Morphometric Parameters of the Calabar River Basin: Implication for Hydrologic Processes

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Abstract

The study examined the morphometric parameters of the Calabar River Basin with emphasis on its implication for hydrologic processes. Data for this study were obtained from topographic map which were subject to field confirmation. The result revealed that the basin area was 1 514km^2. There were 223 streams with a total stream length of 516.34km. The textural dissection was considered to be low as drainage density, stream frequency and drainage intensity values were 0.34km^{-1}, 0.15km^{-1} and 0.05 respectively. The basin was found to be strongly elongated with circularity ratio of 0.34 and elongation ratio of 0.64. The average bifurcation ratio was 2.83. The very low value of drainage intensity implies that drainage density and stream frequency have very little effect on the extent to which the surface has been lowered by agents of denudation. These low values of drainage density, stream frequency and drainage intensity also imply that surface runoff is not quickly removed from the basin, making it susceptible to flooding, gully erosion and landslides, particularly in the lower part of the basin. It is therefore recommended that human activities that could impact negatively on stream network in the basin should be discouraged.

Keywords: Morphometric, Parameters, Hydrologic, Processes

1. Introduction

Studies on drainage basin morphometry have been carried out in many parts of the world. In Nigeria, such works include those of Okechukwu (1974), Ebisemiju (1976), Faniran and Ojo (1980), Anyadike and Phil-Eze (1989), etc. The basins in their areas of studies have been classified as the case may be and drainage basin morphometry related to the processes that are prevalent in such areas. Again, drainage basin morphometric parameters can be used to describe and compare basins of different sizes. Such parameters include stream order, stream length, stream number, and basin area. Others are basin shape factor (eg. circularity ratio, elongation ratio, form factor and compaction ratio), basin perimeter, bifurcation ratios, drainage density, stream frequency and drainage intensity.

But the story is different as far as the Calabar River Basin is concerned. No segment of the basin is gauged and only piecemeal information on the basin is available as no research has been carried in this direction. Yet the basin is characterized by hydrologic and geomorphic problems like flooding, erosion, mass movement, etc.

It should be noted here that some segments of the Calabar River Basin floods perennially. Eze and Abua (2003) have noted that perennial flooding is a common menace of most of the southern part of Nigeria. Such flooding events affect movement of commuters along some segment of the basin. But the situation is getting worse year after year.

In a reconnaissance study embarked upon by the researchers in December 2007 to the area, residents within Akai Effiwat, Ekenkpon, Uwet, Njakachang and those of Oduyama villages within the Calabar River Basin noted that the level of flooding within the areas have been on the increase over the last few years. It was noted that some of the areas that were not usually flooded has been experiencing it in recent years.

There are relationships between drainage basin morphometric parameters and flood potential. For instance, it has been discovered that the higher the drainage density, the faster the runoff and the more significant the degree of channel abrasion is likely to be for a given quantity of rainfall. Also, drainage density provides a link between the form attributes (morphometry) of the basin and its erosional process (Bates, 1981). Such would result to greater probability of flash floods. The measurement of drainage density again, provides hydrologists and geomorphologists with a useful numerical measure of landscape dissection and runoff potential (Pidwirny, 2006). In homogeneous bedrock, bifurcation ratio influences the landscape morphometry and plays an important control over the “peakedness” of the runoff hydrograph (Chorley 1969). Waugh (1996) noted that the human significance of the bifurcation ratio is that as the ratio is reduced so the risk of flooding within the basin increases. It also indicates the flood risk of part, rather than all, of the basin.

Also, basin shape according to Rodda (1969) is of obvious importance in influencing peak flow although it is a feature which is difficult to express numerically. Again Strahler (1964) noted that the shape of a drainage basin may conceivably affect stream discharge characteristics. Long narrow basins with high bifurcations would be expected to have attenuated flood – discharge periods, whereas rotund basins of low bifurcation ratio would be expected to have sharply peaked flood discharges. Quantitative expression of drainage basin shape or outline form was made by Horton (1932) through a form factor.

On the other hand, Schumm (1956) used an elongation ratio R_c, defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length to describe basin shape. Other indices of basin shape include Miller’s 1953 circularity ratio, Horton’s form factor and compaction coefficient.

This study was therefore carried out to elucidate information on drainage basin morphometry in the Calabar River Basin. Such information was used to describe the basin as a landform. Also, the implication of drainage basin morphometry for hydrologic processes in the basin was examined.

2. Study Area

The Calabar River is a major tributary of the Cross River. The river basin is located in the south eastern part of Nigeria and precisely in Cross River State. The delimited catchment falls within Odukpani, Akamkpa, and Biase Local Government Areas of Cross River State in Nigeria.

Figure 1 is the map of the study area showing the Calabar River. This area is characterized by a double maxima rainfall, which starts from April and ends in October, reaching its peak in June and September. The average annual rainfall is about 1830mm. There is however rainfall throughout the year but over 80% of the total annual rainfall falls over the period stated above.

Temperature rarely falls below 19^0C and averages 27^0C all year round. The average daily maximum is above 24^0C with a range of 6^0C; and seasonal variation of the same amount between the hottest month (February) and the coolest month (August) (NMET, 2008). Expectedly therefore evaporation is high.

The relative humidity is usually high, between 80 and 100 percent with the air often being often saturated with water vapour resulting in precipitation in the morning during the rainy season. Vapour pressure in the air averages 29 millibars throughout the year (CRBDA, 1995). Most of the original vegetation in the study area has been replaced as a result of agricultural, industrial and residential activities.

The area falls under the Pre-Cambrian geology of Oban Massif, the Cretaceous sediments of the Calabar flank and the Niger Delta sedimentary basin. The detailed geology of the area has been described by various authors. They include Murat (1972), Petters *et al* (1995), Nyong (1995) and Ekpenyong (1998) for the Calabar Flank and the Niger Delta sedimentary basin, and Ekwueme (1990 and 1995) for the Oban Massif.

3. Conceptual Framework and Review of Literature

The drainage basin has been seen as the fundamental hydrologic and geomorphic areal unit through which precise description of the geometry of landforms could be harnessed as data could be collected, organized, and analyzed. According to Strahler (1964), systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the drainage network, areal aspects of the drainage basin, and relief (gradient) aspects of the channel network and contributing ground slopes.

The American hydraulic engineer and hydrologist Robert E. Horton was the first to establish a quantitative methods for analyzing drainage networks (Eze and Abua 2002, and Thorne 2006). Horton (1945) felt that the main stem stream should be of the highest order. He defined a first - order stream as one receiving no tributaries. That is, a headwater stream with no tributaries. A second - order is formed by the junction of two – first - order streams and can receive other first – order tributaries. A third – order stream is formed by the junction of two streams of like order forms a stream of next higher order, which can receive tributaries of any order lower than it own.

Horton’s system further demands that, after all streams have been classified, an investigator starts at the mouth of the basin study and reclassify part of the streams (Broscoe, 1959 and Haggett and Chorley, 1969). Strahler (1952) modified Horton’s system by allowing his provisional scheme to determine the final ordering, such that; fingertip channel are designated order 1; where two first order channels join, a channel segment of order 2 is formed; where two channel segments of order 2 joint, a segment of order 3 is formed; and so on.

The usefulness of the stream order system depends on the premise that, on the average, if a sufficiently large sample in treated, order number is directly proportional to size of the contributing watershed, to channel dimensions and to stream discharge at that place in the system (Strahler, 1964). He further noted that the number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order.

The ratio of number of segments of a given order, N_u to the number segment of the higher order N_u+1 is termed the bifurcation ratio, R_b. The bifurcation ratio was introduced by Horton (1945) and modified by Strahler (1952). It characteristically ranges between 3 and 5 in homogeneous bedrock (Chorley 1969 and Waugh 1996). When natural log l_n,of number of stream is plotted against order, most drainage networks show a linear relationship with small deviation from a straight line.

4. Research Method

The first part of sampling in a drainage basin involves marking out the network limits. This was done in this study using the blue line method (Gardener, 1990) on the 1:50 000 topographic maps of the area published (1990) by the Federal Surveys Department with field confirmation by the researchers. It was delineated from the following topographic map sheets: UWET SW (SHEET 323); UWET SE (SHEET 323); UWET NE (SHEET 323), UWET NW (SHEET 323), UGEP SW (SHEET 314); UGEP SE (SHEET 314) and IKOM SW (SHEET 315).

A tracing paper was placed over the delimited drainage basin and the drainage channel traced out. The emerging channels were designated according to order. The stream channel network of the entire Calabar River Basin was subdivided into individual lengths of channel, or channel segments, and arranged according to the hierarchy or magnitude of orders as proposed by Strahler (1952).

Stream length was measured by the use of a string. This was done by placing the topographic maps on a flat surface and then placing the string along the blue line crenulations of each stream segment until it encountered another segment of the same or higher orders. The number of streams in each order was counted to obtain the stream number (Table 1). The bifurcation ratio was calculated from the data (Table 2).

The most commonly used methods of areal calculations on maps are the graphical (square) and planimeter methods (Ajaegbu and Faniran, 1992). The use of the planimeter gives more accurate estimates of the area and is less tedious than the use of graph papers. However, the graphical or square method was adopted for this study due to the non-availability of a functional planimeter. The procedures for using this method as elaborated by Ajaegbu and Faniran (1992) were adopted for this study.

Maximum Relief (Highest Elevation) **-** $H_{max,}$ was read-off from the topographic map as the highest contour elevation of the ridge forming the boundary of the basin. Minimum Relief (Lowest Elevation) - H_{min}, was the elevation at the gauging station which was taken as the contour value at the point of gauging.

The relief ratio R_c, as suggested by Schumm (1956) was defined as the total relief of the catchment (elevation difference between the lowest and the highest points in the basin) and the longest dimension of the basin parallel to the principal drainage line. Drainage density was measured as the length of stream channel per unit area of drainage basin. Stream frequency which describes how often one finds a stream segment in a unit area of basin space was calculated as the ratio of total number of streams to the basin area. Drainage intensity I_d, was obtained as the product of drainage density, D_d, and stream frequency, F_s.

Circularity ratio, R_c was taken as the ratio of basin area to the area of a circle having the same perimeter as the basin. Elongation ratio was the ratio of the diameter of a circle of the same area as the basin to maximum basin length. The form factor (F_f) was defined by the area of the basin divided by the square of axial length of the basin. The compaction coefficient (C_c) was defined as the perimeter of the basin divided by circumference of equivalent circular area

The length of overland flow (L_o) was taken as the reciprocal of 2 times the drainage density. Axial width was taken as the maximum width of the basin while the axial length was taken as the maximum length of the basin.

5. Results and discussion

Figure 2 is the drainage map of the basin. Table 3 is the summary of the results of this study. The result shows that the Calabar River basin is a third-order.

The study revealed that there were very few streams in the study area compared to its large size. As was shown in section 4, the total number of streams was 223 within a basin area of about 1 514.00km^2.

Another important factor measured in the course of the study was the shape of the basin. Basin shape is important as it influences the shape of the hydrograph (Ayoade, 1988). It is an important control over the geometry of the stream network. This is so because the shape of the basin determines the lag time and the time of rise among other hydrograph parameters. Several indices were used to describe the basin shape in this study. Such were the circularity ratio, elongation ratio, form factor and compactness coefficient.

The circularity ratio of nearly 0.40 is an indication that the basin is not circular in shape. The elongation ratio of 0.64 is a confirmation of the fact that the Calabar river basin is not circular. According to Mustafa and Yusuf (1999), values of elongation ratio range from 0.4 – 1.0. Chow (1964) had noted that strongly elongated basins have circularity ratios of between 0.40 and 0.50. The shape of the Calabar river basin nearly compares to that Ikpa river basin of Udosen (2008) which had a circularity ratio of 0.45 and collaborates Aniah, *et. al*., (2007).

The value of the form factor which was 0.34 further indicated the elongated nature of the basin. The elongated nature of the Calabar river basin has implication on both hydrologic and geomorphic processes. Mustafa and Yusuf (1999) have noted that the flow of water in elongated basins is distributed over a longer period than in circular ones.

Chorley (1969) had noted that the lower the bifurcation ratio, the higher the risk of flooding, particularly of parts and not the entire basin. The low average bifurcation ratio of the basin under study of 2.83 is an indication that parts of its segments are liable to flooding. This actually confirmed what is obtained in the field as was discovered during the reconnaissance survey. According to Kale and Gupta (2001), bifurcation ratios ranging from 3 to 5 indicate natural drainage system characteristics within a homogeneous rock. Hence, the drainage basin morphometry of the Calabar River Basin may have been affected by human activities.

In this study, the drainage density of $0.34km^{-1}$, stream frequency of $0.15km^{-1}$ and drainage intensity of 0.05 is an indication that the intensity of dissection in the area is very low. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant materials (lithologies or rock types), or those with high infiltration capacities. Except for the areas where there are plantations, streams are widely spaced in the study area as can be seen in the drainage map (figure 2).

The study further revealed a very low drainage intensity of 0.05 for the basin. This very low value of drainage intensity implies that drainage density and stream frequency have very little effect (if any) on the extent to which the surface has been lowered by agents of denudation. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not quickly removed from the basin, making it highly susceptible to flooding, gully erosion and landslides. The case of landslide which occurred recently in the area across the Type Section of Ekenkpon Shale between Akai Effiwatt and Ekenkpon village in Odukpani Local Government Area of Cross River State (CRBC News Bulletin, 2006) could be associated with this.

Furthermore, figures 3, 4 and 5 shows that the Calabar River Basin obeys Horton's laws. This is the implication of the line inserted into the graphs which confirms the linear relationships between stream number and stream order, mean stream length and stream order as well as basin area and stream order.

6. Conclusion

This study has shown that the Calabar River basin is susceptible to hydrologic processes like flooding, erosion and landslide. However, some segments of the basin are more susceptible to these problems than others. For example, the sections that are covered with sedimentary rocks (the lower part of the basin) like Shale are more prone to these environmental problems. This is attributed to drainage morphometry which has shown that the bifurcation ratio in this section is lower than the one for the basement complex.

It is recommended that human activities that could impact negatively on the drainage network should be discouraged. However, there is also the need to examine the other factors (land use, climate, soil type, etc) which are known to affect hydrologic processes to unravel the multivariate nature of the problem with the view to finding a holistic solution.

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Table 1. Stream Numbers, Stream Length and Basin Area against Stream Order in the Calabar River Basin

Stream Order	Stream Numbers	Total Stream Length (km) Average (km)	Stream Length (S.L/S.N)* km	Basin Area (km^2)
1	160	192.31	1.20	1 062.10
2	45	96.04	2.13	1 136.00
3	13	94.88	7.30	1 192.36
4	4	72.45	18.11	1 386.74
5	1	61.10	61.10	1 514.00

*S. L. = Stream Length; S. N. = Stream Number

Source: Authors' Research, 2008.

Table 2. Bifurcation Ratios within the Calabar River Basin

Stream Order	Number of Streams	Bifurcation Ratio
1	160	
2	45	3.49
3	13	3.21
4	4	2.60
5	1	2.00

Average Bifurcation ratio = 2.83

Source: Authors' Research, 2008

Table 3. Summary of Drainage Basin Parameters for the Calabar River Basin

Drainage Basin Parameter	Value
Basin Order	5
Total Numbers of Streams	223
Total Stream Length	516.34km
Length of Overland Flow	1.47m
Axial Width	43.00km
Axial Length	62.00km
Basin Area	1 514.00km^2
Basin Perimeter	235.00km
Relative Perimeter	36.48km
Circularity Ratio	0.34
Elongation Ratio	0.64
Form Factor	0.34
Compaction Coefficient	1.70
Highest Basin Elevation	0.98km
Lowest Basin Elevation	0.015km
Relief Ratio	0.014
Average Bifurcation Ratio	3.57
Drainage Density	0.34km^{-1}
Stream Frequency	0.15km^{-1}
Drainage Intensity	0.05
Longest Dimension Parallel to the Principal drainage Line	68.00km

Source: Authors' Research, 2008

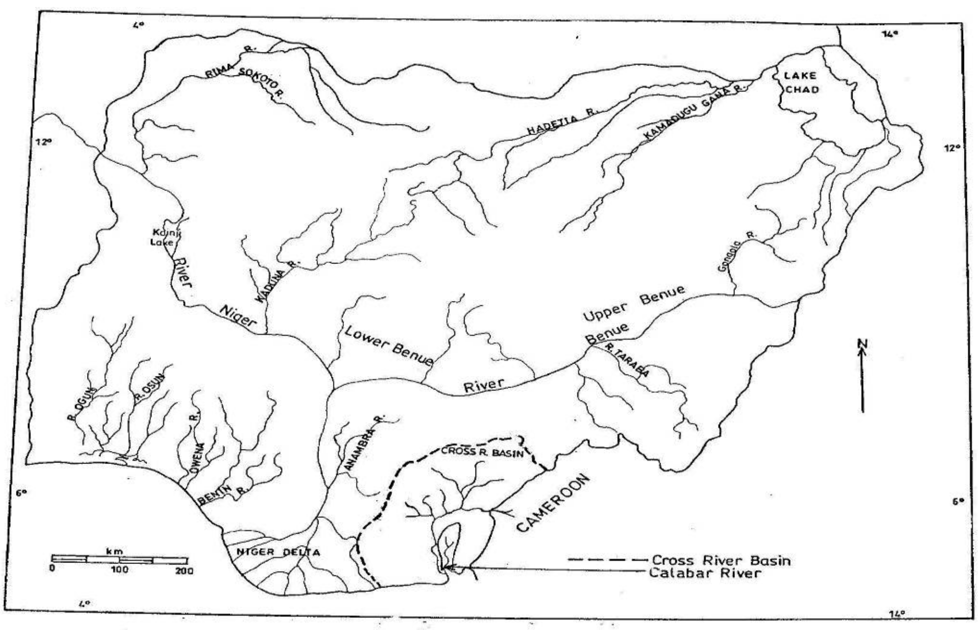

Figure 1. Map of Nigeria showing the Calabar River basin

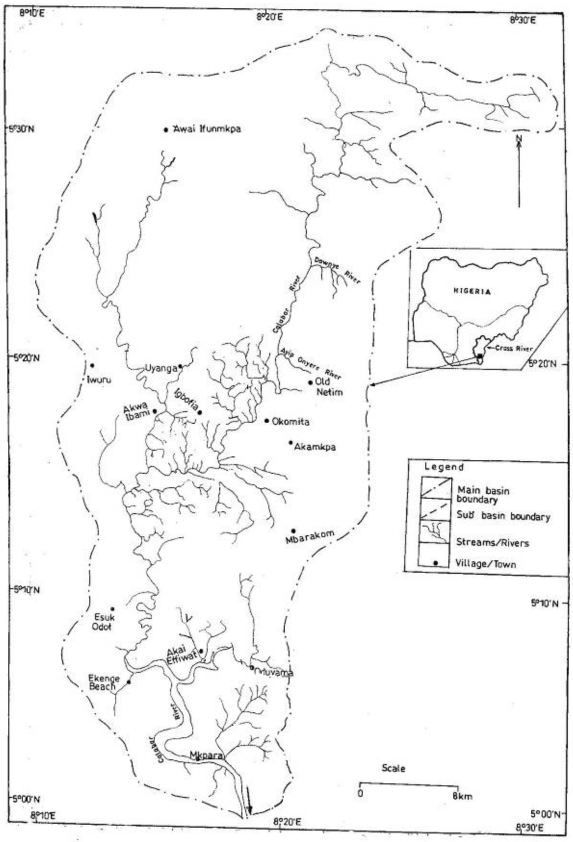

Figure 2. Drainage Map of the Calabar River Basin

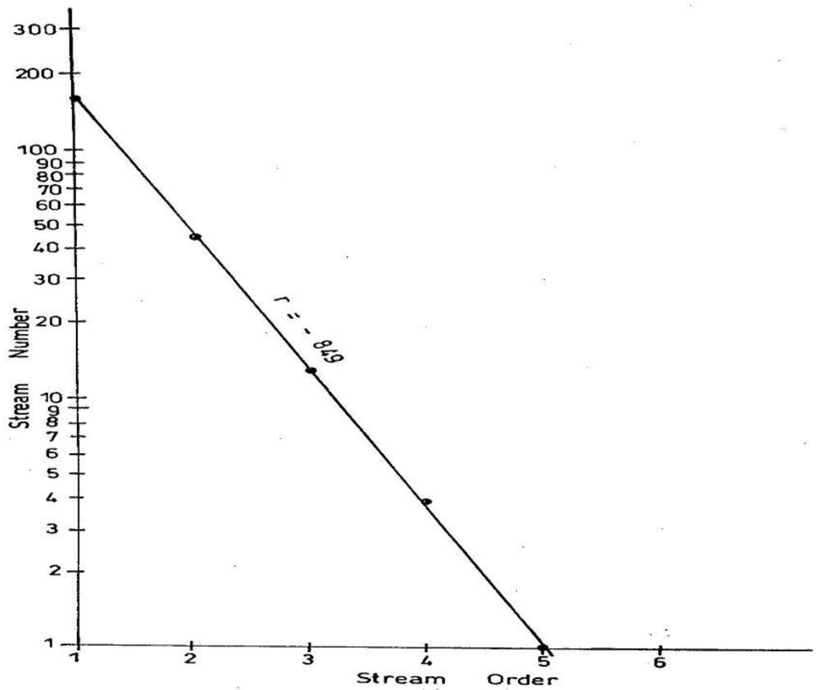

Figure 3. Relationship between stream order and stream number

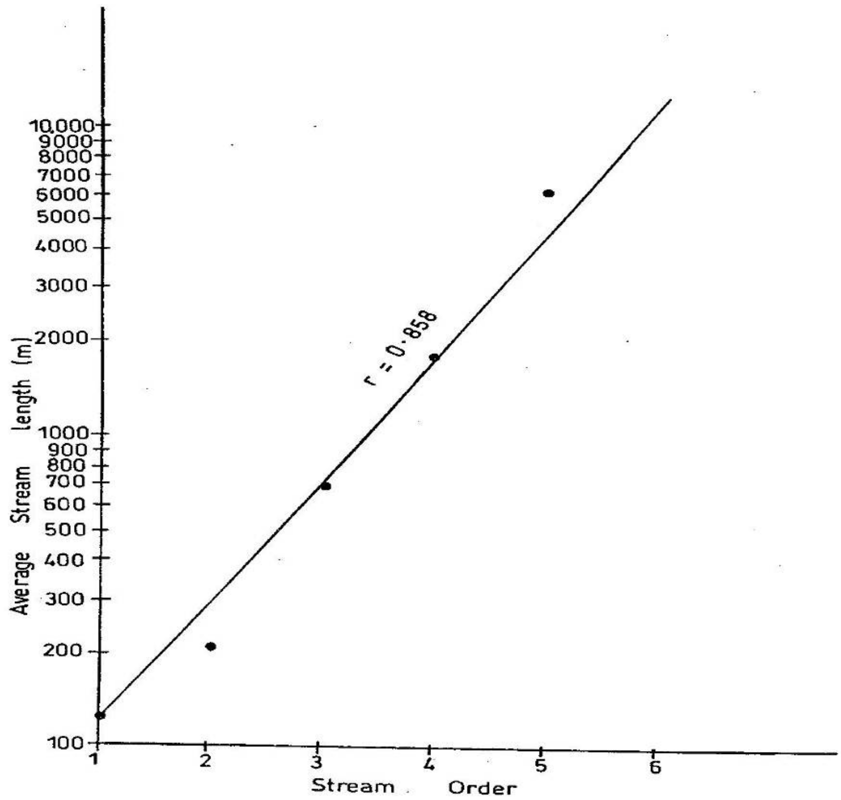

Figure 4. Relationship between stream order and average stream length

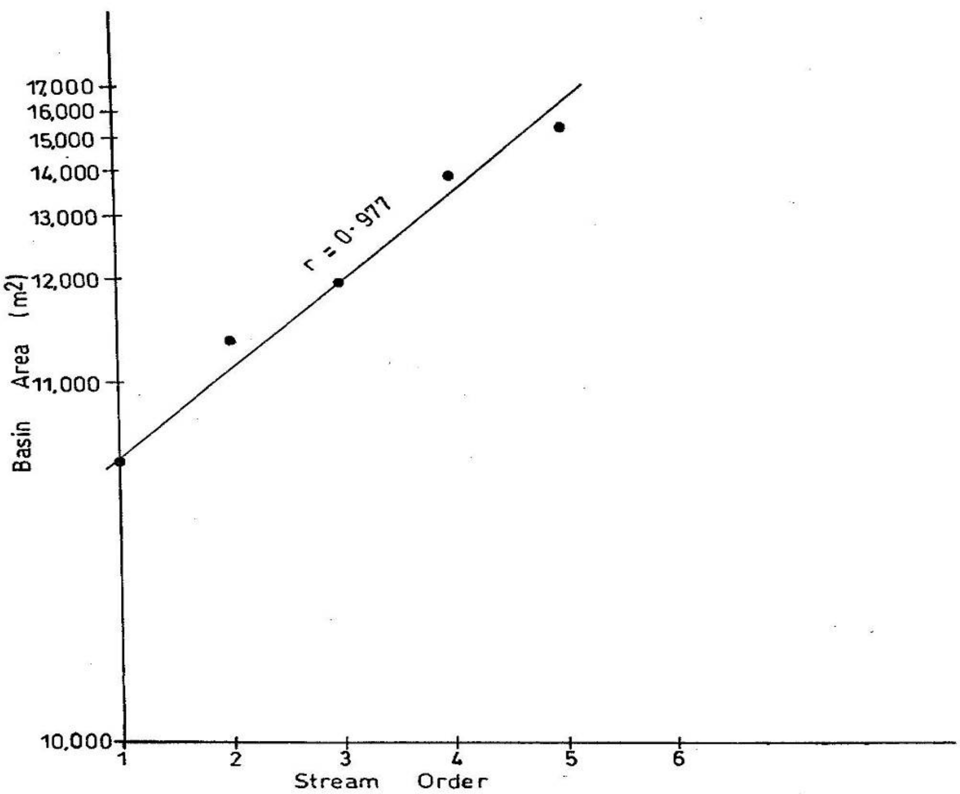

Figure 5. Relationship between stream order and basin area