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RESEARCH ARTICLE

A Preliminary Study of Paleoflood Deposits of the Lukulo, Kebumen Regency, Central Java, based on River Geomorphology

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Abstract Lukulo is a river that flows through pre-tertiary rocks to the recent. The long Lukulo fluvial processes which included erosion, transportation, and deposition were depicted in extensive alluvial deposits downstream of the river. This vast alluvial plain may be a deposit result of the Lukulo flood in the past. The paleo-flood study is a study of flood events in the past with the technique used, namely knowing slack water deposits. Delineation of slackwater deposits is necessary to determine the location of paleoflood deposition. Geomorphology of Lukulo watershed is needed as a preliminary study to determine the characteristics of the Lukulo watershed. Based on geomorphological analysis of the Lukulo watershed with river geomorphological analysis, field research, and literature studies, the result of this watershed geomorphology was obtained, namely; the morphology of the Lukulo watershed included an elongated oblong shape of the watershed, with an average Rc value of all three segments (upstream, middle, and downstream) of 0,52. The average drainage density (Dd) of river flows in the Lukulo watershed is 8,05 km/km^2 (middle class). The Lukulo gradient upstream is 45^0, entering the middle is reduced to 30^0, and downstream the gradient is reduced to 10^0. The morphology and morphometry of the Lukulo watershed are interpreted to mean that Lukulo belongs to the medium-spanned watershed in terms of flood runoff and erosion. The lithology is a mixture of impermeable and permeable rocks. Delineation of diluvial and alluvial deposits is found in the upstream, middle, and downstream, of the Lukulo river. It depicts delineated paleoflood deposits in all segments of the river.

1. Introduction

Lukulo is the river that flows in the South Serayu Mountains in the north and flows relatively southwards with a length of 68,5 km. The area of the Lukulo watershed is 657,53 km^2, with the area of the watershed included in the Kebumen regency area of 572,84 km^2. The remaining area of the Lukulo watershed is included in the Wonosobo Regency and Banjarnegara Regency (BBWS Serayu-Opak, 2003). According to Raharjo & Saifudin (2008), the upper stream of the Lukulo is in Kaliwiro, Wonosobo while the downstream is in Tanggulangin village, Kebumen. Lukulo watershed administratively includes 3 (three) regencies, namely; 1. Kebumen regency; 2. Wonosobo regency, and 3. Banjarnegara regency. The dominant drainage pattern is dendritic in the upstream to the middle, while from the middle to the downstream the development is parallel to sub-parallel (Raharjo *et al*, 2010). Regionally, the physiography of the Lukulo watershed is located in the South Serayu Mountains and the Central Java Depression Zone (figure 1). The South Serayu Mountains consist of the western part and the eastern part. The western part is referred to as the uplift in the depression zone in West Java or as a new structure in Central Java. The eastern part of the Southern Serayu Mountains forms an anticline. the western and eastern part are separated by the Jatilawang Valley, towards the east it forms an anticline cut by the Serayu River. East of Banyumas, the anticline develops towards the east forming an anticlinorium with a width of 30 km from around Karangsambung to Banjarnegara while the eastern end of the South Serayu Mountains forms a dome from Purworejo to the Progo River valley and is known as the Kulon Progo Mountains. Between the Southern Serayu Mountains and the Northern Serayu Mountains, there is a Serayu Depression Zone (Central Java Depression Zone), which extends from Majenang-Ajibarang-Purwokerto-Jatilawang, and Wonosobo (Van Bemmelen, 1949).

The regional geological conditions of the Lukulo watershed and surrounding Kebumen have been studied by several researchers (Asikin, 1974; Suparka, 1988; Harsolumakso, 1996; Asikin *et al*, 1992; Yuwono, 1997; Prasetyadi, 2007; Setiawan *et al*, 2011; Mareta & Ansori, 2020). Asikin *et al* (1992), have compiled a stratigraphic sequence from old to young, namely; 1. Lukulo Melange Complex; 2. Karangsambung Formation; 3. Totogan Formation; 4. Diabase and Basalt Intrusion; 5. Waturanda Formation; 6. Penosogan Formation; 7. Halang Formation; 8. Peniron Formation; and 9. Alluvial.

The alluvial of Lukulo is a type of soil/rock deposits formed due to the deposit of fluvial processes of erosion, transportation, and sedimentation. According to Setyawan & Warsito, (1999), if the material carried by the water settles

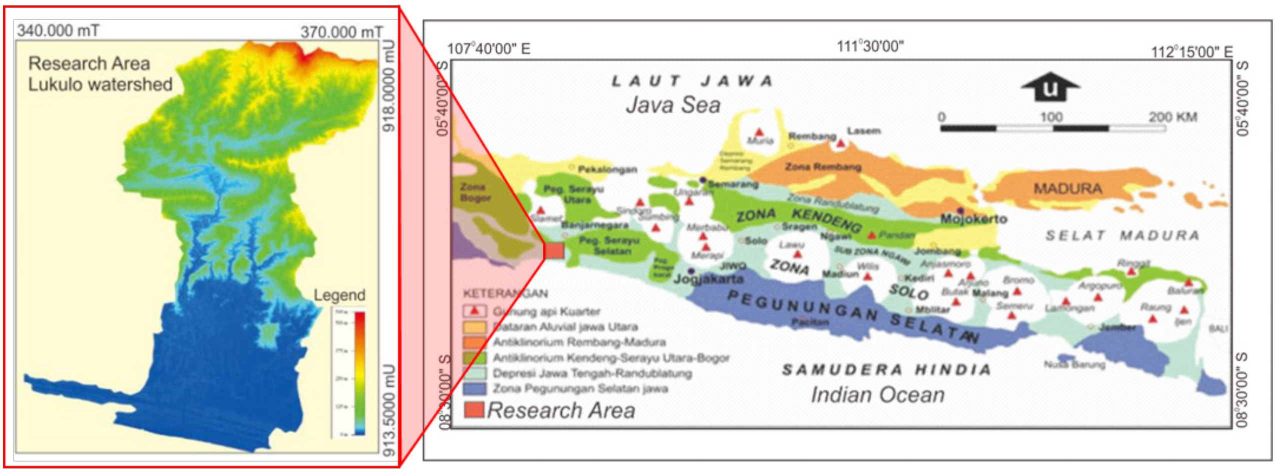

Figure 1. Physiography Map of Central Java modified from Van Bemmelen, R. W, 1949 (right), The Lukulo watershed shown in physiography (left)

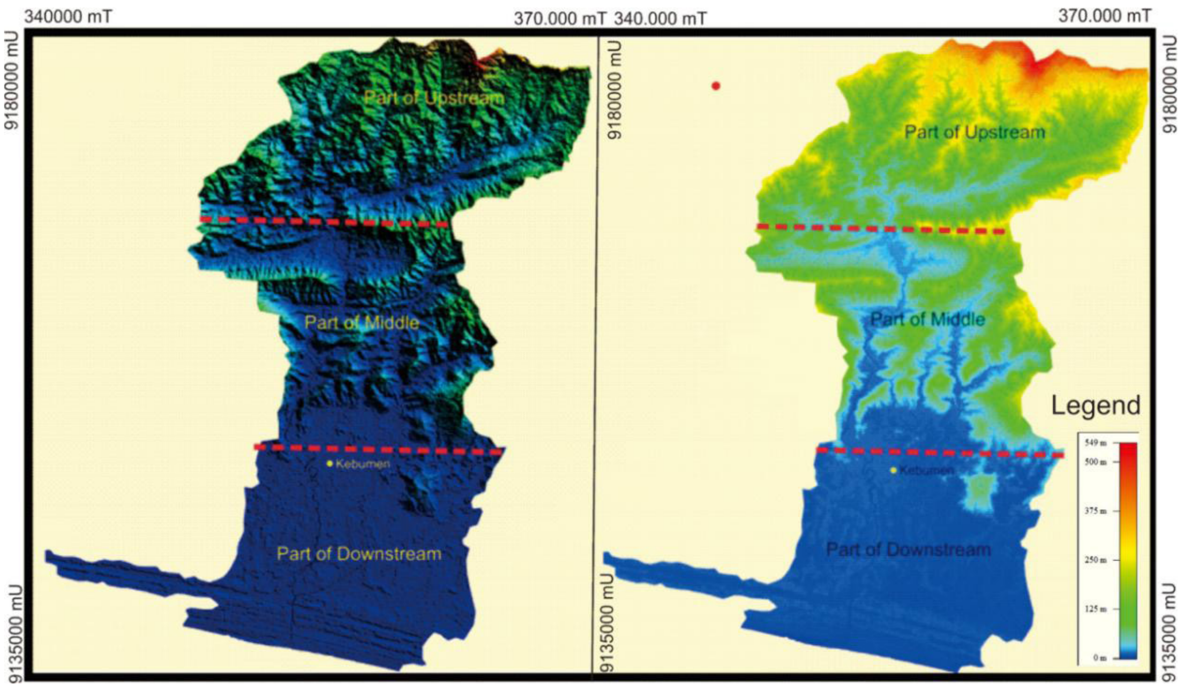

Figure 2. DEM of Lukulo watershed processed using Global Mapper 15

at the bottom of the cliff so that a row of mounds is formed, the material is called diluvial (colluvial). When the material is carried by the movement of water up to the river channel and deposited there, it is called alluvial. According to Mareta & Lubis, (2021), the alluvial of Lukulo is the result of erosion of Pre-Tertiary-age rocks in the upstream to middle and Tertiary age rocks in the middle to downstream.

The characteristics of the upstream Lukulo watershed have been studied by several researchers; (Saifudin & Ansori, 2007; Raharjo & Saifudin, 2008; Saifudin & Raharjo, 2009; Raharjo *et al*, 2010; Puswanto *et al*, 2014; Raharjo *et al*, 2016; Mareta & Hidayat, 2016; Mareta & Lubis, 2021). The characteristics obtained of the upstream Lukulo watershed are hills with steep slopes, which are an average of 33% (Raharjo & Saifudin, 2008), while the middle to downstream morphology is in the form of flats with a slope of 0-8% with a fairly wide spread of more than 50% (Saifudin & Ansori, 2007). The Lukulo River is included in the high-water regime index. A high-water regime index in a river will result in a large overflow of water (Raharjo *et al*, 2018). According to Mareta & Lubis (2021), based on calculations in the Welaran watershed (Upstream Lukulo sub-watershed), 0,62% of the rain falls into surface flows (runoff). The result of the calculation of sinuosity values in the upstream Lukulo watershed obtained values of 1,87 and 1,92. With this sinuosity value, it is indicated that the Lukulo River is an old stager river with a meander (Puswanto *et al*, 2013).

Flooding in the Lukulo River has been reported since 1928. The newspaper De Indische Courant dated December 14 reported a flooding event on this river that affected many livestock and 2000 village market stalls washed away. The water level of the Lukulo was recorded as high as 2 (two) meters and caused the cities of Kebumen, Prembun, and Kutowinangun to also be affected (Hindarto, 2015). Another major flood reported by the newspaper according to Hindarto (2015) was in 1861 and 1937.

Ancient flood studies (paleoflood) are a study of flood events in the past with the technique used, namely knowing slack water deposits (Stedinger & Baker, 1987). Paleoflood studies can be used when data on record flood events on the river are rarely found. Slack water deposits are sand and silt deposited by suspension currents, high-speed flooding that become a narrow canyon in resistant geological material. According to Benito *et al* (2004), paleoflood record was obtained from a new synergetic approach that combines past flood information from geomorphological settings and stratigraphic criteria that distinguish and connect flood units. Paleoflood data sources are geological indicators such as flood deposits, silt deposits, and/or erosion lines found along river channels, valley walls, terraces, and others.

River types based on the morphology of the river flow system according to Nichols (2019), consist of four, namely; 1. Straight-river; 2. Braided-river; 3. Anastomotic rivers; and 4. Meander-river. These types of river morphology cause the speed of flow and the river deposits it produces to be different. The process of abundant water flow during flooding in a river will bring rock and soil materials that will be deposited in the floodplain. There are three interaction zones between water and land in the fluvial system (Schumm, 1977; Potucek & Evans, 2019), namely; 1. The sediment supply zone; 2. The sediment transport zone; and 3. The deposition zone. The delineation of three zones of the river fluvial system is expected to determine the flood deposits that have occurred in the Lukulo. Schumm (1977), in his research on 35 sub-watersheds in Utah, USA, proved that the higher the relief ratio of a watershed, the higher the sedimentation rate.

This study aims to delineate paleoflood in the Lukulo in alluvial based on morphological and morphometric data of the river. The benefit of this study is the possible location of ancient flood deposits.

2. Methods

This research uses a combined method in the form of watershed geomorphology analysis from DEMNAS, field research and checking, and a literature study. The method in the form of Digital elevating analysis of the Lukulo watershed model is used especially to determine the characteristics of the shape of the Lukulo watershed against the possibility of frequent or infrequent watersheds. We divide the Lukulo watershed into three segments, namely, upstream, middle, and downstream, to find out in which segments the chance of Lukulo flood deposits will be recorded. The second method is that we do checking in the field, to obtain and observe the condition of the Lukulo watershed and river deposits along its outcrop. The literature study method was conducted to obtain secondary data on, among others, flood events that have occurred in the Lukulo River. The methodology stages are depicted in the research flow chart (Figure 3).

2.1. Study Area

The study area is in the Lukulo watershed. Boundary watershed is obtained from SHP DAS Indonesia, superimposed with a downloaded digital elevating model (DEM) from DEMNAS. The Indonesian National DEM (DEMNAS) was built from several data sources, including IFSAR data (5m resolution), TERRASAR-X (5m resampling resolution from 5-10m original resolution), and ALOS PALSAR (11.25m resolution), by adding mass point data used in making the Indonesian Topography Map. The spatial resolution of DEMNAS is 0.27-arcsecond, using the EGM2008 vertical datum (https://tanahair.indonesia.go.id/demnas). Lukulo watershed coordinates are 345.000-370.000 mT and 913.50000-918.0000 mU. The division of the Lukulo watershed into three segments (Figure 2), namely; 1. The part of upstream; 2. The part of the middle, and 3. The part downstream. The division of the Lukulo watershed segment is based on the conservation and morphological aspects of the Lukulo River. The division of these segments also facilitates delineating and analyzing each segment to determine the sediment deposits from flooding in the Lukulo River.

2.2. Analysis

Data analysis of the Lukulo watershed DEM used calculation and classification of the shape of the watershed of each segment, the relief ratio of each segment to know the time takes to collect water in a watershed, and the density of drainage in each segment. Calculation and classification used the formula as below;

Measurement of the width of each watershed segment using the formula from Seyhan (1977), namely;

$$W = A/Lb \quad (1)$$

with information, namely;

W = watershed width (km), A = watershed area (km^2), Lb = length of the main river (km).

Measurement of the relief ratio is to determine the time it takes to collect water in a watershed. Morphometric calculation of relief ratio used a formula from Strahler (1954), namely;

$$Su = (h_{85} - h_{10})/ 0.75\ Lb \quad (2)$$

With information, namely;

Su = slope of the river channel (river gradient), h_{85} = height at a distance of 0.85 Lb (masl), h_{10} = height at a distance of 0.1 Lb (masl), Lb = length of the main river (km).

The ratio of circulation (Rc) is a ratio of roundness to classify the shape of the watershed quantitatively. The ratio of circulation is related to geological structure, relief, and slope.

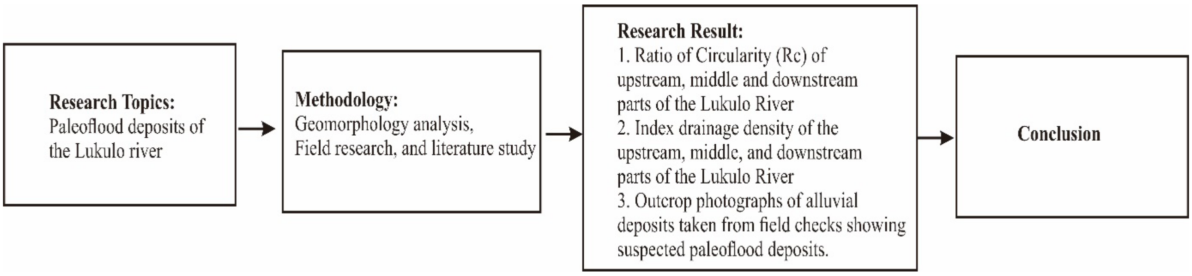

Figure 3. Research flowchart

A watershed with a low Rc value, generally, has an elongated shape, is not controlled in structure, and is included in the young phase of the river network. High Rc values, generally, has a rounded shape, are controlled by geological structure, and are included in the old phase of the river network (Wilson *et al*, 2009; Jamil *et al*, 2021). Calculation of Rc used a formula from Stahler (1954), namely;

$$Rc = 4\pi A/P^2 \quad \text{.......} 3$$

With information, namely;

Rc = Ratio of circularity, A = watershed area (Km^2), P = perimeter of watershed (km)

Drainage density (Dd) is an index that shows the number of tributaries in a flow area. Drainage density is closely related to relief, density of valleys, rocks, soils, climate, and vegetation (Montgomery & Dietrich, 1989). Watersheds that have low drainage density (Dd) value are generally dominated by permeable rock, resistant, dense vegetation, and low relief rocks. Watersheds that have high drainage density (Dd) value are generally dominated by rocks that are impermeable, non-resistant, have sparse vegetation, and have high relief (Vittala *et al*, 2009; Sukristiyanti *et al*, 2017; Jamil *et al*, 2021). The calculation of drainage density (Dd) used a formula from Smith (1950), namely;

$$Dd = L/A \quad \text{.......} 4$$

With information, namely;

Dd = drainage density (km/km^2), L = total length of the river (km), A = watershed area (km^2)

Lindsey et al (1996), stated that if the Dd value is smaller than 1 $mile/mile^2$ (0,62 km/km^2), then the watershed will experience flooding, while if the Dd value is greater than 5 $mile/mile^2$ (3,10 km/km^2), then the watershed will often experience drought.

3. Result and Discussion

a. Upstream Lukulo Watershed

Based on the calculation and analysis of the digital elevating model (DEM) processed by Global Mapper 15, morphometric values were obtained in the Upstream Lukulo watershed (figure 4). The length of Lukulo in the upstream segment is 21,74 km with a watershed perimeter of 66,269 km. The area of Upstream Lukulo watershed is 222,02 km^2. Ratio of circularity (Rc) value 0,63 (oblong) (table 1). The drainage density (Dd) value of the Upstream Lukulo River is 6,67 km/km^2 (medium class) (table 2).

The shape of the Upstream Lukulo watershed is oblong with a value of 0,63 (Wilson *et al*, 2009), this form describes the Upstream Lukulo being in the middle span in terms of maximum runoff and erosion.

Table 1. Classification Ratio of Circularity (Rc)

No	Rc value	Rc class
1.	<0,5	Very oblong
2.	0,5 – 0,7	Oblong
3.	0,7 – 0,8	Slightly oblong
4.	0,8 – 0,9	Oval
5.	0,9 – 1,0	Circular

Source: Wilson *et al*, 2009

Table 2. Index of Drainage density

N0	Dd index	Class
1.	<0,25 km/km^2	low
2.	0,25 – 10 $km.km^2$	medium
3.	10 – 25 km/km^2	high
4.	> 25 km/km^2	Very high

Source: Lindsey *et al* (1996)

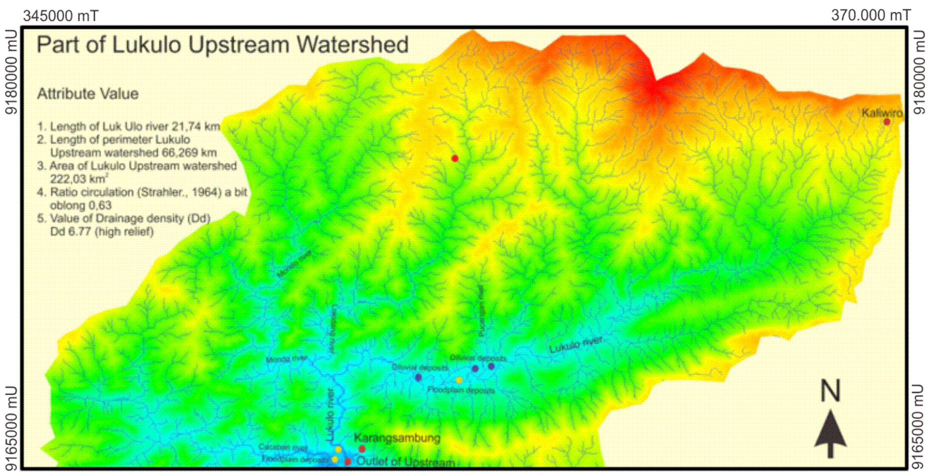

Figure 4. Morphology and Morphometry of the Upper Lukulo watershed as a result of geomorphological analysis

The morphology of the Upstream Lukulo watershed spreads with a dendrite-rectangular flow pattern (figure 4). The dendrite-rectangular pattern depicts the geomorphology of the Upper Lukulo watershed as influenced by the presence of geological structure (fault) resulting in the presence of a weak field. According to Mareta (2016), dendritic patterns describe the uniformity of rock hardness.

The drainage density (Dd) value of the Upstream Lukulo watershed of 6,77 km/km^2. The value illustrates that the Upstream Lukulo watershed area is included in the medium class. According to Lindsey *et al* (1996), medium-density drainage has similarities with the medium texture. The medium texture illustrates that the lithology in the Upstream Lukulo watershed is a mixture of impermeable and permeable rocks (Smith, 1950). The higher drainage density value illustrates that more water is being held in river bodies and increases the risk of flooding. The river gradient in the Lukulo consists of two segments (figure 5). In the first segment with a river length of 10-11 km, the river gradient is very high with an angle of almost 45^0, while in the second segment on the length of the river 11-21,74 km (outlet), the gradient becomes low (less than 10^0). This large gradient change makes around the outlet found many deposits of diluvial and alluvial (floodplain).

The lithology in the Upstream Lukulo watershed namely;

1. The Melange Lukulo Complex is a variety of fragments mixed in a mass of black shale with tectonic inclusions, which is Cretaceous to Oligocene age;
2. Karangsambung Formation is scaly clay with blocks of limestones, conglomerates, sandstones, and basalt mixed due to the olistrostrome process, which is of Eocene to Oligocene age;
3. Totogan Formation is a breccia with components of claystones, sandstones, limestones, and basalt, a matrix of scaly clay, which is Oligocene to Miocene age.
4. A Tuff Member of the Waturanda Formation is an alternation of glass tuff, crystal tuff, calcareous sandstones, and tuffaceous marls, which is Miocene age.
5. Aluvium (Qa) is clays, silts, sands, gravels, and pebbles, which are Holocene to Recent age.

The other rock formations are not exposed in the Upstream Lukulo watershed.

b. Middle Lukulo watershed

Based on the calculation and analysis of the digital elevating model (DEM) processed by Global Mapper 15, morphometric values were obtained in the Middle Lukulo watershed (figure 6). The length of Lukulo in the middle segment is 19,615 km with a watershed perimeter of 68,997 km. The area of the Middle Lukulo watershed is 207,75 km^2. Ratio of circularity (Rc) value 0,55 (oblong) (table1). The drainage density (Dd) value of the Middle Lukulo River is 14,21 km/km^2 (high class) (table 2). The shape of the Middle Lukulo watershed is oblong with a value of 0,55 (Wilson *et al*, 2009), this form describes the Middle Lukulo being in the middle span in terms of maximum runoff and erosion.

The morphology of the Middle Lukulo watershed spreads with a dendrite-trellis flow pattern (figure 5). The dendrite-trellis pattern depicts the geomorphology of the Middle Lukulo watershed as influenced by the presence of geological structure (fold), where the Lukulo River flows straight along a steep valley from both sides (Brujul hills and Selaranda hills) (figure 6). According to Mareta (2016), dendritic patterns describe the uniformity of rock hardness.

The drainage density (Dd) value of the Middle Lukulo watershed of 5,5 km/km^2. The value illustrates that the Middle Lukulo watershed area is included in the high class. According to Lindsey *et al* (1996), high-density drainage has similarities with the high texture. The high texture illustrates that the lithology in the Middle Lukulo watershed is a mixture of impermeable rocks (Smith, 1950). The higher drainage density value illustrates that more water is being held in river bodies and increases the risk of flooding. The river gradient in the Lukulo consists of three segments (figure 7). In the first segment with a river length of 1,25-11,25 km, the river gradient is very high with an angle of almost 30^0, while in the second segment at a river length of 11,25-16,125 km, the gradient becomes low (less than 10^0), and the last segment on the river length of 16,125-19,6 km (outlet), the gradient rises again. A large gradient change in segment 2, making around the outlet found many diluvial and floodplain (alluvial) deposits.

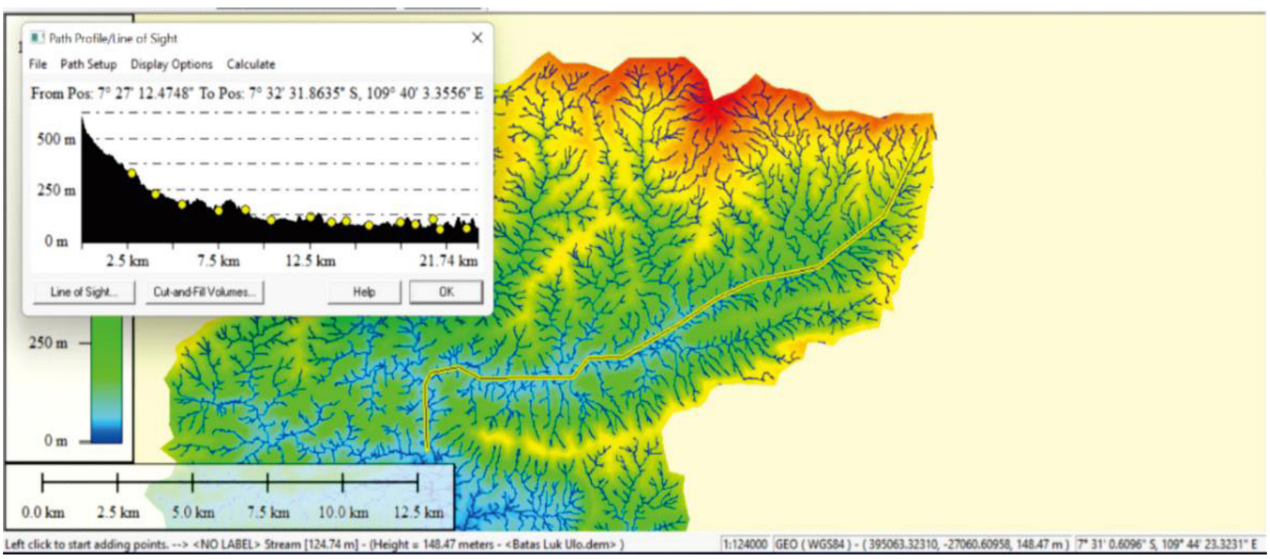

Figure 5. Cross-section of the Upstream Lukulo River from Kaliwiro to Karangsambung

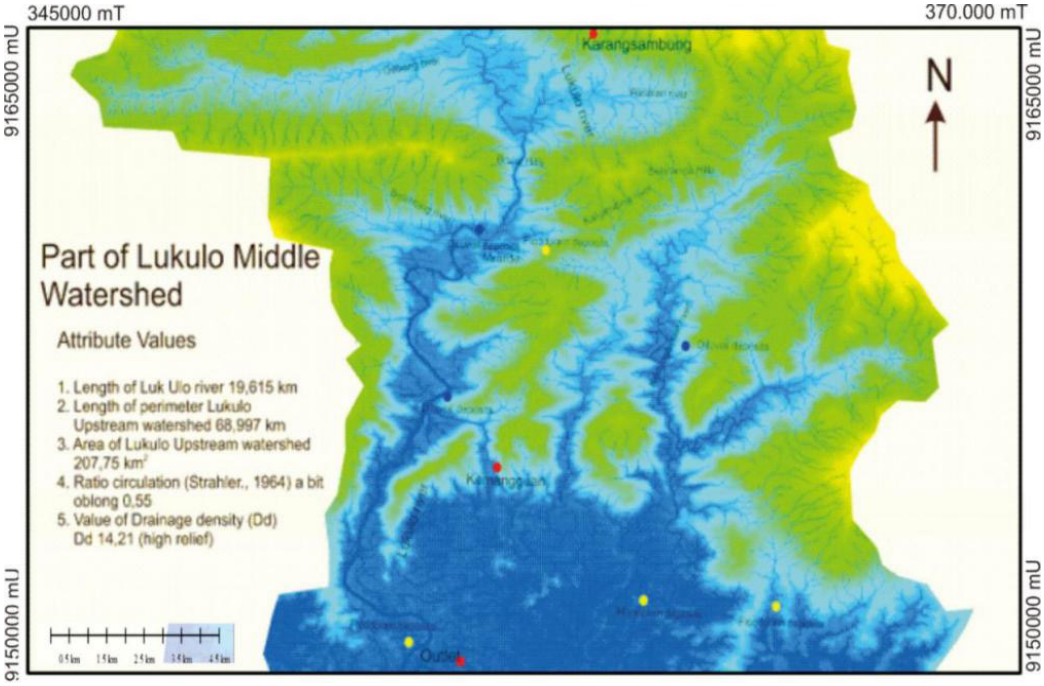

Figure 6. Morphology and Morphometry of the Middle Lukulo watershed as a result of geomorphological analysis

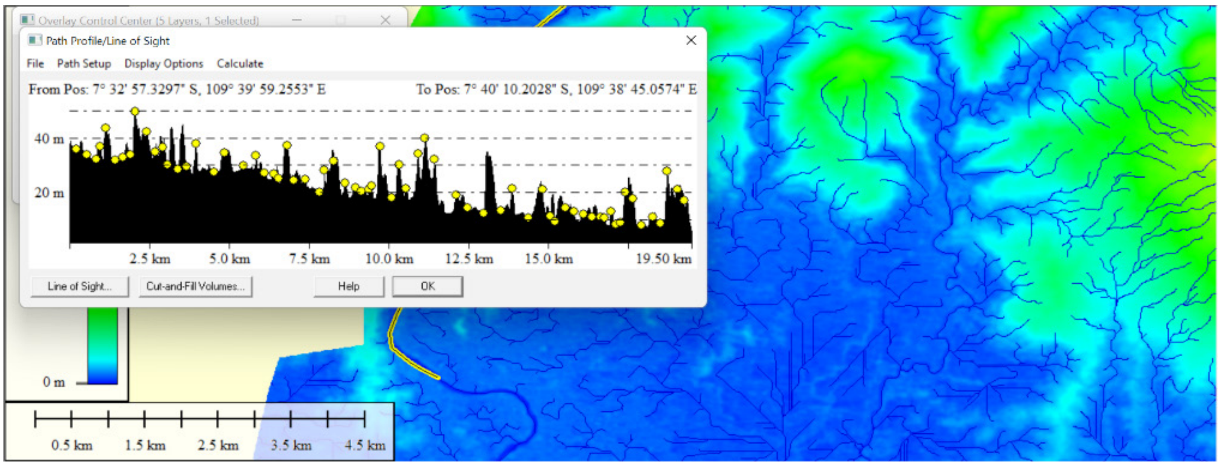

Figure 7. Cross-section of the Middle Lukulo River from Karangsambung to the outlet

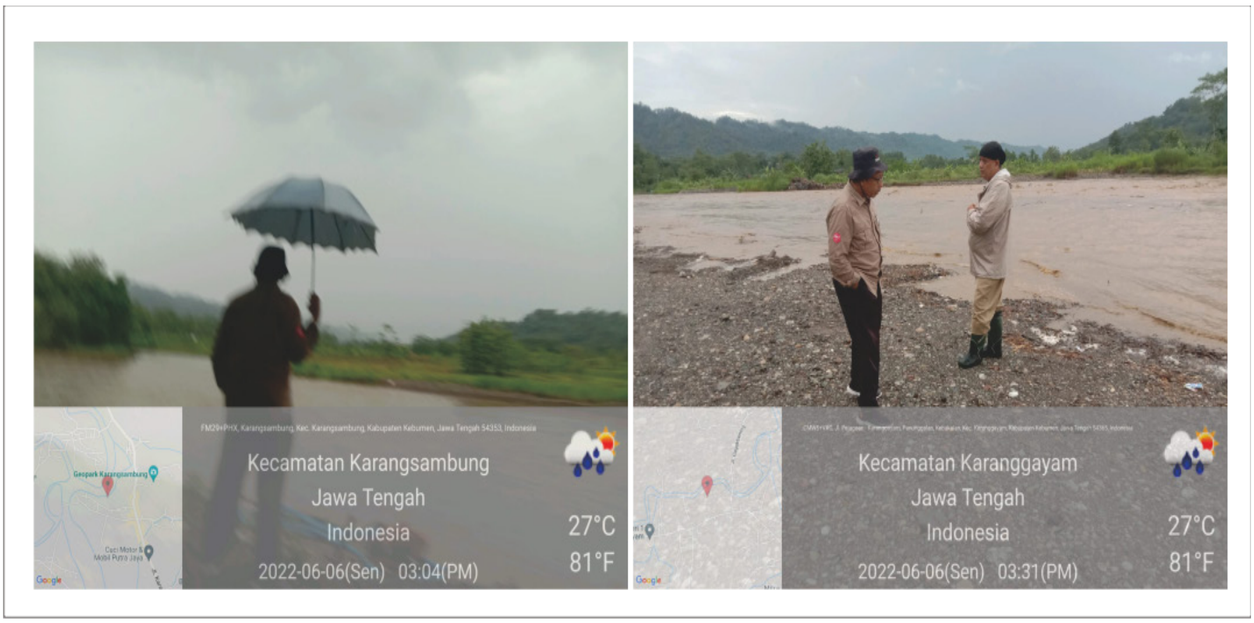

Figure 8. The Lukulo River around Pesanggrahan, Karangsambung which shows alluvial deposits and high-water conditions in the Middle Lukulo watershed (Photo taken by Mareta, 2022)

The lithology in the Middle Lukulo watershed namely;

1. Karangsambung Formation is scaly clay with blocks of limestones, conglomerates, sandstones, and basalt mixed due to the olistrostrome process, which is of Eocene to Oligocene age;
2. Totogan Formation is a breccia with components of claystones, sandstones, limestones, and basalt, a matrix of scaly clay, which is Oligocene to Miocene age.
3. A Tuff Member of the Waturanda Formation is an alternation of glass tuff, crystal tuff, calcareous sandstones, and tuffaceous marls, which is Miocene age.
4. Aluvium (Qa) is clays, silts, sands, gravels, and pebbles, which are Holocene to Recent age.

The other rock formations are not exposed in the Middle Lukulo watershed.

c. The Downstream Lukulo Watershed

Based on the calculation and analysis of the digital elevating model (DEM) processed by Global Mapper 15, morphometric values were obtained in the Downstream Lukulo watershed (figure 9). The length of Lukulo in the downstream segment is 23,019 km with a watershed perimeter of 82,268 km. The area of the Downstream Lukulo watershed is 201,2 km^2. The ratio of circularity (Rc) value is 0,37 (very oblong) (table 1). The drainage density (Dd) value of Downstream Lukulo River is 3,16 km/km^2 (medium class) (table 2). The shape of the Downstream Lukulo watershed is very oblong with a value of 0,37 (Wilson *et a*l, 2009), this form describes the Downstream Lukulo being in the high span in terms of maximum runoff and its erosion.

The morphology of the Downstream Lukulo watershed spreads with a dendrite-rectangular flow pattern (figure 9). The dendrite-parallel pattern, where the parallel pattern depicts the geomorphology of the Downstream Lukulo of the sharp slope difference between the hills and the flattening. According to Mareta (2016), dendritic patterns describe the uniformity of rock hardness. There is a radial pattern of the Cantel hills joining the Kedungbener River and the Lukulo River as the main river.

The drainage density (Dd) value of the Downstream Lukulo watershed of 3,16 km/km^2. The value illustrates that the Downstream Lukulo watershed area is included in the medium class. According to Lindsey *et al* (1996), medium-density drainage has similarities with the medium texture. The medium texture illustrates that the lithology in the Downstream Lukulo watershed is a mixture of impermeable and permeable

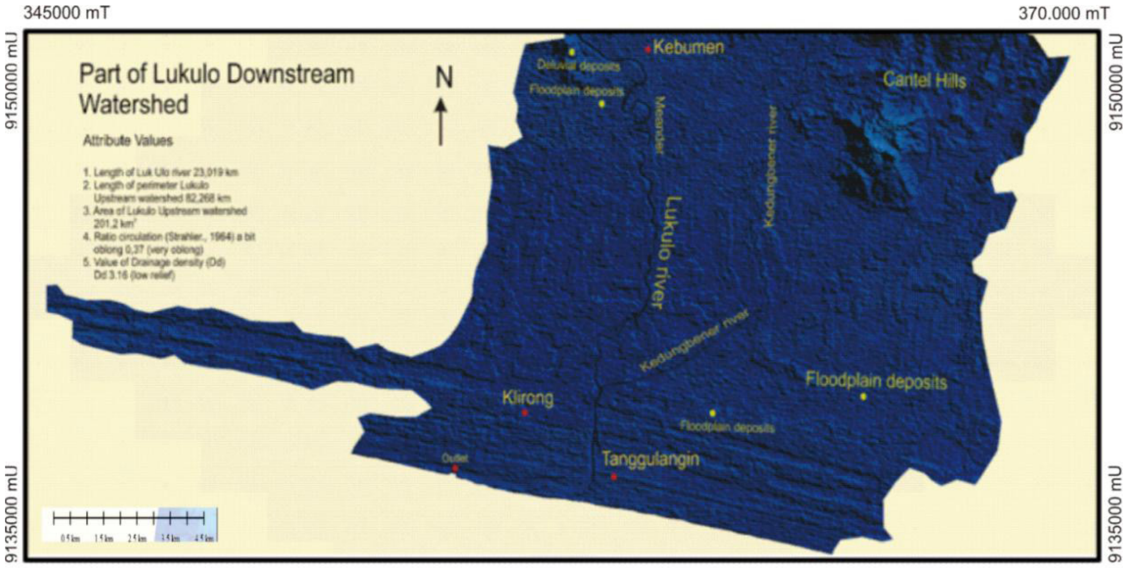

Figure 9. Morphology and Morphometry of the Downstream Lukulo watershed as a result of geomorphological analysis

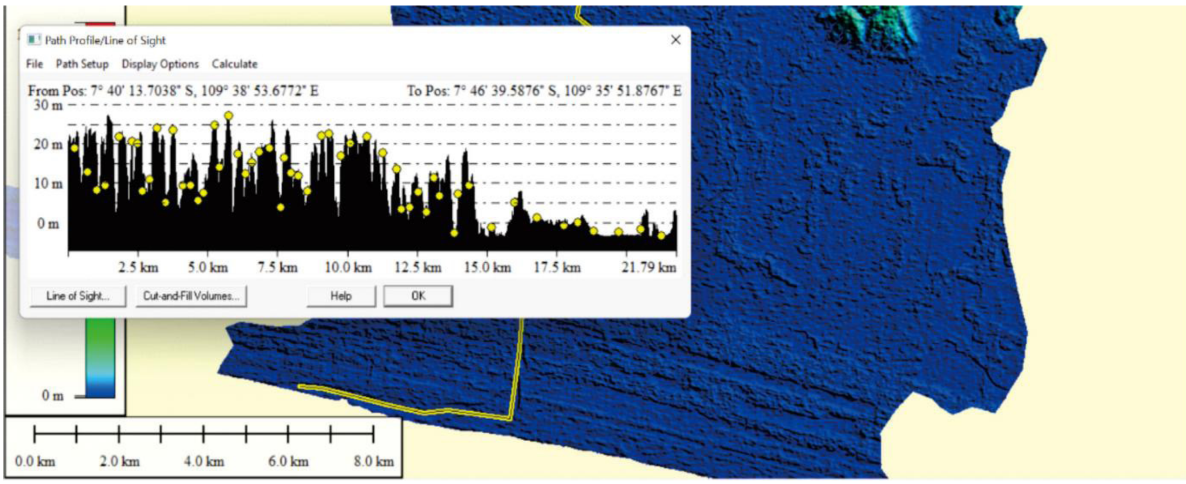

Figure 10. Cross-section of the Downstream Lukulo River from Kebumen to outlet

Figure 11. Thick alluvial deposits in the Middle to Downstream segment are suspected to be paleo-flood deposits of the Lukulo River (Photo taken by Mareta, 2022)

rocks (Smith, 1950). The higher drainage density value illustrates that more water is being held in river bodies and increases the risk of flooding. The Dd value obtained in the Downstream Lukulo watershed is increasingly visible from the river gradient. The downstream Lukulo watershed whose relief is very rough with a river gradient trend of 20^0 (figure 10). Gradient differences make for diluvial deposits in the inlet segment and extensive floodplain (alluvial) in the alluvial segment (figure 10).

The lithology in the Downstream Lukulo watershed namely;

1. Penosogan Formation is an alternation of calcareous sandstones, claystone, tuffs, marls, and calcarenite, under the influence of turbidity currents, which is Miocene age.
2. Halang Formation is an alteration of sandstones, claystones, tuffs, and marls, with breccia intercalation, under the influence of turbidity currents and sub-marine slidings, which is Miocene to Pliocene age.
3. Breccia Member of Halang Formation is a breccia with components of andesite, basalt, and limestone, a matrix of coarse-grained tuffaceous sandstones, intercalations of sandstone and basaltic lava, which is an alternation of glass tuff, crystal tuff, calcareous sandstones, and tuffaceous marls, which is Miocene to Pliocene age.
4. Peniron Formation is polymeric-breccia with components of andesitic rocks, claystone, limestone, matrix of tuffaceous sandstones, and tuff intercalations, which is Pliocene age.
5. Aluvium (Qa) is clays, silts, sands, gravels, and pebbles, which are Holocene to Recent age.

The other rock formations are not exposed in the Middle Lukulo watershed.

Delineation of diluvial and alluvial deposits in the Lukulo watershed is an important key to seeing the paleo-flood that has occurred.

4. Conclusion

The morphology of the Lukulo watershed includes an elongated oblong shape, with the average Ratio of circularity (Rc) of the three segments (upstream, middle, and downstream) of 0,5166 (rounded to 0,52), where sequentially from the most oblong downstream segment (0,37), is the most oblong segment then the middle (0,55), and the upstream segment (0,63). This elongated oblong shape, depicting the Lukulo watershed is in the middle span in terms of maximum runoff of flooding and its erosion.

The gradient of the Lukulo River upstream is very high (45^0) but entering an outlet in Karangsambung is flattened with the shape of a meandering river. The high gradient plus the sharp meander of the Lukulo River make it widely found diluvial in the upstream. Entering the middle of the river gradient is divided into three segments with a reduced river inclined angle (30^0), compared to upstream, so that in this segment the Lukulo River has two meanders with a wide alluvial (floodplain). Diluvial (the result of deposits of the branching of the Lukulo with tributaries) is found also in this middle. Entering the downstream, the gradient of the Lukulo River is again reduced (20^0), which is caused by a large height difference entering the flat and wide alluvial (floodplain). Diluvial is still delineated and found downstream other than the dominating alluvial (floodplain).

The lithology of the Lukulo watershed from upstream, middle, and downstream, shows the increasingly younger stratigraphy the downstream, namely: The Melange Lukulo Complex is a variety of fragments mixed in a mass of black shale with tectonic inclusions, which is Cretaceous to Oligocene age; Karangsambung Formation is scaly clay with blocks of limestones, conglomerates, sandstones, and basalt mixed due to the olistrostrome process, which is of Eocene to Oligocene age; Totogan Formation is a breccia with components of claystones, sandstones, limestones, and basalt, a matrix of scaly clay, which is Oligocene to Miocene age; A Tuff Member of the Waturanda Formation is an alternation of glass tuff, crystal tuff, calcareous sandstones, and tuffaceous marls, which is Miocene age; Penosogan Formation is an alternation of calcareous sandstones, claystone, tuffs, marls, and calcarenite, under the influence of turbidity currents, which is Miocene age; Breccia Member of Halang Formation is a breccia with components of andesite, basalt, and limestone, a matrix of coarse-grained tuffaceous sandstones, intercalations of sandstone and basaltic lava, which is an alternation of glass tuff, crystal tuff, calcareous sandstones, and tuffaceous marls, which is Miocene to Pliocene age; Peniron Formation is polymeric-breccia with components of andesitic rocks, claystone, limestone, matrix of tuffaceous sandstones, and tuff intercalations, which is Pliocene age; Aluvium (Qa) is clays, silts, sands, gravels, and pebbles, which are Holocene to Recent age.

The youngest alluvial (floodplain) deposits (Holocene to Recent) are delineated in all segments (upstream, middle, and downstream). This illustrates the ancient (paleo-flood) deposits delineated in all segments of the Lukulo watershed.

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