Controlling factors of underground river system of karst region in Pacitan Regency, East Java

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Abstract. One of the interesting karst areas is the Pegunungan Sewu, because of the existence of an underground river system that developed below it. The underground river system of Bribin in Gunung Kidul, Yogyakarta is one of the evidence found by previous researchers. In Pacitan District there are karst landscapes that have not been widely studied. Pacitan karst area is in the eastern part of the karst area of Pegunungan Sewu. As the characteristics of the karst region in general, in the Pacitan karst region, there are small hills, vertical hole, closed depressions, rough and pointed surface outcrops, stalactites and stalagmites, and the presence of muddy and water sources. The Pacitan karst area is similar to the Gunung Kidul karst area which has an underground river system. However, the development of underground river systems from these two regions is thought to be different. The purpose of this study is to analyze typical and the controlling factors that influence the development of underground river systems in the Pacitan karst area, East Java. This research was conducted using VES (Vertical Electrical Sounding). The results showed that the typical underground river system that develops in the area of research is more shallow than in Gunung Kidul and suspected to be in the Vadose and it is controlled by the movement of water from the incoming surface through rock fractures.

1. Introduction
Pegunungan Sewu is one of the interesting karst areas due to the existence of the underground river system that develops beneath it. One of them is Bribin underground river system in Gunung Kidul, Yogyakarta. The underground river system that has developed in Gunung Kidul is at a depth of 100 meters forming an underground stream. The Pacitan karst area is the eastern part of the Karst area of the Pegunungan Sewu. The Pacitan karst area is similar to the karst area of Gunung Kidul that have underground river system. This can be seen from the surface manifestations such as the many found caves, vertical hole, the flow of surface river that suddenly disappeared, and streams appear from underground.

Characteristics of karst area generally consists of small hills, closed depression, surface outcrop that looks rough and pointed, stalactites and stalagmites, and the existence of vertical hole and water sources. The karst landscape is formed due to the dissolution process by rainwater and carbon dioxide that are found in soluble rocks, such as limestone [1]. The dissolution process that occurs in the carbonate rock will cause the forming of caves and underground river system. In the theory of the forming of underground caves, it can be formed in three zone, the vadose zone where the cave development takes place above the water table, the deep phreatic zone where the beginning of the cave
and most of the cave widening occurs at random depths below groundwater levels and phreatic zones, and caves can be formed near groundwater [1]. The caves that found in Gunung Kidul are mostly caves in the vadose zone. Caves in the vadose zone are usually flooded only in the rainy season and formed like a perched channel. While others are formed at groundwater levels, such as the Bribin cave. The cave at the ground water level of the canal is watered throughout the season.

The process of underground river formation in the karst landscape certainly depends on the process of karstification in the area. The process of karstification is influenced by two things, the first is the controlling factor associated with the lithological conditions that composed by rocks that are soluble and massive and have cracks or stocky that will increase the permeability and porosity of rocks so they are easily penetrated by water. The rainfall is high enough that the water is abundant as the solvent medium and the area located at a relatively higher position of the surrounding area so that water can flow smoothly thus speeding up the karstification process. Second is the driving factor that associated with temperature and vegetation cover [2]. This study aims to analyze the controlling factors affecting the development of underground river systems in the karst area of Pacitan, East Java. The research was done using VES (Vertical Electrical Sounding) geoelectrical method. Based on Neumann et al VES method can determine the distribution of hollow and water-saturated bodies, or water-saturated layers in depth profiles that have high resolution even within meters [3].

2. Regional Geology

Generally, East Java is divided into four physiographic zone zones, namely Rembang Zone in the north, then to the Southern part there is Zone Kendeng and Zone Solo, and in the southern most is the South Mountain Zone [4]. Geographically, Pacitan regency is located between 110.55°-111.25°E and 7.55°-8.17°S with an area of 1,389.8716 km2 or 138,987.16 Ha, mostly in the form of hills, ie approximately 85%, small mountains of approximately 300 pieces spread throughout the region of Pacitan and steep cliffs. Based on geographical location of research area and its surroundings included in South Mountain Zone which stretches from Yogyakarta to Malang [4], on subzona of Gunung Sewu. This subzona is a hill with karst landscape, the landscape with limestone hills forming many cones with a height of several tens of meters. The southern mountainous zone in East Java is generally a block that is raised and tilted to the south, bounded by a fairly complex escarpment in the north [4].

The research area is passed by two horizontal faults, namely Punung Fault which trending Northwest-Southeast and Grendulu Fault that trending Northeast-Southwest. Based on Van Bemmelen the Southern Mountains area has undergone four liftings [4]. The structural geology system in the Northwest-Southwest research area is dextral shear fault and the Northeast-Southwest direction is a sinistral shear fault that occurred because of subduction of the Indo-Australian plate during the Eocene to the Middle Miocene. Based on the Regional Geology Map of Pacitan, the research area is part of the Wonosari formation composed of coral limestone, layered limestone, sandy limestone, and napal in the age of Middle Miocene to Late Miocene, and formed in shallow marine environments. This unit is deposited quietly in the sea above the Nampol Formation, the local lower part has a tendency to interfingering with the Oyo Formation [5].

The field conditions in Dersono Village are karst hills, plantations and village. Which are Luweng Tati, Luweng Tanggung, and Luweng Jomblang. Some of the vertical hole that found in this unit indicate the existence of sub-surface streams that form an interconnected underground river system. Direction of the underground flow is estimated to have the same direction with the rivers located in the east of the study area that are the Northeast-Southwest and West-East. The valley formed is a sinkhole or doline. It is the characteristic of karst morphology that has been dissolved.

3. Methodology

Controlling analysis of underground river system development in Dersono Village, Pacitan is based on geoelectrical research using VES (Vertical Electrical Sounding) method. This method has been used in Bribin, Gunung Kidul area by Neumann, et al. The results of the research that has been done by Neumann, et al [3] note that the increase of electrical resistance means low water content and also the
otherwise. At a depth of 100 m, the transition from very low water to very high water content is seen. It was interpreted as part of a cave containing air into the water that flows in the river.

Similarly, in this study, VES measurements were performed at 14 points at two different locations, namely 7 VES points in the Northeast of Luweng Winong (VES W) and 7 VES points East of Luweng Tanggung (VES T). VES measurements were done with Schlumberger method with lengths at each location are 260 meters and 200 meters, with estimated depths of 40-50 meters, 1/5 of the total length [6]. The Schlumberger configuration is also good enough in detecting sub-surface contrast and can identify the difference in vertical resistivity values of the rock. Distribution of VES points is 5 meters to 15 meters. Field data obtained are voltage and current, and will get the value of apparent resistivity at each measurement point VES.

Apparent resistivity value at each point of VES then processed using geoelectrical software and then will be correlated using Surfer to obtain the cross-correlation of the actual distribution of resistivity values versus depth at the study site. The cross-correlation of resistivity values obtained were analysed and linked to regional geology, and compared with the results of VES in Gunung Kidul. Thus it will be known how the development of underground river systems in Dersono Village, Pacitan, and possible controlling factors that influence the development of underground river systems in the karst area of Pacitan.

4. Result and Discussion

4.1 Correlation Result Among The VES Points

After doing the same method on the other VES points then he correlation between the VES points was made to obtain the results as in Figure 4. Broadly speaking at the measurement points from VES W1 to VES W7 obtained information about subsurface condition that consist of top soil layer which is supposed to be weathering material with thickness < 0,7 meter. Under the top soil layer, coral limestone are suspected to have undergone a karstification process that is capable of storing and draining water due to the formation of cavities with high porosity. Then there are clay intrusion and also solid carbonate on the inside. Figure 4. shows low to a high anomaly change that visible at a depth of 20-25 meters and 45-50 meters around VES W2 point and 45-50 meters around VES W7 point. The anomaly shown in the figure shows that at the site of this study have developed 2 subsurface stream systems of air or empty cavities [3]. The first system is at a depth of about 25 meters but has not been suspected to have developed complexly in view of its still very local anomalies. While the second system is deeper that is at a depth of 40 meters. Meanwhile, at the second location to the exact east of Luweng Tanggung, the dispersion anomaly of resistivity value can be seen in Figure 4(b). Based on Figure 4(b) it shows low to high changes anomaly seen at a depth of 15 meters and 30-35 meters around VES T2-T3 points. The author interprets the anomalous change as a cave containing air or an empty cave, this is based on the references from research that has been done by Naufaldi [7] interpretation of the distribution of resistivity values at the research conducted by Naufaldi. Just as in the VES W location, in general the system can be developed in this location consists of two levels namely at a depth of about 15 meters and 35 meters. But it is suspected that the more massive karstification process is at a depth of more than 30 meters because it has a relatively large anomalies dispersion.

4.2 The Differences of Underground River System in Dersono, Pacitan with Bribin, Gunung Kidul

The typical difference of underground river systems developed in Dersono, Pacitan with the underground river system that developed in Bribin, Gunung Kidul can be analyzed from the results of the interpretation of the spread of resistivity values in some of the VES points shown in Figure 4 and 5. From the Figure 4 and Figure 5, can be seen that the subsurface conditions in the area Karst Pacitan almost the same as the area of Gunung Kidul. At a depth of 0-10 meters has a low resistivity value. Then there is a change of low to high resistivity values begin at a depth of 10 meters. Resistivity changes are also visible at deeper meters. This is due to the heterogeneity and discontinuity in the
limestone karst system causes the varied of resistivity value although work on the same formation, despite that anomalies still occur on karst caves and underground river. The dried underground rivers and caves will provide a type of resistance value that ohm meter in values, higher than the surrounding rock layers. On the other hand, streams and subsurface water-saturated caves have much smaller resistance values than the surrounding rocks [8].

Figure 1. Interpretation of VES Correlation (a) Northeast Luweng Winong (b) East Luweng Tanggung

However, from Figure 4 The interpretation of some VES points result in Dersono, Pacitan reaches a depth about 40 meters, and found anomalous changes in low to high resistivity that interpreted as underground river system in the form of empty caves. While in Figure 5 it is known that the increase of electrical resistance means low water content and vice versa. At a depth of 100 m, the transition from very low to high water content is seen. It was interpreted as part of a cave containing air into the water that flows in the river [3]. This means that the underground river system that develops in Dersono, Pacitan is relatively shallower compared to the underground river system developing in Bribin, Gunung Kidul.

Figure 2. Interpretation of several VES points in the Bribin Underground River System Gunung Kidul, Jogjakarta [3]
4.3 Controlling Factor of Underground River Systems at Dersono, Pacitan

Information on the existence of underground river system developed in Desono, Pacitan based on VES measurements can be one of the basis for conducting an analysis of underground river system control especially in Desono and the karst area of the eastern Sewu Mountains in general. The development of the underground river system in Desono, Pacitan can be analyzed based on the theory of cave formation in karst area proposed by Ford & Williams [1] as well as analysis of the factors of karstification by Haryono [2].

Based on the depth information of the underground river system that developed in Desono, Pacitan, at a depth of < 40 meters, much more shallow than the system in Bribin. The authors suspect that this subsurface system develops in the vadose zone or upper part of the underground aquifer system layer, which occurs due to movement of water through rock fractures or holes on the surface like luweng. The flow of water that occurs infiltrate vertically into the ground through the rock holes and then into the water saturated zone. When it reaches the water saturated zone, the water will move in a horizontal direction by following the cracks in the rock, such as the plating, stocky, cracks and so on. The path that passed by this water will be scraped and dissolved slowly. So it will produce wide gap and in a long time can produce a tunnel like a cave where the dissolution process occurs above ground water level [9]. This is also expressed by Adji and Suyono [10], the water contained in limestone is dynamic, where water is moving from the surface to the water saturated zone. The path passed by this water has the potential to dissolve the rock so that in certain period of time will form a hole with a large diameter. However this needs to be proven by further research on ground water aquifer mapping in the karst area of Pacitan.

Then if it is analyzed based on factors that affect the process of karstification based on Haryono [2], the type of lithology in the research location when viewed from the distribution of resistivity value is dominated by thick coral limestone so the karstification is possible to occur. In addition, if seen from the location of research areas that are located close to the Grindulu Fault, it is suspected that this also became one of the controller of the karstification process developed in the area. Cave passages formed from crevices as well as lining fields, especially at the second meeting and also the fault that can produce optimal dissolution process [11]. Based on Eko Ridarso, underground river in the tropical karst regions are derived from surface runoff during the rainy season entering through limestone gaps, sometimes the river is partially or completely lost to the soil through fractures and / or depressions [12]. The depression transfers large amounts of surface water into underground water. The effect of the existence of this fault is strengthened by the results of research about the identification of subsurface by using 2D geoelectrical method conducted by Nurfitriana, where from the research it is known that the direction of underground river flow is in the same direction with Grindulu Fault [13]. The results of research conducted by Abdullah regarding the analysis of particle motion on microtremor method, the direction of underground river that developed in the study location has orientation of Northeast-Southwest direction, in the same direction with Grindulu fault [14].

Another controlling factor in the underground river system in the karst area of Desono Pacitan is the topographic elevation level. Based on the topographic elevation at the research sites located about 100 m, this allows the development of air-filled caves. Based on Puradimaja, on the karst mountain system, the topographic elevation level of 100-200 m is the elevation range where water caves can be found. The rainwater that permeates through the fractures on the surface will flow through the cracks to a height of 200 m and accumulate at an elevation level between 100-200 m [15].

5. Conclusion

It turns out that a typical underground river system developed in karst area of Pacitan, East Java is different from underground river system that developed in Gunung Kidul, Yogyakarta. This is seen from the results of research conducted in the karst area of Desono Village, Pacitan where underground river system developed in the form of empty caves as many as two levels are analyzed based on the difference of low to high resistivity anomaly at a depth of about 25 meters and 40 meters. Compared to the developing system in Gunung Kidul, the underground river system in Dersono
Village is shallower and suspected to be in the Vadose Zone where the cave development takes place above the water table and it is controlled by the movement of water from the incoming surface through rock fractures. It is assumed that rock fractures in the karst area of Pacitan are formed due to the structural control by Grindulu Fault. While on the underground river system in Bribin, Gunung Kidul, formed at groundwater level at a depth of relative within 100 meters.

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