Analysis of Cave Morphology in Wediombo and its Surrounding Area, Gunungkidul

Eni Paryani¹, Eko Haryono¹

¹Department of Environmental Geography, Faculty of Geography, Gadjah Mada University, Yogyakarta, 55281, Indonesia

*Corresponding email: eni.paryani@mail.ugm.ac.id

Abstract. Wediombo and its surrounding area is an isolated highland at the southern rim of the Gunung Sewu sub-zone. This area has contact between old volcanic rock with limestone that cave system has underground-hydrological condition. This study aims to determine the morphological characteristics of cave at Wediombo and its surrounding area. This data was collected by observation and cave mapping using the BCRA 5C grade. Data analysis was carried out by passage morphometric analysis and morphographic analysis. This study shows that cave pattern distribution is clustered following the joint and fault lines. The passage morphometry analysis show that Duren and Greweng caves are horizontal with straight passage, while the Pulejajar cave is considered to be a horizontal cave with meander passages. Based on the value of the width and height ratio, the shape of passages are semi-circular with canyon that direction to northeast and southeast. Results of the passage morphography analysis show that Duren and Greweng caves are single and straight passage caves, while the Pulejajar cave is leveled passage and curvilinear branchwork pattern. The cross section variation of the cave passage’s shape are rectangular passage, elliptical passage, canyon, joint passage, gorge sharped passage, keyhole, and chamber.

1. Introduction

Wediombo and its surrounding area is an isolated highland situated at the southern rim of the Gunung Sewu sub-zone [16]. This area is called as the khuluk of an extinct volcano because of the existence of volcanic rock outcrops that constructed the body of a volcano in addition to its location that is isolated by carbonate rocks [6]. Geologically, Wediombo area is made up of Wuni formation at the south and Wonosari formation at the north. The Wuni Formation is a rock that was formed because of volcanic process and is composed of agglomerate rock with tuffen inserts and coarse sandstone, while the Wonosari Formation is a carbonate rock that is composed of layered limestone and reef limestone [9]. Therefore, Wediombo and its surroundings is a contact area between shallow old volcanic rock and limestone. The terrain of the Wuni formation formed Mount Batur intrusion, andesite breccias, and andesite lavas around the Wediombo Beach [6], on the other hand, the Wonosari formation formed endokarst and exokarst features in the form of karst hills, dolines, uvalas, ponors, underground rivers, caves, and cave ornaments [7].

One of the distinctive characteristics of the karst area is the presence of caves that are formed by intensive dissolution of limestones [4]. A cave is a passage/cavity under the ground surface that is naturally formed and can be entered by humans [10]. The form of cave is diverse and is always changing due to geomorphological processes that occur continuously along with factors that influence the development of the cave [3]. The factors of cave’s formation and development of caves are geological
The combination of several factors that influence the development of a cave resulted in the difference of the passage’s morphology of each cave [5].

The process of cave development begins with the occurrence of seepage and cracks in the limestone. The gap of the cracks will get bigger along with the erosion and dissolution process that continues to occur. The identification of cave’s development can be seen from the various forms of passages in the cave. The study of cave morphology is divided into two parts, which are morphometry and morphography. Morphometry is a quantitative study of the shape of the cave passage based on the measurement results, while morphography is a qualitative description of the shape of the cave passage based on the results of the observation on the features in the cave.

The study of the morphology of the cave passage is used to reconstruct the process of cave formation and the level of karst development [11]. By knowing the formation and the development of a cave, it is hoped that special interest tourism activists, tourists, and the public will have an awareness of maintaining the ecosystem around the cave because a cave is formed in a very long time, a place where there are rare fauna and flora, non-renewable, and vulnerable to environmental degradation [11]. Information on the formation and development of caves can also be used in forecasting hydrological and geomorphological conditions of karst, aquifer production, along with the soil and rock stability [1]. The aim of this study was to determine the morphological characteristics of the cave passages in the Wediombo and its surrounding area.

2. **Methodology**

2.1. **Study Area**

The area used as the object study is the area around Wediombo Beach in Tepus Sub-district and Girisubo Sub-district, Gunungkidul Regency. The absolute location of the study area using UTM coordinates is at 465000-470000 mE and 9094000-9099000 mN in the 49S zone that covers 3 villages, which are Balong Village and Jepitu Village in Girisubo Sub-district and Purwodadi Village in Tepus Sub-district. This area of 30 km² is located 72 km away from the center of Yogyakarta City or 30 km from Wonosari City.

![Figure 1. Administrative map of the area of study](source)

*Source: Geoportal Provinsi Daerah Istimewa Yogyakarta*
2.2. Data collection and analysis

This is a descriptive research that is using a quantitative approach in the calculation of the passage morphometry and a qualitative approach in describing the morphography of the cave’s passage. The data required consists of primary data and secondary data. Primary data includes morphometric data, morphographic data, rock characteristics, and hydrological characteristics which are detailed in Table 1. The secondary data that are used include Indonesian Topographical map, geological map, DEM data, cave entrance distribution data, and cave maps that previously have been made by other party.

Table 1 Characteristics of the primary data and the methods of obtaining it

| Data                     | Characteristics                  | Source                     |
|--------------------------|----------------------------------|----------------------------|
| Passage morphometry      | Cave length                       | Cave measurement and mapping|
|                          | Cave width                        |                            |
|                          | Roof height                       |                            |
|                          | Passage direction                 |                            |
|                          | Passage slope                     |                            |
| Passage morphology       | Characteristics of the cave entrance |                            |
|                          | Cave’s shape from above and the front |                            |
|                          | Chambers                          | Cave mapping and observation|
|                          | Speleogen                         |                            |
|                          | Ornament (Speleothem)             |                            |
|                          | Debris                            |                            |

Based on Table 1 above, the primary data collection was done by mapping the cave along as well as observation. The cave mapping was carried out by using the BCRA grade 5C mapping system. Grade 5 means that the mapping is done by utilizing magnetic equipments, with accuracy of the horizontal and vertical angles at ±1°, distance accuracy at ±10 cm, and the station position error is less than 10 cm. The detail level of class C means that the details of the passages are measured and drawn directly at the survey station [12].

The mapping was carried out using bottom to top technique, which means that the mapping is executed from the end of the cave to the entrance after field observations had been done [11]. Initial observations were carried out to provide an overview of the conditions inside the cave and also to make it easier to determine the station points. The mapping technique was performed using forward method, which is a cave mapping technique where the tool reader (shooter) and the note taker (data descriptor and sketcher) are positioned at the back while the targeted person (stationary) is positioned at the front as the station point determinate [11]. The determination of station points is random while taking into account several distinct characteristics such as the level of accuracy of the mapping, the difference of the passages’ shape, the difference of the passages’ slope, and the existence of unique cave ornaments.

The acquired mapping data was then processed using Excel and Compass softwares to figure out the concept of the passage direction along with the calculation of the passage morphology. Next, he concept of the passage direction (centerline) was sketched using Corel Draw software to make the visualization of the cave map in accordance with the result of the sketches that were drawn at the field. Georose software was also needed to process the passage direction data.

Data analysis was carried out by using 2 methods, which are morphometric analysis and morphographic analysis. The morphometric analysis was conducted to identify the typology of the cave’s passages based on the calculation results of the passages’ morphometric parameters and their morphometric indexes. The parameters data and the passage morphometry indexes are shown in Table 2. Morphographic analysis is description of the shape of the passage that is visible from above as well as the front (cross section) based on the cave map that had been made.
Table 2. Parameters and passage morphometric indexes

| Symbol | Description                      | Scientific Procedure     |
|--------|----------------------------------|--------------------------|
| Lr     | The actual distance of the cave  | Compass Software         |
| Lp     | Cave map distance                | Compass Software         |
| Ex     | Horizontal distance of the cave  | Compass Software         |
| Dn     | Negative decline                 | Lowest point – entrance  |
| Dp     | Positive decline                 | Highest point – entrance |
| Rv     | Cave depth                       |                          |
| Pa     | Length of cave area              | Compass Software         |
| La     | The width of the cave area       | Compass Software         |
| Mw     | Average width                    | Compass Software         |
| L/W    | Ratio of length to width         |                          |
| A      | Cave area                        | Compass Software         |
| Vi     | Cave volume                      | Compass Software         |
| P      | Porosity                         | Compass Software         |
| S      | Sinousity of cave passage        |                          |
| Vi     | Vertical Index                   |                          |
| Hi     | Horizontal Index                 |                          |
| Li     | Linear Index                     |                          |
| Hci    | Horizontal Complexity Index      |                          |

Source [10]

3. Results and Discussion

3.1. Caves in Wediombo and its surrounding area

The Wediombo and its surrounding area have 15 cave entrance points that are scattered in a cluster following the fault of Gunung Sewu karst area which can be explained by the cave entrance distribution map in Figure 2. The caves are located at the east and the north of Mount Batur and have entrances that are situated at enclosed dolines, narrow valleys, hillsides, and cliff sides.
Figure 2. Cave entrance distribution map in Wediombo and its surrounding area  
Source: ASC, Pangea Cruiser, and Geoportal Daerah Istimewa Yogyakarta

Based on Figure 2, there were 3 caves that were selected as the samples for this study, which are Pulejajar Cave, Duren Cave, and Greweng Cave. These three caves were chosen because all of them are horizontal caves so they are easier to be mapped while the location of these three caves are still close to the boundary of the two formations, and it was also in consideration of the time, the energy, and the research funds. Pulejajar is a watery horizontal cave that has various forms of passages and these passages are quite long. The passages of the Pulejajar Cave were divided into 3 sections to make the morphological analysis easier, which are the main passage, upstream passage, and downstream passage. These are shown in Figure 3. This cave has an underground spring that is raised to the surface to fulfill the needs of clean water in the study area. This is related to the problem of limited access to clean water resource that is faced by most of the local people in Gunung Sewu karst area [18]. Pulejajar Cave is counted as a cave that is quite popular in the Wediombo area and for caving activists. Duren Cave, which is located at the east side of Mount Batur, has a surface river that enters the cave through the mouth of the cave. This river is intermittent which means that this river will only be filled by water only when it rains. Greweng Cave has two entrances. One is named Greweng cave entrance which is marked by the Greweng river that is flowing out of the cave. The other one is named Banyu Sumurup entrance cave which is located at a hillside with dense vegetation.
3.2. Morphometry

Passage morphometry is a study of quantitatively describing the shape of the cave’s passage based on the results of cave mapping calculation [11]. Morphometric aspects that are used to identify the passage’s type are length, depth, passage morphometric index, direction of the passage, and the passage’s cross-sectional ratio. Length and depth can also be used to find out the development of the cave, where the longer and deeper it is, then the cave that was formed is quite old and is more developed. Based on Table 3, it appears that the longest cave is Pulejajar Cave, which is more than 2.8 km when the main passage length of 1,580 m is added to it. The length of this passage haven't included the unmapped passage yet, so it is estimated to be even longer. Greweng Cave and Duren Cave have smaller passage lengths. It shows that these two caves have slow passage development. This is due to the condition of vadose passage which lack water that caused the grinding and widening of the passage to take a long time.

Table 3. Results of the calculation of passage morphometry parameters

| Parameter | Upstream Passage | Downstream Passage | Duren Cave | Greweng Cave |
|-----------|------------------|--------------------|------------|--------------|
| Lr        | 477              | 768                | 174        | 254          |
| Lp        | 477              | 768                | 171        | 250          |
| Ex        | 243              | 458                | 135        | 192          |
| Dn        | -0.5             | -11                | -21        | -0.6         |
| Dp        | 11               | 21                 | 0.5        | 17           |
| Rv        | 11               | 32                 | 22         | 18           |
| Pa        | 248              | 454                | 131        | 177          |
| La        | 134              | 252                | 48         | 77           |
| Mw        | 3                | 7                  | 3          | 5            |
| L/W       | 159              | 110                | 51         | 47           |
| A         | 33192            | 114574             | 6245       | 13615        |
| Vi        | 301632           | 1391321            | 101562     | 219617       |
| P         | 1.42%            | 2.68%              | 1.99%      | 3.38%        |
| S         | 1.97             | 1.68               | 1.29       | 1.32         |

The size of Pulejajar’s cave system can also be seen from the area and the volume of its cave. The larger the area and also the larger the volume of the cave, then it shows that the cave has greater length...
and width, and vice versa. The porosity (P) of the four passages which are less than 5% indicates that the four passages have poor porosity and are classified as confined aquifers. This occurred because the process of limestone’s deposition was not sorted properly and the result was that the pores storage cavity of the rock became the smaller. Meanwhile, the sinuosity (S) or the passage’s curvature characteristic of the four passages show different results. The upstream passage and the downstream passage are meander passages, while the Duren Cave and the Greweng Cave are straight passages. This can be made clearer by the planview (seen from above) cave map.

The results of the calculation of the passage morphometry parameters can be used to calculate the morphometric indexes that are shown in Figure 4. The vertical index, horizontal index, and linearity index were scaled from 0 to 1, where the larger the value is, then the stronger it will be, meanwhile, the horizontal complexity indexes are varied, but the greater the value is, then the the shape of the passageway will be more complicated and formed the pattern of a maze cave [7]. The vertical index and the horizontal index are opposed to each other, which can be shown by the four passages that have horizontal index values of 0.98 to 1 while the vertical index values are only at 0.02 to 0.13. This shows that the shape of the four passages are horizontal. The linear indexes of the upstream and downstream passages of the Pulejajar Cave are smaller than the horizontal indexes, which indicates that these two passages are inclined to be not straight and are winding, because their horizontal complexity indexes are still too small for them to form labyrinth caves. Their shape are slightly different from the Duren Cave and the Greweng Cave which have larger linear index values and smaller values of horizontal complexity index, so these two passages are determined to be straight passages.

![Figure 4. Comparison graph of morphometric indexes](image)

The shape of the passage when viewed based on the ratio of the width and height of the roof (R) from the cross section of each measurement station can be divided into 3 categories, which are the canyon (R<1), circular passage (R=1), and semicircular passage (R>1) [14]. The results of the calculation of the ratio of the width and height of the roof (R) of the three studied caves are presented in Figure 5. Based on the graph, it appears that Pulejajar Cave has the highest number of observation stations as there are 185 points, where the most dominant shape of the passage is semicircular passage. The canyon passage shape tends to be almost identical in the upstream passage, where the upstream passage is small, narrow, and high. There are also circular passages in the upstream passage. Meanwhile, in Duren Cave and Greweng Cave, the semi-circular passage is more dominant. The shape of the semicircular passage indicates that the development of the passages of the three caves is influenced by the results of hydrological activity from the flows underground river.
The direction of the passages’ development can be seen from the rose diagram which shows the frequency of the passage’s trend for each measuring station. The rose diagrams as the result of the measurements in the field are shown in Figure 6, where (a) is the direction of the Duren Cave’s passage, (b) is the direction of the Greweng Cave’s passage, (c) is the direction of the Pulejajar Cave’s upstream passage, and (d) is the direction of the Pulejajar Cave’s downstream passage. Based on Figure 6, it is shown that the trend of the fourth passages are inclined towards the northeast and the southeast. The direction of the development of these passages is influenced by the joint structures and faults that existed in the eastern Gunung Sewu karst area which are directed to the south and the southeast. Aside from that, the passage’s direction of the cave system will follow the flow direction of underground river that moves from a higher place to a lower place, which is towards the sea.
3.3. Morphography

Passage morphology is a study on the description of the passage’s shape based on the analysis of the passage map seen from above, from the side, and from the front [11]. The analysis of the passage’s shape that was seen from above (plan view) was intended to determine the overall shape of the passage, the direction, and the curve of the passage. The form of passage that is seen from plan view according to White (1988) [17], is grouped into single passage and labyrinth passage. The single passage is grouped again into three, which are linear passage, angular passage, and sinuous passage, while the labyrinth passage is also grouped again into three, which are network passage, anastomonic, and sponework pattern. This classification was chosen because the classification by Palmer [13] of passage morphology patterns that is seen from above is only suitable for large cave systems that involves several caves that are connected to become one cave system, meanwhile the cave systems at the research site are not connected.

Based on the maps of the caves’ passage seen from above (Figure 7), the three studied caves are categorized into the single passage cave because the shape of all the three caves are still simple and are still controlled by one of the strongest structural factors. Duren Cave and Greweng Cave are classified into the linear passage group because each of these two caves only have one passage segment, no turns, and there is influence from major joint that controls the flow direction. The Pulejajar Cave has different characters and is classified into the sinuous passage because the shape of its winding passage resembles a meandering river. Although the Pulejajar Cave has branching passages, this cave is still not yet included in the labyrinth passage (maze cave). It is classified into the curvilinear branchwork pattern.

The passage morphology seen from the front, or the cross-section, is used to describe the passage’s shape from the width and the height of the passage along with the widening of the passage that has occurred. The shape of the passage that turn up is strongly influenced by structural and hydrological factors that control the development of a cave. The classification of the passage’s shape seen from the front is divided into vertical passage (shaft), rectangular passage, elliptical passage, canyon, joint passage, George sharped passage, keyhole, and chamber [2].

Based on the observation results and the cave maps that have been made, Pulejajar Cave has the most diverse shape of passage based on what was seen from the front. All categories of passage shape are found in Pulejajar cave which are spread over several segments of the passage. Vertical passage, rectangular passage, elliptical passage, joint passage, george sharped passage, and chamber can be found at the main passage. Elliptical passage, joint passage, george sharped passage, and canyon are often found in the upstream passage, while the downstream passage is dominated by elliptical passage, rectangular passage, and george sharped passage. The Duren Cave has the shape of rectangular passage, elliptical passage, joint passage, and keyhole. The Greweng Cave only has the shape of rectangular passage, elliptical passage, joint passage, and chamber. The visualization of the passages’ shape in Wediombo area and its surroundings are explained through Figure 8 and Figure 9.
Figure 7. Cave maps of the study area
Figure 8. Characteristics of cross-sectional cave passages in Wediombo area and its surroundings in the form of:
(a) Elliptical passage in Greweng Cave, (b) Elliptical passage in Pulejar Cave, (c) Rectangular passage that is controlled by the layering plane of horizontal passage, (d and e) Canyon in Pulejar Cave, (f) Keyhole in Pulejar Cave, (g) Keyhole in Duren Cave, (h) Chasm passage formed between the combination of a joint and the layering plane, (i and j) Rectangular passage in Pulejar Cave, (k) Vertical passage that is controlled by joint (joint passage), (l) Joint passage that is controlled by the layering plane of horizontal passage in Duren Cave, (m) Vertical passage (shaft) in Pulejar Cave, (n) Sloping passage that is controlled by inclined joint in the rock layers.
Figure 9. The characteristics of the chambers in the caves in Wediombo and its surroundings: (a) Chamber shape that was formed from debris of the confluence of 3 passages in Pulejajar Cave; (b) Chamber shape in Pulejajar Cave that occurred due to collapse (c) The shape of chamber in Greweng Cave that formed due to collapse (d) Chamber in the form of a fairly large pool that was formed from debris and a large passage system in a small passage flow inside the Pulejajar Cave

4. Conclusion

Cave distribution in Wediombo area and its surroundings has clustered pattern that follows the joint and fault lines in the south of Gunung Sewu karst area. The results of the passage morphometry analysis show that Duren Cave and Greweng Cave are categorized as horizontal caves with straight passages, while the Pulejajar Cave is categorized as horizontal cave with winding (meandering) passages. The shape of the passages based on the value of the width and height ratio tends to be in the form of semi-circular passage and canyon with the direction of development that progressed towards the northeast and the southeast. The results of the passage morphography analysis seen from planview show that the Duren Cave and the Greweng Cave are single and straight passed caves, while the Pulejajar Cave is included in the group of single and winding passed cave. The variation of the shape of the cave’s passage that was seen from the front (cross section) of the caves in Wediombo area are rectangular passage, elliptical passage, canyon, joint passage, george sharped passage, keyhole, and chamber.

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