

Relationship Between Drainage Basin Area and Stream Length for River Gongola, Nigeria

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ABSTRACT

Many discharge basin features that are important to the hydrologist can be quantified in terms of length, length squared, and length cubed. Examples are elevation, stream length, basin perimeter, drainage area, and volume. The concept of geometric similarity can be applied to drainage basins just as it is to many systems. Most readers would be aware of model-prototype studies of aircraft, dams, and turbo machinery. Such studies involve considerations as well as dynamic similarity. In the same manner that inferences as to the operation of a prototype can sometimes be drawn from a geometrically similar model, inferences can also be drawn about the operation of one drainage area on the basis of information obtained from a similar one. Perfect similarity will never be realized if drainage systems are compared, but striking similarities have been observed which can often be put to practical use.

The objective of this study is to evaluate a power equation relating drainage basin area to stream length with respect to the Gongola River Basin (Case Study and shown in Figure 1). The Gongola River is one of the two (2) major rivers in Bauchi State within Northern Nigeria and is a tributary of the River Benue. This area has poor rainfall and hence the need to properly study the River for water resource management. The logarithm of cumulative stream length is plotted against the logarithm of drainage area basin. Theories postulated shows that drainage area and stream length are related in a power function. The result obtained which affirmed the theory also gives a foundation for the comparison or computation of drainage basin morphology given that the new basin being considered is of a similar geometry and exists within the same hydrologic cycle.

(Keywords: topographic maps, Strahler Stream Order, stream length, drainage basin, divides, basin area)

INTRODUCTION

The Sahel Savannah part of Nigeria is a moderately populated area. Because of its geographic location, it has problems with continuous water supply and also has flooding problems. The Gongola River is an important perennial river in the area and a large population depends on it as a year-round source of water (Figure 1). A proper knowledge of its drainage area and other geomorphologic relationships will help in the control of floods and in general water resource management since farming is the major occupation in the area.

A drainage basin is a tract of land drained by a river and its tributaries. It is a region of land where water from rain or snowmelt drains downhill into a body of water. The constituent body of water as well as the land surfaces from which water drains into those channels still forms part of the drainage basin. The drainage basin acts like a funnel, collecting all the water within the area covered by the basin and channeling it into a waterway. Each drainage basin is separated topographically from adjacent basins by a ridge, hill, or mountain which is known as a water *divide* (Figure 2). For a given stream, it is a tract of land drained of both surface runoff and groundwater discharge which is significantly different from a watershed which is the area that supplies runoff to a stream or river. The importance of drainage basins abounds and range from forming geopolitical boundaries to even resource management. In hydrology, the drainage basin is a logical unit of focus for studying the movement of water within the hydrological cycle, because the majority of water that discharges from the basin outlet originated as precipitation falling on the basin.



Figure 1: Map of Northern Nigeria showing River Gongola (Courtesy Microsoft Encarta 2007).

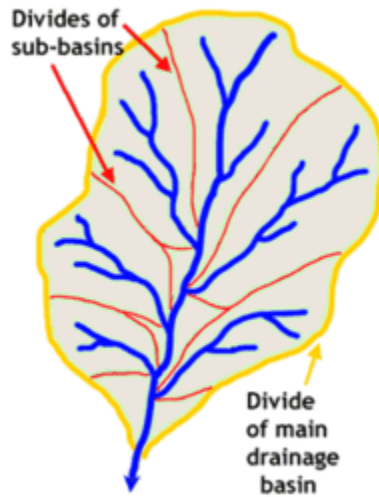


Figure 2: Elements of a drainage basin (Courtesy Wikipedia).

A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network.

Drainage basins are important elements to consider also in ecology. As water flows over the ground and along rivers, it can pick up nutrients, sediment, and pollutants. These get transported towards the outlet of the basin and can affect the ecological processes along the way as well as in the receiving water body. In hydrology, the drainage basin is a logical unit of focus for studying the movement of water within the hydrological cycle because the majority of water that discharges from the basin outlet originated as precipitation falling on the basin. A portion of the water that enters the groundwater system beneath the drainage basin may flow towards the outlet of another drainage basin because groundwater flow directions do not always match those of their overlying drainage network. Measurement of the discharge of water from a basin may be made by a stream gauge located at the basin outlet.

This relation can be used to analyze streams of similar geometry, similar hydrologic cycle, and underlying rock strata. This is based on the theory that on the average, if a sufficiently large sample is 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. Because order number is a dimensionless quantity, two (2) drainage networks differing greatly in linear scale can be compared with respect to corresponding points in their geometry through use of order number and thus, the relationship that would be achieved.

A proper knowledge of the area of a drainage basin and other geomorphologic parameters will help in combating the various problems and also provide solutions. The relationship between drainage area and stream length is just one of the proto-types that can be derived for any drainage basin.

METHODS

To quantify the geometry of a basin, the fundamental dimensions of length, time, and mass will be used. Many drainage basin features that are important to the hydrologist are quantified in

terms of length. Geomorphological parameters are divided into linear and area measures as discussed earlier. Important linear measures of drainage basin characteristics include overland flow lengths and stream lengths. Important area elements or measures include drainage area, drainage density, form factor, and stream frequency.

Stream Ordering

Stream ordering was originally introduced into the United States by Horton (1932) and slightly modified by Strahler (1952). The designation of stream orders is usually the first step in drainage basin analysis. Stream ordering is a simple hydrology algorithm used to define stream size based on a hierarchy of its tributaries (Figure 3). To qualify a stream, it must be perennial. When two first-order streams come together, they form a second order stream. When two second order streams come together, they form a third order stream. Streams of lower order joining a higher order stream do not change the order of the higher stream.

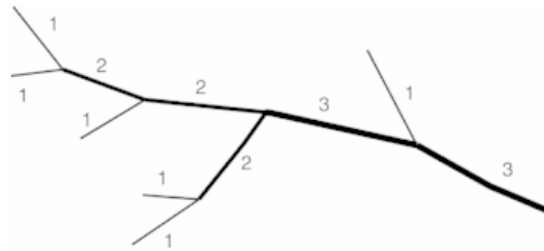


Figure 3: Diagram Showing Strahler Stream Ordering System (Coutesy Wikipedia).

It is important to appreciate that stream order is dependent upon map scale. As scale decreases and more detail is added to the river network (i.e. new tributaries) the river may increase its stream order.

As stated earlier, the topological maps obtained and used for this project has a scale of 1:500,000.

Delineation of a Watershed

This is usually the first operation carried out in the calculation of the area of a drainage basin. This entails outlining perimeters around all the first, second and higher orders of streams on a

topographic map. This will allow for the use of the planimeter (area measuring device) to measure the area.

Stream Length

The Stream Length refers to the total length of stream channels in the drainage basin and therefore has units with dimension (L). It is considered as a linear aspect of drainage network. Stream lengths are determined by the measurement of the projection onto a horizontal plane. Topographic maps are very useful for obtaining such measurements. Channel length is measured using a chartometer (map measurer) directly from the map and therefore represents the true length. Stream lengths are calculated for each stream order and documented differently.

Drainage Area

Drainage area indicates the size of the drainage basin and has the dimension (L²). It is an area aspect of the drainage network. The drainage area is important because it is often used as a surrogate for other hydrological properties, such as the flow or discharge. This is because the discharge normally increases (in a predictable fashion) with basin size due to the increase in runoff contributing area with basin size. Important exceptions to this rule occur when basins lose water downstream, either artificially (e.g. irrigation, water transfers, etc.) or by natural processes such as an infiltration into permeable strata.

The Area A_u of a basin of a given order u is defined as the total area projected upon a horizontal plane, contributing overland flow to the channel segment of the given order and including all tributaries of lower order. For example, the area of a basin of the fourth order, A₄, would cumulate the areas of all first-, second-, and third-, order basins, plus all additional surface elements, known as inter-basin areas, contributing directly to a channel of order higher than the first. A planimeter was used to calculate the individual areas of all the orders on the Gongola River after the perimeter has been outlined.

Frequency distribution of areas and lengths has been studied by Miller (1953) and Schumm (1956) who found that a strong right skewness in the distribution could be largely corrected by using the logarithm of area and length.

Relation of Area to Length

The relation between area and stream length can be drawn by plotting the graph of the logarithm of

cumulative stream length against the logarithm of basin area (which is already a cumulative), order by order. Assuming the validity of the laws of stream lengths and basin areas, in which both properties are related in an exponential function with order, length should be related to area by a power function (Morisawa (1959)). He also plotted both logarithms of mean stream length and logarithm of cumulative length against logarithm of basin area for each order of representative basins of the Appalachain Plateau Province, USA obtaining highly linear relationships. Hack (1959) also demonstrated the applicability of the power function relating length and area as thus defined for streams in seven areas of Virginia and Maryland.

If works done by Morisawa (1959) and Hack (1959) are correct, a linear relationship would be derived as regards the Gongola River basin. A power relation equation can be then derived which would be in the form:

$$L = aA^b$$

Where L = Stream length
 A = Drainage Area
 & a, b = constants

RESULTS AND DISCUSSION

The Gongola River, after the application of Strahler’s stream order theorem had an order of five (5). This corresponds with previous work done on geomorphological parameters on the Gongola River Basin by Dr. Adeaga (1997).

Tables 1 and 2 show the length and basin area obtained from the map, order by order. Logarithm of both values is shown in Table 3.

Table 1: Showing Stream Length of the River Gongola plus all its Tributaries According to Stream Orders.

Stream Order	Stream Length (KM)
First Order	79
Second Order	128
Third Order	78
Foruth Order	35
Fifth Order	26

The graph of Logarithm of cumulative stream length (CSL) against drainage area is plotted. The result is a straight line graph (as shown in Figure 4).

Table 2: Showing Actual Drainage Area of the Gongola Basin According to Stream Orders.

Stream Order	Drainage Area (KM ²)
First Order	462.5
Second Order	9777.5
Third Order	17219.5
Fourth Order	25891.5
Fifth Order	35926.5

Table 3: Showing Logarithm of Cumulative Stream Length and Logarithm of Drainage Area According to Stream Orders.

Stream Order	Stream Length (KM)	Drainage Area (KM ²)	Cumulative Stream Length (CSL)(KM)	LOG of CSL	LOG of Drainage Area
First Order	79	462.5	79	1.898	2.665
Second Order	128	9777.5	207	2.316	3.990
Third Order	78	17219.5	285	2.455	4.236
Fourth Order	35	25891.5	320	2.505	4.413
Fifth Order	26	35926.5	346	2.539	4.555

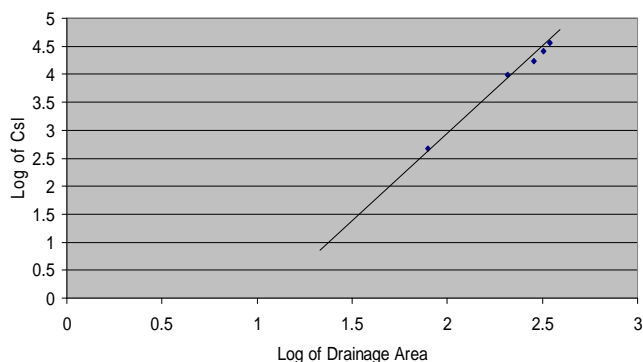


Figure 4: Plot of Logarithm of Cumulative Stream Length (CSL) to logarithm of Drainage Area for River Gongola in Km

The X axis (abscissa) represents the Drainage Area while the Y axis (ordinate) represents cumulative Stream Length.

The power relationship achieved was:

$$L = 1.109A^{0.545}$$

CONCLUSION

The Gongola River is a very important river within the Northern part of Nigeria. With a large population depending on the river all year, it becomes necessary to understudy the full nature of the river's dynamics. The drainage area – stream length relationship is one of the many morphometric relationships that can be computed for drainage basin analysis. This relationship is most important because the two parameters are fundamental drainage basin properties. The relationship and other geomorphometric parameters can form a proto-type in comparing this drainage basin to others with similar geographical parameters.

The procedures used during the project were similar to those used by Morisawa (1959) and Hack (1959) for similar geographical regions. A straight line graph with its skewness corrected by plotting of the logarithm of the values of both drainage area and stream length was also achieved. It is important to note that the various theoretical boundaries include that the drainage basin systems to be compared must be of similar geometry and also lie within similar hydrological regions.

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SUGGESTED CITATION

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