Watershed Characteristics of West Progo Dome and Its Implications on Neotectonic

by Listiyani Retno Astuti

Watershed Characteristics of West Progo Dome and Its Implications on Neotectonic

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Abstract. This geomorphological study discusses the characteristics of the watershed that compose the West Progo Dome, conducted using a field survey method, topographic map analysis, and remote sensing imagery. Analysis of watershed characteristics includes area, flow pattern, bifurcation ratio (R_b), and river density (D_d), accompanied by statistical analysis of the T^2-Hotelling multivariate mean difference test. The results shows that the West Progo Dome has three large watersheds, namely the Bogowonto, Serang, and Progo watersheds, with an area of about 270.4, 110.9, and 140.3 km^2, respectively. The drainage patterns in this area are dendritic, radial, sub-parallel, trellis, rectangular and angulate. R_b of drainage in the study area varies from low to high, indicating the presence of tectonic influences. The R_b value in System IIA is 2.0 – 5.8, and in System III is 1.290 – 6.630. The D_d value on System IIA is 0.921-1.592 km/km^2 and on System III is 0.990-1.200 km/km^2. This very rough D_d also indicates the presence of tectonic influences. The average R_b and D_d values between System IIA and System III were not significantly different. It means that tectonics influences the watershed morphometry in the West Progo Dome and is still active until the Quaternary (neotectonic).

Keywords: Watershed, drainage pattern, drainage density, bifurcation ratio, morphometry

1. Introduction

The physiography of the West Progo Dome is interesting to study because of its uniqueness in geology. The West Progo Dome is part of the physiography of the South Serayu Mountains but with an anomaly in its longitudinal direction [1]. The morphology of these hills is a unique landscape, where the shape resembles a dome that extends relatively north-south. Because of this peculiarity, the authors are interested in studying this dome concerning the tectonics that controls the dome's morphology. In brief, this research wants to learn aspects of morphometry and its relation to tectonics.

Many researchers have studied drainage morphometric parameters and their influence on landforms and geology in various regions [2-6]. In recent years, morphometric analysis has become an important concern and has been applied in various aspects of geological and environmental perspectives [4,5,7].

Furthermore, the morphology of the drainage basin can be studied as an indicator of active geological structures (*Bahrami et al, 2020*). The river network morphometric index, which includes drainage density, flow length, drainage pattern, and drainage basin area, can be evaluated to understand the geological structure of a site [4]. Analysis and interpretation of morphometric data can be used to interpret morphoneotectonics related to buried rocks and structures. In addition, the flow profile can be used to identify vertical deformations affecting the drainage network [8].

In environmental geology, morphometric analysis based on the GIS technique is a competent tool for hydrogeological studies. These studies help identify and plan groundwater potential zones and watershed management [3]. Based on geomorphic parameters, knowledge of drainage patterns has also been widely applied in various fields, including hydrological modeling, water resource management, and flood risk analysis [7].

The rapid development of modern remote sensing technology provides spatial data that provides a wealth of information about drainage networks [2]. This research also uses remote sensing image interpretation to provide spatial data.

This watershed study in the West Progo Dome was carried out to determine the characteristics of the watershed and to see the tectonic influence on the morphometry. The watershed morphometry includes area, flow pattern, bifurcation ratio (R_b), and river density (D_d). In particular, the morphometric variables studied to see the tectonic influence in this study were R_b and D_d.

The research area is limited to the West Progo Dome, at coordinates 110°00'00” – 110°16'00” E and 7°34'00” - 7°52'30" S. This area is located in the Kulon Progo Regency, Yogyakarta Special Region, and Purworejo Regency, Central Java (Figure 1).

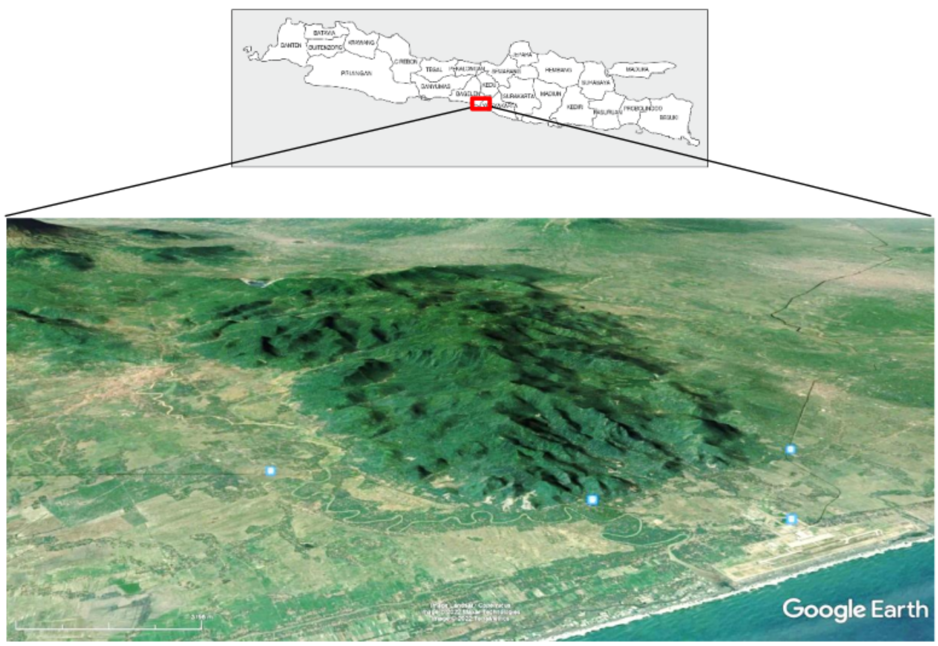

Figure 1. The landscape view of the West Progo Dome from the southwest side.

This research is a geomorphological study of the West Progo Dome, focused on watershed morphometry. The aim is to determine the characteristics of the dome's watershed and its relation to tectonics that affect the research area's geomorphology. Tectonic analysis was carried out for morphometry of watersheds which are located in the Quaternary rock (System III) and the unconformable Tertiary rock (Kaligesing–Dukuh Formation) below it (System IIA).

2. Methods

This research on morphometry was carried out by analyzing secondary data, which included topographic maps and remote sensing images, and equipped with ground checks in the field. The stages of the research, in brief, are as follows.

1. Determination of watershed was based on topographic maps and 3D morphology through Landsat images, aerial photographs, and topographic maps, compiled with field data and google earth application.
2. Interpretation of Landsat 7 ETM+ image, aerial photography, and topographic maps. Landsat image interpretation is made manually and with computer aids.
3. The interpretation of topographic maps is prioritized for the forms of drainage patterns and the distribution of watershed/sub watershed for each system.
4. Comparing the variables R_b and D_d in System IIA and System III were analyzed using the T^2-Hotelling multivariate mean difference test to determine the role of tectonics in the study area.

Bifurcation ratio (R_b) is the ratio of the number of streams of a certain order (N_u) to the number of streams of a higher order (N_{u+1}) [9]. Rb is obtained based on a formula: the tributaries' ratio to the main river. The formula is [10]:

$$R_b = \frac{N_u}{N_{u+1}} \quad (1)$$

Where :

R_b = Bifurcation ratio index

N_u = The number of streams for the order-u

N_{u+1}= The number of streams for the order-u+1

Drainage density (D_d) is defined as the river channel density [9]. D_d is an index number that shows the number of rivers in a watershed/sub-watershed. The index can be obtained by the following equation [11]:

$$D_d = \frac{\sum L}{A} \quad (2)$$

Where :

D_d = Flow density

L = The total length of the river, including the length of the tributary (Km)

A = Area of watershed/sub watershed (Km^2)

A low Dd indicates a coarse drainage texture, while a high D_d indicates a fine texture [9].

3. Results and Discussion

3.1. Watershed Delineation on The West Progo Dome

The division of watersheds, including sub-watershed as the constituent units of watersheds, uses a topographic base map and is assisted by a morphological unit map and three-dimensional morphological features of the study area. The delineation of the watershed boundary is done by drawing a line along the hill ridge that intersects the contour. The delineation of all river branches includes main rivers, intermittent rivers, and perennial rivers.

In the above manner, the study area can be divided into three watersheds (Table 1) with several sub-watersheds [12] (Figure 2). Some examples of tributary appearances that represent each of these watersheds are shown in Figure 3.

Table 1. Location and area of the watershed in the West Progo Dome.

Watershed	Location	Rock	Area (km^2)
Bogowonto	The watershed is in the western part of the West Progo Dome, flowing from the north to the south of the dome; covering the areas of Bener, Loano, Kaligesing, Bagelen, Samigaluh, Kokap.	Andesite breccia unit; andesite lava unit; and alluvial deposit.	270.4
Serang	Flows at the southern end of the central dome, covering the areas of Kokap, Girimulyo, Pengasih.	Kaligesing – Dukuh andesite breccia unit; Jonggrangan – Sentolo limestone unit; alluvial deposit.	110.9
Progo	The watershed is in the north and east and partly in the southeast of the dome; covering the areas of Salaman, Borobudur, Samigaluh, Kalibawang, Girimulyo, Nanggulan, Sentolo.	Kaligesing – Dukuh andesite breccia unit; Jonggrangan – Sentolo limestone unit; Nanggulan sandstone - claystone unit; and alluvial deposit.	140.3

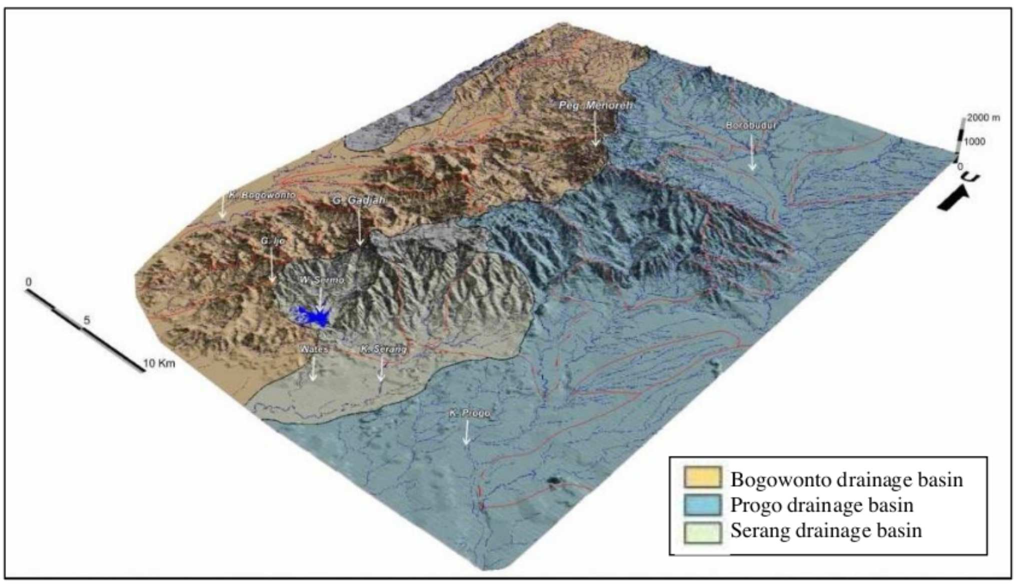

Figure 2. The 3D view of the watershed in the West Progo Dome [12].

3.2. Watershed Characteristics

3.2.1. Drainage pattern. The landscape's appearance in the form of a distribution system as a pattern of continuity of the tributaries and the main river together form a pattern called the drainage pattern. Flow patterns are generally controlled by geological structures and lithological types in the watershed region [13].

Figure 3. Morphological photos of tributaries included in the Bogowonto (a), Serang (b), and Progo watersheds.

From the interpretation results, there are six drainage patterns in the study area: dendritic, radial, sub-parallel, trellis, rectangular and angulate [14] (Figure 4).

(1) Dendritic

This pattern occupies the eastern part of the study area around the Progo River and slightly in the western part around the Bogowonto River. The Progo and Bogowonto rivers flow to the south with a wide downstream valley resembling the letter U, indicating that vertical erosion is no longer intensive. This drainage pattern is shaped like tree branches that reflect the same rock resistance (deposits of volcanic material from Mt. Merapi). This drainage pattern has horizontal or sloping layers with less clear structural control.

(2) Radial

This pattern occupies the central-south part of the study area, which is part of the upper reaches of the Bogowonto and Serang Rivers. The former ancient volcanoes probably control this radial pattern in this area (Mt. Gadjah and Mt. Ijo).

(3) Sub-parallel

This pattern occupies the northeastern part of the study area, which is upstream of the Progo River on the southwest slope of Mt. Merapi. This pattern is indicated by the direction of river flow almost parallel toward the Elo River. This pattern is controlled by a gentle slope starting from the upper slopes of Mt. Merapi. The lithology is dominated by volcanic deposits that are not yet compact and have relatively uniform resistance.

(4) Trellis

This pattern occupies the northern part of the study area around the northwestern part of the Progo, Sileng, and Merawu Rivers. This pattern is characterized by small river branches whose flow direction is almost perpendicular to the main river. This pattern develops because rivers and their tributaries are controlled by geological structures (faults and joints).

(5) Rectangular

This pattern occupies the west-central part and partly in the southeastern part of the study area. In the west-central part, this pattern is found around Kaligesing. Whereas, in the southeastern part, it is found in the sub-branches of Serang and Progo Rivers.

This pattern is characterized by tributary branches that flow almost perpendicular to the direction of the main river but are not as dense or complex as the trellis pattern. This pattern is controlled mainly by cracks (faults) in the rock that act as the base for the flow pattern.

(6) Angulate

This pattern is spread over the narrowest area, occupying the middle part of the research area, which is the upper reaches of the western part of the Serang River. This pattern is characterized by sharp river bends due to joints that develop on coarse-grained lithology with horizontal bedding.

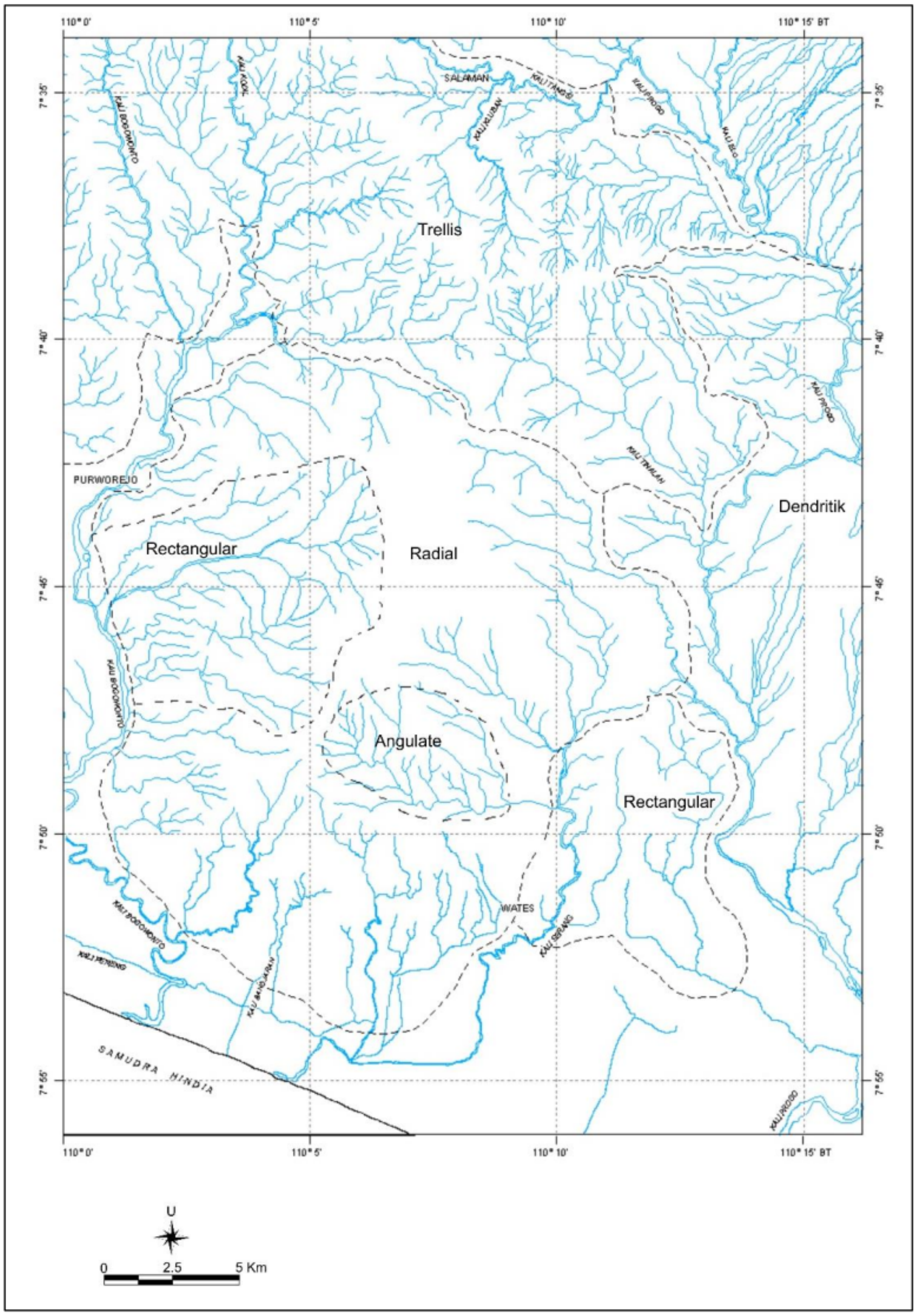

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Figure 4. Map of the drainage pattern of the research area [12].

3.2.2. Bifurcation ratio (R_b). In watershed analysis, the bifurcation ratio (R_b) is an important parameter to be analyzed. R_b can indicate the existence of geological influences, both rocks and geological structures [5].

There is no definite classification for the value of R_b, but from several papers, it can be concluded that R_b can be categorized into low (< 5) and high (>5) [15]. A low R_b value (0 - 5 km/km^2) indicates a highly permeable area [5]. R_b values < 3 are usually found in almost flat areas and have no structural effect. R_b values ranging from 3-5 occur in areas with geological structures, but these structures have little effect on drainage patterns [5,9]. R_b on the watershed with normal category indicates that the watershed has moderately permeable rock layers and coarse drainage texture [2].

Data collection from the field is in the form of a field test/ground check at certain places, which are considered to strengthen the results of the verification test. The tabulation of R_b and D_d values in the West Progo Dome is shown in Figure 5.

Based on the calculations, the value of R_b in System IIA is known to be 2.0 – 5.8, and in System III, it is 1.290 – 6.630 [12] (Table 2). It means that the West Progo Dome has a drainage system with varying R_b (low to high), both in Tertiary rock (System IIA) and Quaternary (System III). The variations in these two rock systems indicate that the geological structure plays a more important role in controlling the branching system of the river.

3.2.3. Drainage density (D_d). D_d can be divided into two classes, namely low/coarse and high/fine class (Sukristiyanti et al, 2018). Some researchers divide it into five classes, namely very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) km/km^2 [16,17].

A low D_d (<1) indicates a coarse drainage texture, meaning less runoff and high percolation in the watershed [3]. D_d in the moderate category of watershed indicates that the watershed has a moderately permeable rock layer and a coarse drainage texture [2].

The value of D_d in the study area in the System IIA is 0.921-1.592, while in System III, it is 0.990-1.200 km/km^2 [12] (Table 2). It indicates that the West Progo Dome has a very coarse density drainage system.

Several things that affect D_d include rock type, fracturing, foliation, soil type, relief, vegetation, rainfall, and evapotranspiration. The higher the permeability, the lower D_d [11]. Low D_d can indicate the presence of rock or soil with high permeability. However, the geology of the study area does not support this because the old rocks that dominate the West Progo Dome are low-permeable. Thus, the low river density in the study area is most likely controlled by the geological/tectonic structure.

3.3. Implications for neotectonics

The characteristics of R_b and D_d were analyzed to see the influence of neotectonics in the study area. The tectonic effect on the parameters of R_b and D_d was then studied using multivariate statistics. Tectonics affecting Tertiary rocks are interpreted to also develop into the Quaternary (neotectonic). The presence of neotectonics is characterized by the similarity of R_b and D_d in the Quaternary deposits and the older (Tertiary) rocks [12].

The effect of tectonic on the parameters of R_b and D_d can be determined by comparing them simultaneously in Tertiary rocks (System IIA) and Quaternary deposits (System III). Tests involving the two variables (bivariate) were carried out with the T^2-Hotelling multivariate mean difference test [18 - 20]. In this test, it is assumed that the variance-covariance matrix of the two populations is the same.

Table 2 is a tabulation of R_b and D_d data from System IIA and System III, where each assumption of normality has been tested. The results of testing the assumption of homogeneity of variance-covariance between the population of System IIA and the population of System III show the similarity of the variance-covariance matrix [12] (Table 3). The results of the multivariate test [12] (Table 4) show that there is no difference in mean between Systems IIA and III. It shows that the R_b and D_d parameters are jointly influenced by tectonic impact on old and young rocks. In other words, Tertiary tectonic also develops into the Quaternary and, at the same time, proves that neotectonics works on both Tertiary and

Table 2. Tabulation of R_b and D_d data of System IIA, which is based on Tertiary rock, and System III, which is based on the Quaternary rock [12].

System IIA			System III		
No	R_b	D_d	No	R_b	D_d
1	3.410	3.131	**1**	4.078	3.010
2	5.830	2.918	**2**	3.730	3.080
3	3.310	3.291	**3**	3.321	1.940
4	3.620	2.743	**4**	2.904	2.750
5	5.470	3.634	**5**	4.990	0.990
6	3.120	2.719	**6**	6.630	2.210
7	4.240	2.749	**7**	2.640	3.010
8	4.100	2.986	**8**	2.440	3.300
9	3.610	2.717	**9**	3.460	4.270
10	4.120	1.810	**10**	2.440	4.450
11	4.240	2.156	**11**	2.997	3.410
12	4.180	2.401	**12**	1.290	1.200
13	2.970	2.560			
14	4.350	2.403			
15	2.230	1.592			
16	2.440	1.832			
17	2.000	0.921			
18	5.000	2.174			
19	3.000	1.750			
20	3.460	1.965			
21	4.350	1.960			
22	2.980	3.229			
23	2.890	3.728			
24	4.300	3.316			
25	3.600	2.796			
26	2.500	3.508			
27	2.690	3.861			
28	3.315	4.516			
29	4.890	3.744			
30	5.476	3.696			
31	3.920	4.206			
32	3.700	3.772			
33	3.500	3.478			
34	4.000	3.116			
35	3.000	2.975			
36	4.020	3.035			
37	4.120	2.174			
38	3.420	2.193			
39	5.000	2.275			
40	3.310	2.278			
41	4.240	2.080			

Quaternary rocks. It also means that the structure (tectonic) greatly influences the formation of the watershed morphometry in the West Progo Dome.

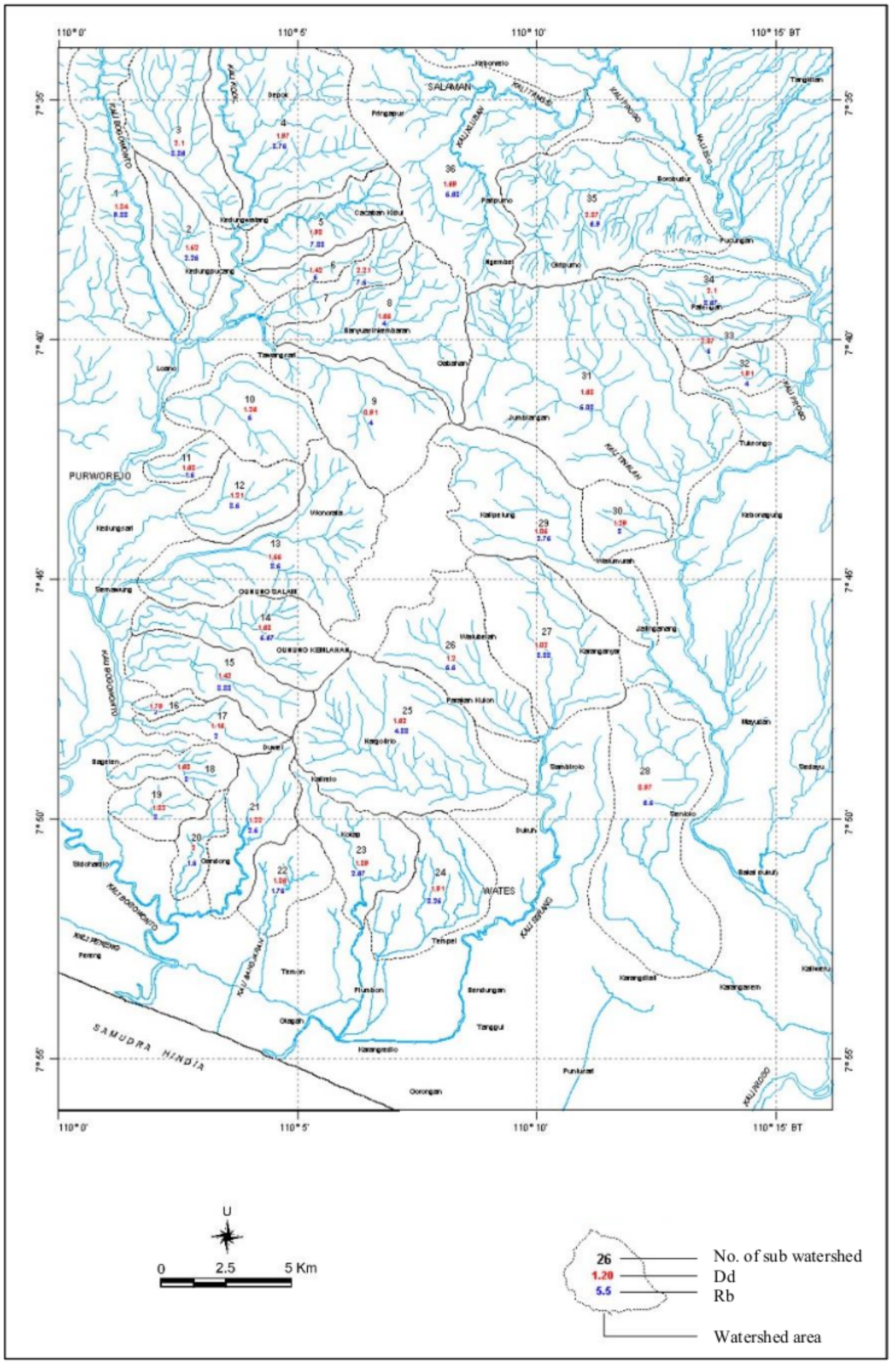

Figure 5. Value of R_b and D_d on the watershed in West Progo Dome [12].

Table 3. Results of the homogeneity of variance test (multivariate) System IIA with System III [12].

Tested population	M	c1	u	$\chi_3^2(0.05)$	Decision	Conclusion
System IIA & System III	0.045	0.070	5.788	7.8147	H_0 accepted	Not different

Table 4. The results of the multivariate mean difference between System IIA and System III [12].

Tested population	T^2 - Hotelling	T^2 0.05, 2, 51	Decision	Conclusion
System IIA & System III	3.469	6.503	H_0 accepted	Not different

4. Conclusion

The West Progo Dome is flowed by three watersheds, namely Bogowonto, Serang, and Progo. The study of the characteristics of this watershed was carried out in terms of flow patterns and morphometry, which included bifurcation ratio (R_b) and drainage density (D_d). The drainage system that develops in the West Progo Dome forms six patterns: dendritic, radial, sub-parallel, trellis, rectangular and angulate.

The value of R_b in the West Progo Dome varies from low to high, indicating a tectonic influence in the formation of this morphometry. R_b in System IIA (Tertiary) is calculated at 2.0 – 5.8, and in System III (Quaternary) is 1.290 - 6.630. Meanwhile, the D_d value in the study area shows a very coarse category, indicating a strong tectonic control. D_d on system IIA is 0.921 - 1.592 km/km^2, and on system III, it ranges from 0.990-1.200 km/km^2.

Based on the T^2-Hotelling multivariate analysis, it was found that the average R_b values in System IIA and System III were not significantly different. It shows that the structure (tectonic) is very influential in shaping the watershed morphometry in the West Progo Dome. The average D_d value in these two systems is also not significantly different, indicating active tectonics in the study area. The two morphometric variables are influenced by tectonic occur up to the Quaternary (neotectonic).

Acknowledgments

The author would like to thank our institution, ITNY, for the funding and all its facilities so that this paper can be published in this international seminar.

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