". Cambridge University Press: United Kingdom, (1995).
- [6] S. Arifin, "Relative Bouguer Anomaly," The Leading Edge, 23, 9, 850-851, (2004).
- [7] Google Inc, (2020), Google Earth: Map of Kebumen Regency at <https://www.google.com/earth>, accessed on 27 October 2020.
- [8] International Gravimetric Bureau. GGMPLUS2013 Global Model at <https://bgi.obs-mip.fr/data-products/grids-and-models/modele-global-ggmplus2013>, accessed on 27 October 2020.