

WATERSHEDS GEOMORPHOMETRICS IN RELATION TO THE FLOW REGIME IN AYA RIVER SYSTEM OF THE CROSS RIVER BASIN, NIGERIA

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ABSTRACT

The study aimed at justifying the variable flow in the Aya river system. It involved delineating the sub-catchments that outlet directly to the trunk Aya River; characterize the geomorphometric parameters that influence runoff; relate these to the expected runoff response and stream flow regime; and highlight the sub-basin(s) that mostly influence the Aya stream flow. Thirty-nine sub-basins were delineated using topographic map on a scale of 1:100000. The standard deviation and coefficient of variation was higher for stream density, watershed slope and basin area. Analysis of variance confirmed that these parameters significantly varied from basin to basin, implying that runoff significantly varied between the sub-basins. These variations suggest that for the trunk river (Aya) variable flow regime at different points along the profile exist significantly.

KEYWORDS: Basin delineation, Flow regime, Geomorphometrics, runoff response, Sub-basins.

1. INTRODUCTION

The flow regime of streams in spatial and temporal context is a reflection of an array of environmental factors. Many studies tend to emphasize climate and physiographic parameters such as geology and soil characteristics, as well as land use changes, as critical determinants. Yet geomorphometric parameters also play key roles in determining basin response to runoff and flow regime.

As pointed out by Salleh et al, (2004), Farajzadeh (2002) and Harlim (1984) changes in any of the geomorphometric properties of basins would influence their role as basin regulators, thus influencing a change in basin response to rainfall. The impact of geomorphometric parameters in altering the flow in Aya river system thus cannot be over-emphasized. This is more so, if we assume that rainfall within the larger basin is relatively uniform. On this basis, the sub-system (sub-basin) within the system (larger basin) would respond differently.

Achieving an understanding of this forms a valuable tool and provides basic indicators for comparing drainage basins (Sreedevi et al, 2005; McCammon et al, 1998). This kind of study has not been undertaken for the Aya River basin. As a follow-up to McCammon et al (1998), fulfilling any watershed responsibility requires gaining an understanding of the geomorphometric parameters that govern the rate and timing of water flow.

Analyzing flow regime on the basis of average flow at one station for drainage basins with multiple sub-catchments does not give the true picture of the regime in spatial context as the variation in the morphometry can be significant. Such analysis for large basins may not provide true local scale

conditions, as this is likely to suppress the sensitivity of the basin to local scale alteration of the watershed characteristics (Chow, 1964). In addition, relating the sub-basin geomorphometric parameters to the variable flow, is valuable for determining the critical watersheds in the flow regime.

The existing conditions within many parts of the Aya basin and the nature of flow vary spatially. Thus the flow characteristics of individual sub-catchments differ from the sum of the characteristics as expressed by the average conditions for the larger basin (Wisler and Brater, 1959).

Changes in the flow regime and the flashy conditions of the flow as regularly experienced are likely the attributes of differential sub-catchments characteristics, such as drainage density, bifurcation ratio, shape factors and topography. This study attempts to provide an exposition of the geomorphometric characteristics of the Aya River system, while relating these to the expected flow regime.

On this basis, the study seeks to: Delineate and characterize the geomorphometric parameters of the outlet sub-basins of the Aya river; Relate these parameters to the flow regime in the river system; Identify which sub-basin exerts more influence on the flow regime of the trunk river based on geomorphometric analysis, and Examine the relation between drainage density, and length of overland flow, and other geomorphometric parameters, and relating these relationships to the expected runoff.

2. Study area

The Aya river system in the southeastern flank of the Cross River Basin is located between 6°27' and 6°53' and 9°15'E. The basin consists of a network of stream channels, which is generally of the dendritic pattern (Fig. 1).

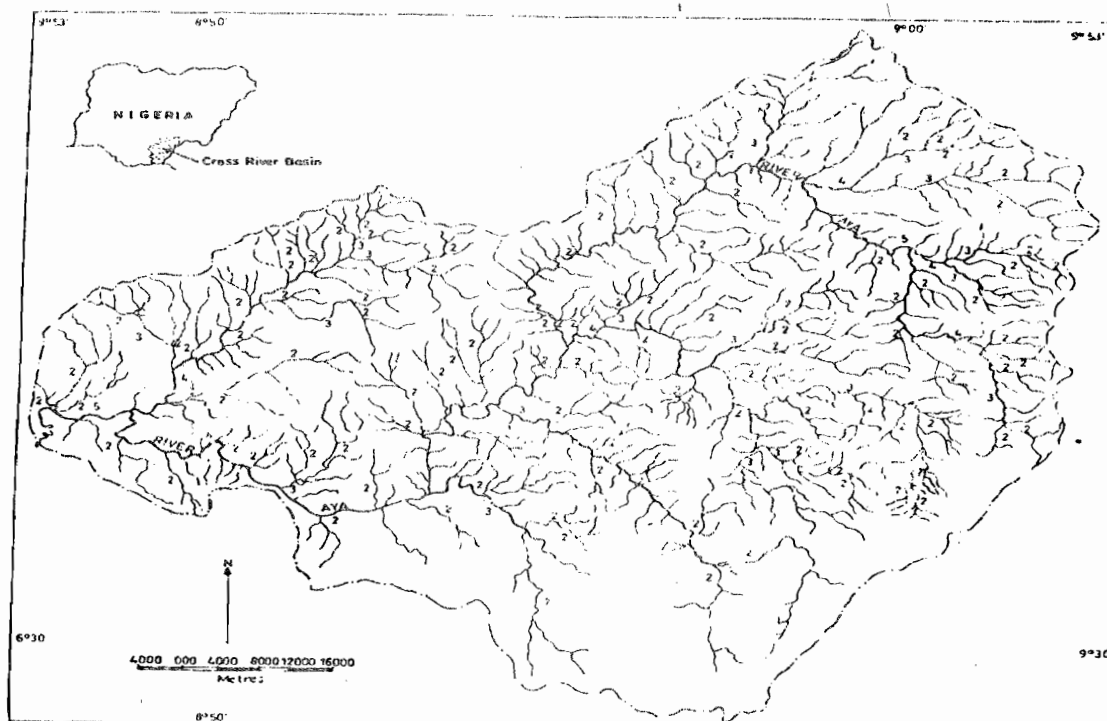


Fig. 1: Drainage network of Aya River system.

Source: Topographic map, Ogoja and Obudu, sheet 290 and 291.

The flow regime generally follows the rainfall regime, but consist of one maximum as against the double maxima rainfall. The regime lends credence to Beckinsale's (1978) description, that river regime of small and moderately size basins closely reflect regional runoff controls, especially climate. The unreliable water level at the outlet of the trunk Aya River (Utang, 2007), reflects the differential local characteristics, which provide variable inputs to the trunk channel at different points along its profile.

Five 4th order and seven 3rd order basins join the trunk river (a 5th order stream) at various points. The 4th order basins are Moniaya, River Be (Abeb), Asham, Shangev Ya and Suwo, while the 3rd order basins are Ayabie, upper Vandeikya, Akasom, Echin (Betsuen) Utumchu and Debekim. Other 1st and 2nd order sub-catchments directly empty into the trunk channel at different points.

Climate is of the humid tropical hinterland type with rainfall between 1000-1800mm and up to four months of dry season (Ojo, 1978). Mean annual temperature is about 27°C. Rainfall in the basin is spatially variable, with high intensity and amount in the eastern flank, controlled by the great relief. The annual rainfall for Ogoja in the western flank is 1773mm, while that for Obudu in the east is 1906mm (Utang, 2007).

Two rock types underlie then area. These are crystalline basement in the eastern flank and sedimentary formations in the west. The areas of sedimentary formations are of the Asu river group and also shales of Eze-Aku formation (Ofomata, 1975) in some parts. Within these are four distinct hydrogeology zones identified by 'Survey and Geodata' limited for the Cross River Basin Authority. The crystalline basements are characterized by high slope gradient with high direct runoff yield; and medium to high slope gradient areas, also with high direct runoff. There are areas with shales and sandstones also characterized by high runoff and distinct slope, while there are low slope gradient areas, but with high direct runoff and danger of flooding in flat river plains, because of the presence of compacted clay inter-layered by sandstones.

The basin is characterized by complex elevation. This is higher in the eastern flank where the elevation reaches

as high a 762.5m above mean see level. On the western flank, around Ogoja, elevation reduces to as low as 45.75 meters.

3. MATERIALS AND METHODS

Geomorphometric parameters used for this study consist of basin area, drainage density, length of overland flow and bifurcation ratio. Others are elongation ratio, circularity ratio and watershed slope. These are considered to directly, singly or in combination influence flow regime in environments with relative homogeneity of climate and other physiographic factors.

Measurements of the parameters were obtained from the topographic map of scale 1:100,000. The sub-catchments were first delineated based on the topographic divide. A total of thirty-nine (39) sub-catchments whose outlets open directly into the main trunk (Aya) river were delineated. These include: twenty-seven (27) 2nd order catchments, seven (7) 3rd order and five (5) 4th order sub basins. The drainage areas were measured using the planimeter. A scale-rule was used to measure the maximum length of the watershed from the point of longest distance on the divide to the basin outlet.

Statistical analysis tools employed were coefficient of variability, multivariate analysis of variance and multiple correlation and regression. The coefficient of variation was used to examine the degree of variation between the sub-catchments in terms of each geomorphometric parameter, while analysis of variance was used to test whether the means are also equal or significantly different, assuming that means of each variable follows a normal distribution (Mather, 1976). Correlation was to examine level of relationship between drainage density, length of overland flow and some other parameters. These dependent variables were isolated for regression analysis because they are usually considered to be the critical elements influencing flow. The analysis was to estimate their level of change can be caused by other geomorphometric parameters, while the other variable may be considered on their own to actually be independent variables that influence runoff.

4. RESULTS AND DISCUSSION

4.1 Distribution of geomorphometric parameters and their relation to stream flow

Table 1: Distribution of Geomorphometric characteristics of the sub-watershed of Aya basin with direct outlets to Aya River

Basin type	Basin characteristics																		Basin area
	Dd			Lo		Rb			Ws			Er			Cr				
	>1	1-2	>2	<5	>5	1-2	2.1-5	>5	<1	1-2	>2	>.4	.4-<.6	.6-.8	>.8	<.6	.6-.8	>.8	
2 nd	7	19	1	21	5	12	14	1	9	17	1	1	11	14	1	11	14	2	216
3 rd	2	5	=	5	2	-	6	1	7	-	-	-	1	6	-	2	5	-	387,24
4 th	1	4	-	4	1	-	5	-	3	1	1	-	-	5	-	2	3	-	742.8

Source: Obtained from topographic map sheet 290

Source: Derived from topographic map sheet 290

Where: Dd = Drainage density; LO = Length of overland flow; Rb = Bifurcation Ratio; Er = Elongation ratio; Cr = Circularity ratio;

Ws = Watershed slope

Table 1 shows that basin areas are spatially variable even between basins of the same order. This implies that the volume of flow for the trunk stream (the main Aya River) varies greatly at different points because of variation in discharge into it. Rainfall, even if uniform across the Aya basin, may translate into runoff volume differently in the different sub-basin. It is identified (Waugh, 1996; Hack, 1975; and Strahler, 1964) that higher order basins, though smaller in number, contribute more runoff volume than smaller order basins because of their larger sizes compared with the sum of sizes of smaller basins. That the River Be catchment (4b) alone contributes more runoff than all the 27 2nd order basins combined, while the 4th order basins contributes almost twice the volume of flow from the 3rd order basins and 3 times the volume from the 2nd order can be deciphered. As noted by Chow (1964) and Strahler (1964) however, drainage basin effects go beyond area characteristics, as the hydrologic behaviour is a function of the dominating characteristics.

Although the drainage density as shown in table 1 appears to be spatially variable, 71.7 percent falls within the range of 1 to 2 km/km². The variation in density implies that incidences of flash floods differ from one sub-basin to another. This variation is higher within the 3rd order basins. On the whole, the few number of low and high drainage density basins suggest moderate incidences of flash flood for most parts of the basin. Generally high drainage density implies high risk of flash floods and higher drainage efficiency (Wisler and Brater, 1959; Waugh, 1996; Eze and Abua, 2004).

The observed incidences of flash flood in many parts of the Aya basin may therefore not necessarily be attributed to observed drainage density, but their changes due to changes in land use and rainfall pattern (Gregory, 1976). When Land use changes occur (example vegetation clearance), drainage density may increase, hence, accelerated flash floods irrespective of the prevailing climatic conditions.

Very close to drainage density is the low bifurcation ratio, where 30.8 percent of the catchments have ratios between 1 and 2 and tending to approach the theoretically minimum of 2.0 (Strahler, 1964). The higher number of basins with bifurcation ratios between 2.1 and 5 suggests that the risk and susceptibility of the basins to flash floods is equally low for many sub-basins. Any observed increase in incidences of flash floods could therefore be attributed other variables (Gregory, 1976). On the whole, 51.3 percent of the bifurcation ratio falls within the range 3.0-5.0 for watershed, which the geologic structures do not distort the drainage pattern (Strahler, 1964). The high bifurcation (>4) for River Be (4b), Debekim (3c) and Echin (3e) suggests that these basins are less susceptible to flash floods, and the relatively low drainage density confirms this. This condition however attenuates the conditions within the individual sub-basins. Therefore, the

current experience of flash floods in River Be can rightly be attributed to the variable drainage density and land use within the sub-basins of lower order in this basin.

The elongation ratio as shown in table 1 indicates that 64.1 percent of the sub-basins fall within the 0.6-0.8 range of Schumm (1956) for basins with steep ground slope and great relief and 94.9 percent within Mustapha and Yusuf's (1999) 0.4-0.8 range. Only 2.6 percent approaches 1.0, which according to Schumm is characteristic of basins with gentile slope.

Apart from the above is the high circularity ratio of the basins. The overall within the 0.6-0.8 for rotund basins (Miller, 1953; Strahler, 1964), being about 56.4 percent, implies that the basins are highly rotund. This means that runoff from various parts of the watershed could reach the outlet at the same time. This is a possible determinant of the flashy flows that are observed for parts of the Aya basin. Therefore, although the drainage density maybe low, the high circularity ratio can also determine the flashy nature of most of the basins. This high rotundity is more in the 3rd order basins with 71.4 percent within the 0.6-0.8 ranges. Others are 60 percent for 4th order basins and 51.9 percent for 2nd order basin. In the 3rd order basins, the low circularity in the Debekim and Echin (<0.6) corresponds to their elliptical shape, confirming that runoff response in these basins slow, hence low incidences of flash floods.

The watershed slope (WS) also appears to be highly variable even among drainage basins of the same order and similar sizes. On the whole, about 51.3 percent of the sub-basins have slope >1 percent. Generally, the slope is higher (> 1 %) in the 2nd and 4th order basins, which are equally characterized by comparatively high drainage density, elongation and circularity ratios. The rate and momentum of runoff in the basin is therefore expected to be higher (Wisler and Brater, 1959), but the downstream effects maybe regulated by the slow runoff response of the Debekim and Echin (3rd order) basins. This can be compounded in basins with corresponding higher drainage density.

The low watershed slope in Debekim and Echin basins appears to synchronize directly with the low drainage density, low circularity and elongation ratios, and high bifurcation ratio. These help to control downstream flood regime and the sustenance of dry season low flow.

The high slope in the River Be (4b) catchment suggests that in addition to the high circularity and elongation ratio, and the comparatively high drainage density (> 1 km/km²), much of the runoff volume and flash flows in Aya river come from this catchment despite the high bifurcation ratio. Being a very large sub-basin, regulating flow through appropriate watershed controls within this basin will help to regulate downstream effects.

The length of overland flow, considered to be inversely related to the drainage density (Wister and Brater, 1959), also differs among the sub-basins of Aya River. On the basis of the different orders, the 2nd and 4th order basins have shorter length of over land flow than the order basins. This confirms that the 3rd order basins respond slowly to storm, while the 2nd and 4th order basins have sharper peak discharge and higher risk of flash floods (U. S. EPA, 2006; Strahler, 1964).

Relating stream flow to geomorphometric parameters using multivariable, Taylor and Schwartz (1952) used 20 basins of different sizes, located in different areas to examine the relationship of stream flow with channel length, main stream length to centroid and main slope. They identified that these variables influence runoff. Potter (1953) and Morisawa (1959) observed that significant relationship existed between average runoff and peak runoff, and stream length, basin area, relief ratio and shape ratio within sub divisions of a single watershed

Salleh et al (1994) established the relationships between geomorphometric properties and the minimum low flow discharge of undisturbed drainage basins. Selecting 3rd order drainage basin only, as common base for sampling and performing an unbiased statistical analysis, they observed three levels of relationships. Significant relationship existed

between the geomorphometric properties; individual geomorphometric properties were observed to influence minimum flow discharge; and regression analysis showed that minimum flow discharge was dependent on basin area, stream length, maximum relief, average relief and stream frequency.

The implication of all the above is that changes in the flow of stream in spatio-temporal contexts, apart from being dependent upon climate and land use are determined by the changes in the geomorphometric attributes of the basin. The attributes, which are rather more stable could be altered by natural and human activities hence, it is asserted (Harlim, 1994) that variations in climate and degree of geomorphic development as well as land use in large measure affect morphometric complexities. The variable flow regime in Aya River may be attributed to the spatial and temporal variations of the drainage basin characteristics.

4.2 Nature of variation in the geomorphometric parameters in Aya basin

Statistical analysis was carried out to examine the level of variation in the parameters. On the whole however, the descriptive statistics as shown in table 2 shows that many of the parameters did not appear to vary much from the mean condition between sub-catchments.

Table 2: Descriptive statistics of the geomorphometric parameters

Parameters	Mean	Std. Deviation	Coefficient of variation
Overland flow	4749	17852	37.6
Large density	1.2395	29713	23.8
Elongation ratio	6251	10440	16.7
Circularity ratio	6185	12963	21
Watershed slope	11.1605	6.98765	62.6
Basin area	31.3397	55.26	76.3
Bifurcation	3.31158	1.90848	57.6

Source: Analysis result, 2007.

From table 2 we can decipher that the most probable determinants of the changing flow regime generally are watershed slope, basin area, and bifurcation ratio. These parameters varied markedly from the mean and have higher coefficient of variation, implying that they are more spatially variable; hence their more general contribution to variation in flow. The influences of other parameters are therefore mostly

localized and may be dependent on the size of basin, watershed slope and land use change

Analysis of variance was used to determine the level of variation between the sub-catchments in terms of the parameters considered to be less variable and reliable. These variables include Drainage density, circularity and elongation ratio and length of overland flow

Table 3: ANOVA TABLE

Source of variation	Difference squares	of	Degree freedom	of	Variance estimate	F calculated	F table value
Between samples	1.53		38		0.04		
Within samples						5.25	<1.70
Total	32.58		156		0.21		
	34.11		194		0.25		

Source: Analysis result, 2007

The result as presented in table 3 shows that there is still a significant variation between the sub-catchments of Aya in terms of the five parameters. This implies that the contribution of these variables to the variable flow regime significantly varies between the sub-catchments, given the higher calculated F value

The degree of variation between the sub-catchments' geomorphometric attributes determines which attributes contribute more or less to the changing flow. Establishing the

relationship between the parameters provides an idea of the dominant likely independent variable within a basin

4.3 Relating the various drainage basin geomorphometrics

The relatively moderate drainage density suggests average flashy nature of the streams, while other parameters suggest high susceptibility to flash flood, except perhaps among the 3rd order basins. Correlation analysis was therefore carried out to examine the nature of interrelationship

between these variables, so as to ascertain their independent roles in the flow regime.

Pearson Correlation matrix (table 2) shows that non of the parameters correlated highly with drainage density, implying that drainage density and other parameters are truly independent variables in the prediction of stream flow. The matrix also shows that collinearity existed between the bifurcation ratio (Rb) and Elongation ratio (Er). The implication

is that these variables are highly interrelated such that the presence of one regulates the effects of the other in influencing stream flow. The later confirms with Strahler (1964), that the bifurcation ratio is influenced by the elongation ratio being lower in rotund (circular) than elliptical basins and lower in areas with steep slope than those with gentle ground slopes.

Table 4: Zero Order Correlation Matrix of drainage density and other geomorphometric parameters

	Dd	A	Rb	S	Cr	Er
Dd	1	-.228	-.002	.082	.189	-.021
Ls			.289	.278	-.011	-.017
Rb			1	.368	-.114	.788
S				1	.159	.206
Cr					1	-.043
Er						1

Source: Analysis result. 2007.

Relating the above to stream flow would suggest that all the variables are truly independent determinants of flow regime except bifurcation ratio and elongation ratio, which are strongly inter-related parameters such that the presence of one can either accelerate or dampen the effect of the other. The low correlation between other variables does not imply that a functional relationship does not necessarily exist (Mather, 1976). As pointed out by Uma and Kehinde (1992), it suggests that such a simplified model may not explain the relationship.

In this study, a positively low and linear correlation between drainage density and basin slope was also established. Areas with low drainage density in most of the sub-basins are therefore associated with low slope gradient. In such areas, groundwater potential is higher and so is sustained base flow contribution to stream flow.

4.4 Relating length of overland flow with other parameters

The analysis was to determine which of the other basin parameters influence length of overland flow most, so as to ascertain the level of independence of this parameter in explaining the stream flow regime.

The result of analysis shows that a high correlation (.839) existed between length of overland flow and other basins parameters such as drainage density, elongation ratio,

circularity ratio and watershed slope. The coefficient of determination of .704 shows that 70.4% of the variation in length of overland flow is explained by the above named independent variables. The low error of estimate of .10589 implies that the relationship did not occur by chance. In addition the F value of 12.665 > P (0.000) also confirms that a significant relationship existed between length of overland flow and the other geomorphometric parameter collectively.

The regression equation developed is of the form:

$$L0 = 1.096 - .902Dd + .145Er - .158Cr - .077S \dots \dots (2)$$

$$t = (7.246) \quad (.785) \quad (1.196) \quad (1.211) \quad (-.077)$$

$$t \text{ sig. } .000 \quad .000 \quad .241 \quad .239 \quad .467$$

Where Dd, Er, Cr, and S are as explained in table 1

This model shows that a significant relationship existed more between drainage density and length of overland flow while that between length of overland flow and watershed slope was not significant and linear.

The zero order Pearson correlation matrix as shown in table 4 confirms that drainage density highly negatively correlated length of overland flow.

Table 5: Zero Order Correlation Matrix of length of overland flow and other parameters

	Lo	Dd	Er	Cr	Ws
Lo	1	-.827	-.008	-.077	-.179
Dd		1	.082	0.55	.189
Er			1	.452	.159
Cr				1	-.681
Ws					1

Source: Analysis result, 2007

The above confirms that length of overland flows is lowest in areas with high drainage density (Wisler and Brater, 1959) but in this case it is less associated with slope (Strahler, 1964). However, the higher coefficient of variation (table 2) for watershed slope means that runoff response (flow regime) varies between the sub-basin more on the basis of slope than length of overland flow and drainage density.

5. CONCLUSION

The flow regime in Aya river can also be attributed to geomorphometric characteristics of the sub-basins. Examining the flow based on the average conditions of the geomorphometric parameters could be misleading as the local scale conditions, which contribute to the variable flow, are

likely to be suppressed and dampened in the course of analysis.

Analysis of spatial pattern of the geomorphometric parameters reveal that three of them, including basin area, watershed slope and bifurcation ratio, differ significantly between sub-basin, even where they are of the same order. The variation implies variable control/contribution to the stream flow from the sub-basins.

On the whole, these parameters are considered as the most important determinants of the flow regime. However, with a high co-linearity between bifurcation and elongation ratio and between drainage density and length of overland flow only one of these pair of parameter can be used to explain flow regime without the consideration of the other as well. On the

other watershed area and basin slope can be considered actually independent in explaining flow regime

We must understand that most of these geomorphometric parameters are relatively stable in temporal context. However, changes in climate and land use can alter these parameters, hence their influence on stream flow. It becomes imperative that in examining the variable flow regime, an understanding of the whole drainage system characteristics is necessary. Management of watersheds through land use planning and control is valuable for assuaging the alteration of the basin geomorphometrics, thus sustaining the flow pattern.

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