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MORPHOMETRICAL ANALYSIS AND PEAK RUNOFF ESTIMATION FOR THE SUB-LOWER NIGER RIVER BASIN, NIGERIA

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Abstract

This study utilized Spatial Information Technology (SIT) such as Remote Sensing (RS), a Geographical Information System (GIS), the Global Positioning System (GPS) and a high-resolution Digital Elevation Model (DEM) for a morphometrical analysis of five sub-basins within the Lower Niger River Basin, Nigeria. Morphometrical parameters, such as the total relief, relative relief, relief ratio, ruggedness number, texture ratio, elongation ratio, circularity ratio, form factor ratio, drainage density, stream frequency, sinuosity factor and bifurcation ratio, have been computed and analyzed. The study revealed that the contribution of the morphometric parameters to flooding suggest catchment No. 1 has the least concentration time and the highest runoff depth. Catchment No. 4 has the highest circularity ratio (0.35) as the most hazardous site where floods could reach a great volume over a small area.

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Key words

- Digital Elevation Model,
- Drainage Network,
- Morphometrical Parameters,
- River Basin,
- Spatial Information Technology,
- Sustainable Development.

1 INTRODUCTION

"Hydromorphology" is a term used in river basin management to describe the hydrological and geomorphological processes and attributes of rivers, lakes, estuaries and coasts. The formulation of proper management plans and its attendant consequences require reliable and up-to-date information about various factors such as morphology (size and shape of the watershed, drainage parameters, topography), soil and its characteristics, land use and cover, etc., which affect the behavior of a watershed. Furthermore, it is necessary to translate the watershed ecosystem dynamics into predictive statements from a long-term quantitative analysis and an assessment of all the climatological, hydrological and geological factors that are likely to instigate flood disasters and unsustainable catchment use. Floods are responsible for more than one-third of the total estimated costs incurred due to disasters and for injuries to two-thirds of the people affected by natural disasters (Ramshoo et al., 2012). Consequently, many countries have long-term study programs in place that monitor the hydrogeological factors that contribute to vulnerability to floods. The study of vulnerability to floods involves:

- The pre-determination of factors leading to the occurrence of floods, i.e., pre-flood studies, including mapping of areas prone to flooding or inundation, etc.
- Assessment of the extent of damage to life, property and the environment
- Post-flood mitigation of the effects that affect agriculture and food production, intervention tools to reduce vulnerability, and conducting post-flood environmental impact assessments.

The Tada Shonga catchment is a major floodplain of the River Niger that is undergoing intensive water management work. However, due to incessant flooding, an extensive and high rate of erosion, the depletion of soil nutrients and unsustainable water use in the catchment area have been experienced. This excessive flooding can be due to a number of factors related to topography, geology, climate and human activity. Prior to the establishment of the Kainji and Jebba dams, flooding occur once in every seven to ten-year intervals (Atakpu, 1999). However, after the construction of these dams, floods occurred perennially with very high discharges of the River Niger and its tributaries in September and December, causing a rise in water levels and overflows of river banks at some places within the Tada Shonga (Pearce, 2001; FGN, 2006; Olukanni and Salami, 2010). Spatial information technologies, particularly Geographical Information Systems (GIS), represent efficient tools in the determination of the morphometrical properties of drainage basins for water resources management and environmental planning (Koshak and Dawood, 2011).

The hydrological response of a drainage basin is defined by the production of runoff from a given rainfall, which in turn is characterized by the basin's morphometrical properties, soil characteristics and land use patterns. While the soil characteristics and land use patterns control the infiltration loss, the distribution of the remaining excess rainfall is governed by the basin's morphometrical properties (Ajibade et al., 2010). When a morphometrical analysis is carried out, it helps to predict the direction of flows and the total discharge useful for the design of any hydraulic structures. However, this study highlights pre and post-hazard studies that lead to an organized approach to flood forecasting, prevention and management. It provides the necessary data required to forecast, manage, and estimate the magnitude of an impending flood disaster.

2 MATERIALS AND METHODS

2.1 Description of the Study Area

The investigated area is enclosed between the latitudes of $7^{o}\,45'$ N and $9^{o}30'$ N and longitude of $2^{o}\,30'$ E and $6^{o}\,25'$ E covering an area of 2924.62 km^2. It lies to the right bank of the River Niger within the flood plain downstream of Jebba. Fig. 1 is a map of Nigeria showing Kwara State, while Fig. 2 is a map of Kwara State where the study area is located. The study area shares common boundaries with Niger State and Kogi State as well as Edu and the Irepodun Local Government Areas of Kwara State; it is about 110 km northeast of Ilorin, the Kwara State capital (www.kwarastate.com). A humid climate prevails within the study area with two distinct seasons (the wet and dry seasons). The rainfall ranges from 50.8 mm during the driest months to 2413.3 mm in the wettest months.

The minimum average temperature throughout the state ranges from 21.1 ^{o}C to 25.0^{o}C, while the maximum average temperature ranges from 30.0 ^{o}C to 35.0 ^{o}C (NIMET, 2007). The availability of water resources was the major attraction when this site was chosen for newly arrived Zimbabwean farmers to Nigeria in 2004.

2.2 Data Collection and Analysis

The morphological characteristics, including the watershed platform, shape factors and watershed area factors of the study area, make it a typical watershed in the Lower Niger River Basin (LNRB) area of Nigeria. The morphological parameters were measured from DEM, stream networking, and the delineated watershed using ArcGIS tools and further processed to compute important morphological parameters. The number of streams of various orders in the basin are counted, and their lengths from mouth to drainage divide are measured with the help of GIS software. The procedure adopted by Abel (2005) was modified and employed here to characterize the watershed.

The main data utilized is the Digital Elevation Model (DEM) for the study area from the published global ASTER and SRTM3 data. This was processed in Arc GIS and Arc Hydro to determine the basin's morphometry. Additionally, some programming steps have been performed within the attribute tables of the Arc Hydro software to compute the necessary morphometrical quantities. The order was given to each stream by utilizing the Strahler (1964) stream ordering

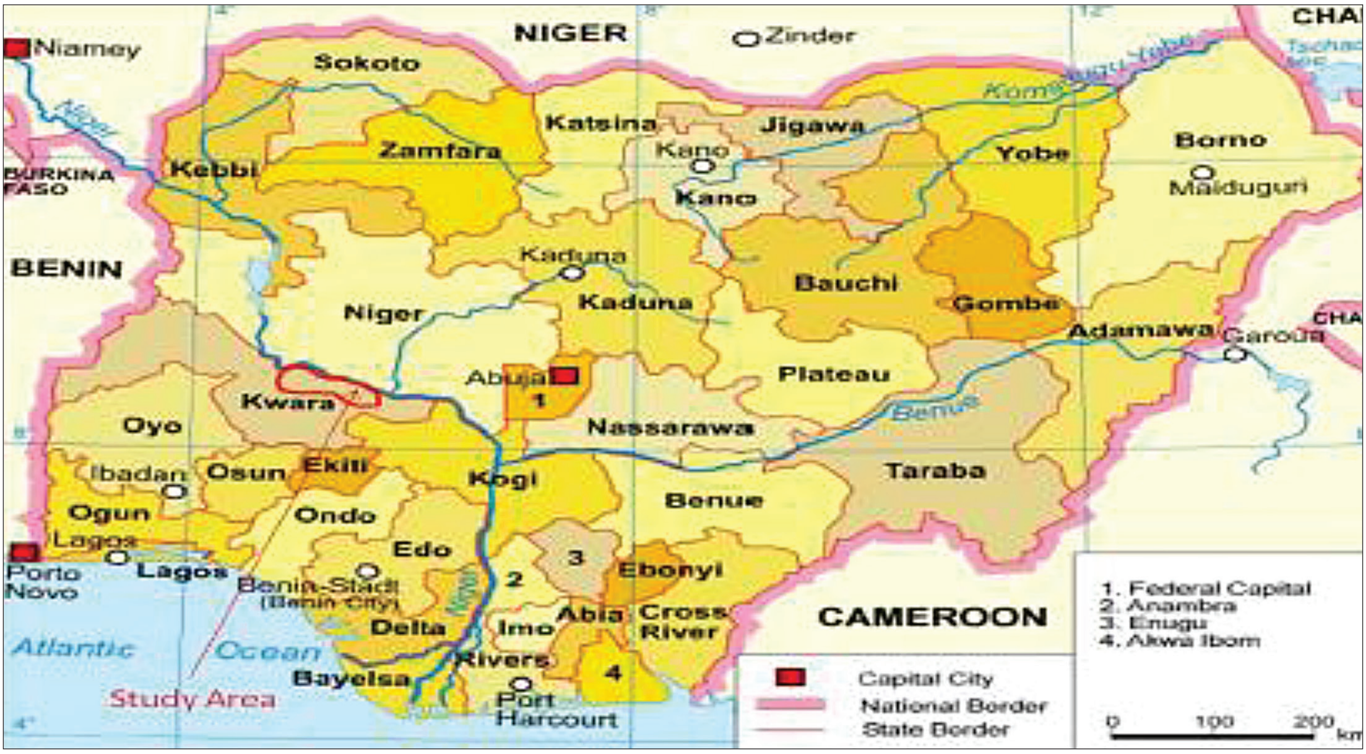

Fig. 1 *Map of Nigeria showing location of Kwara State.*

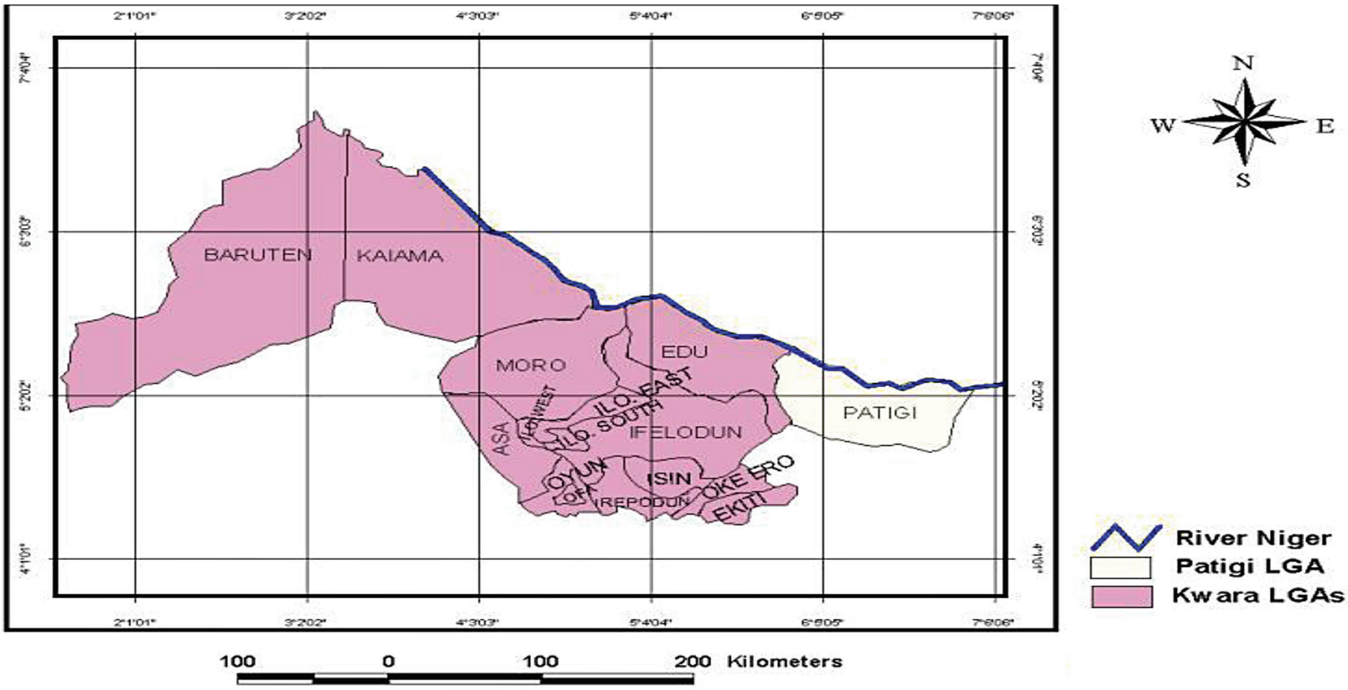

Fig. 2 *Map of Kwara state showing the study area*

technique. The attributes were assigned to create a digital data base for the drainage layer of the river basin, and the map of the drainage pattern of the study area was prepared after a detailed ground inspection with a GPS survey on the channel network and water tanks as presented in Fig. 3. Also, the map showing the land slope of the study area is presented in Fig. 4, while the map depicting the distribution of the land use and land cover for the watershed is presented in Fig. 5.

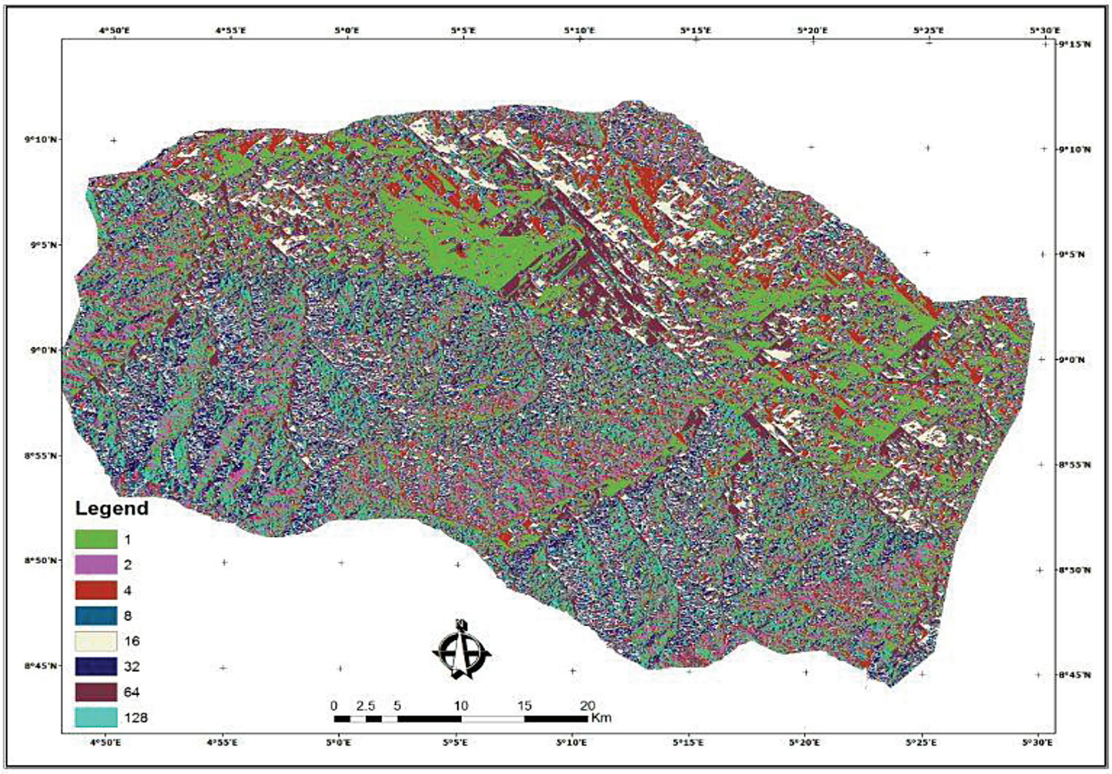

Fig. 3 *The digital elevation model for Shonga District*

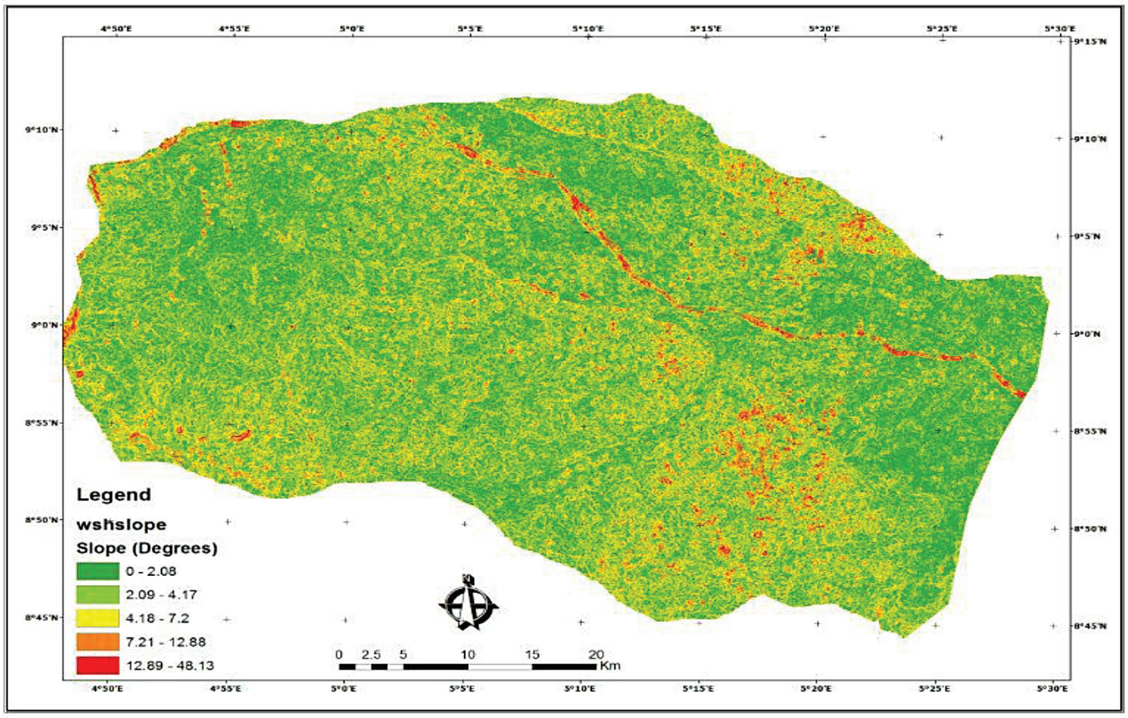

Fig. 4 *The land slope map of the study area*

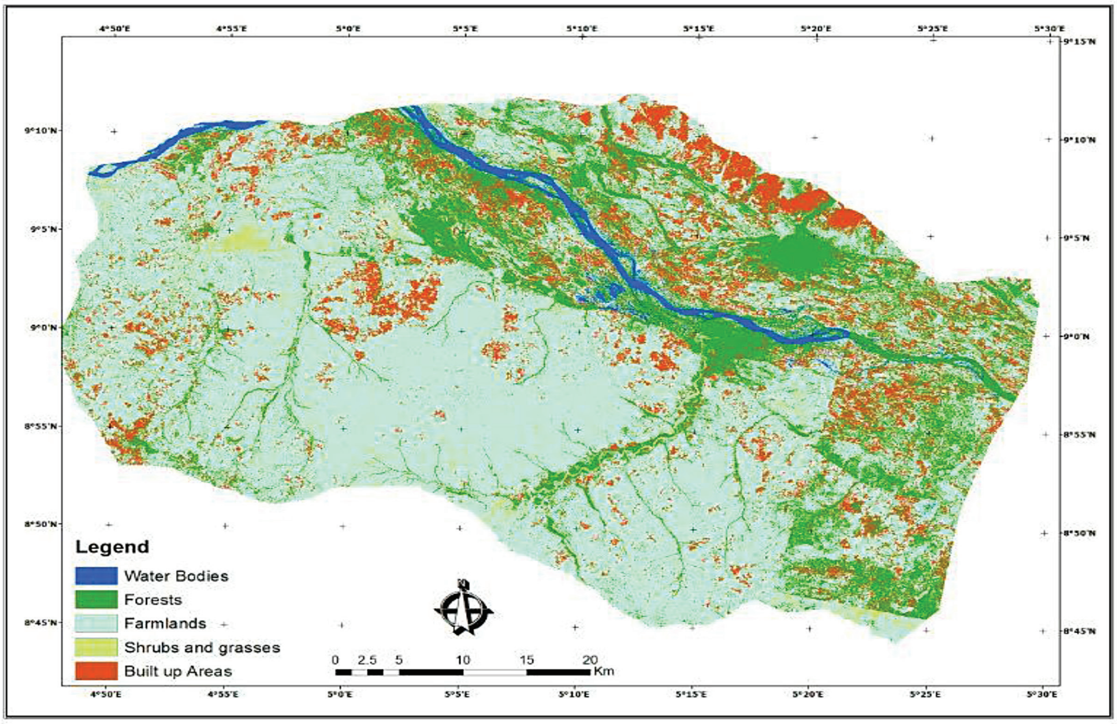

Fig. 5 *Depicts the distribution of land use and land cover for the watershed*

2.3 Morphometrical Parameters of the Study Area

A number of common parameters are usually utilized in order to describe the morphometrical and geomorphological properties of a watershed. However, the morphometry of a basin is broadly predicted by:

i. The relationship between the stream numbers of each order in a drainage basin as dictated by Horton (1945) and modified by Strahler (1964).
ii. The average length of the streams of each order.
iii. The slope of the gradient of the streams of each order.
iv. The drainage basin area for the streams of each order. Such parameters can be grouped in four categories: topographic, areal, relief, and network properties.

The details can be found in the literature: (Horton, 1945; Strahler, 1964; Krishnamuntly and Srinwas, 1995; Srivastara and Mitra, 1995;

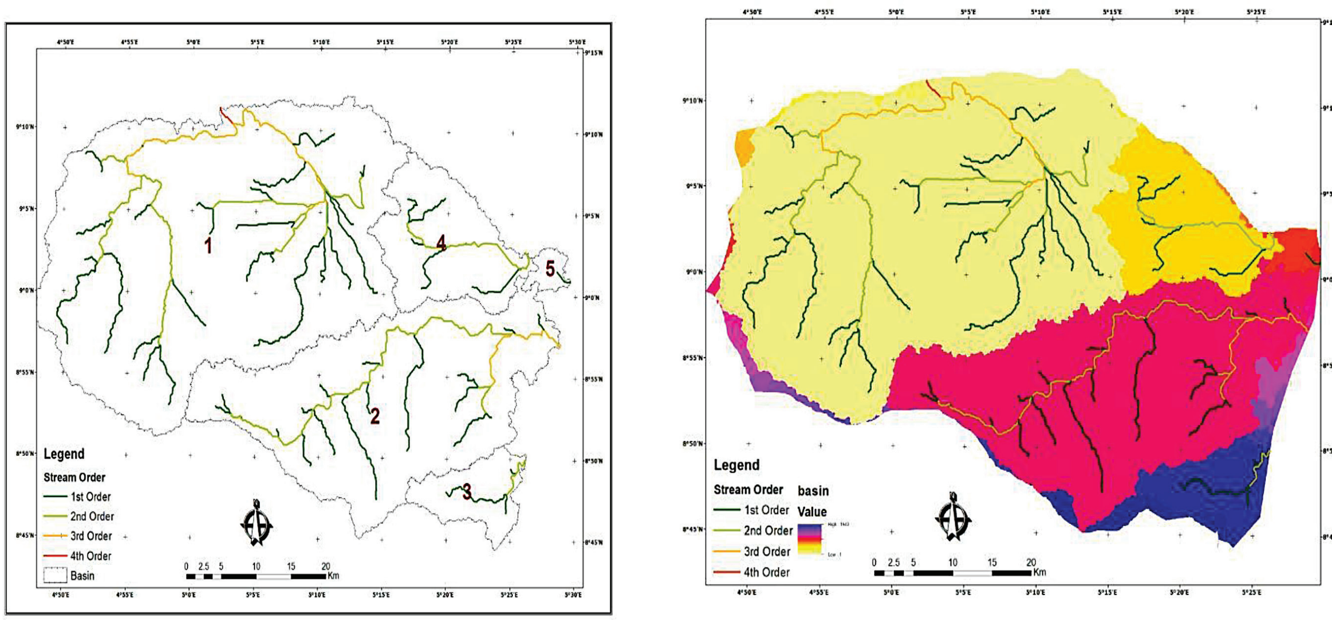

Fig. 6 *Stream order and drainage patterns of the study area*

Argawal, 1998; Biswas et al., 1999; Narandra and Nagaswera, 2006). Utilization of the Arc GIS software, along with some other associated extensions, has resulted in the delineation of five watersheds within the Shonga area as presented in Figure 6. The topographical and hydrographical configurations of the watershed are identified and used to infer what can be expected from the watershed's hydrology.

The various shape indices or morphometrical parameters of the River Niger basin area were determined and are summarized in Tabs. 1 to 3.

Tab. 1 *Topographic and linear aspects of the channel system*

River basin	Stream order	Number of streams (N_u)	Total length of streams (km) (L_u)	Log N_u	Log L_u
Lower Niger River Basin (LNRB)	1	97	308.85	1.987	2.4898
	2	96	179.67	1.982	2.2545
	3	57	66.35	1.756	0.8028
	4	1	2.75	0	0.4394
Bifurcation ratio R_b				**Mean bifurcation ratio**	
1st order/ 2nd order	2nd order/ 3rd order	3rd order/ 4th order	4th order/ 5th order		
18.390	1.620	0.500	0.400	4.182	

Tab. 2 *Stream length of the sub-basins and order of basin streams*

Sub basins	Stream order							Steam order				
	1st	2nd	3rd	4th	Total	Mean		1st	2nd	3rd	4th	Total
	Stream length (km)							Number of stream				
A1	180.12	88.97	48.83	2.75	320.68	80.17		56	76	53	1	186
A2	81.44	61.54	17.52	0	160.49	53.50		21	13	4	0	38
A3	14.48	6.31	0	0	20.78	10.39		13	2	0	0	15
A4	30.47	22.85	0	0	53.32	26.66		6	5	0	0	11
A5	2.34	0	0	0	2.34	2.34		1	0	0	0	1
Total	308.85	179.67	66.35	2.75			Total	97	96	57	1	251

Tab. 3 *Computed morphometrical parameters of the study area*

Morphometric Parameters	Symbol/ formula	Sub basins					Mean value	Total value
		A1	A2	A3	A4	A5		
Topographic properties								
Area (km^2)	A	1407.90	774.54	101.17	245.64	21.34	510.120	2550.59
Perimeter (km)	P	222.37	193.28	62.74	94.62	28.93	120.380	601.94
Length of main stream: (Km)	L	180.12	81.433	14.472	30.46	2.343	61.760	308.83
Relief properties								
Basin relief: ΔH (m)	$\Delta H = H_{max} - H_{min}$	59.82	51.99	16.88	25.46	7.78	32.39	161.93
Relative relief	$R_{hp} = \Delta H / P$	0.009	0.011	0.048	0.060	1.218	0.2692	1.346
Relief ratio (slope)	$R_h = \Delta H / L$	0.012	0.011	0.017	0.031	0.195	0.0532	0.266
Ruggedness number	$N = \Delta H \,.\, D$	9.131	10.087	14.703	26.117	320.94	76.196	380.98
Areal properties								
Texture ratio: T	$T = N_1 / P$	0.391	0.450	1.387	0.919	3.007	1.230	6.154
Elongation ratio:Re	$R_e = 2 [\sqrt{(A / \prod)}] / L_u$	0.076	0.056	0.020	0.032	0.009	0.039	0.193
Circularity ratio: Rc	$Rc = 4 \prod A / P^2$	0.358	0.261	0.323	0.345	0.321	0.320	1.608
Form factors ratio: Rf	$R_f = A / Lb^2$	0.043	0.117	0.483	0.265	3.886	0.960	4.80
Network properties								
Drainage intensity (km/sq. km)		1.724	4.223	4.156	4.847	2.343	3.459	17.29
Drainage density (km/ sq. km):D	$D = L_u/A \quad D_d = L/A$	0.228	0.207	0.205	0.217	0.110	0.193	0.967
Stream frequency:Fs	$Fs = N_u / A$	0.132	0.049	0.049	0.045	0.047	0.064	0.322
Sinuosity factors: S	$S = L_b / L_{min}$	76.97	34.80	6.184	13.02	1.001	26.395	131.98
Length of overland flow (km)		8.78	9.65	9.74	9.22	18.22	11.12	55.61
Shape coefficient (K_f): L is the length of the longest stream (Km)	$K_f = \frac{A}{L^2}$	0.0434	0.1168	0.4831	0.2648	3.8873	0.9591	4.80
Gravelius or compactness coefficient (K_c):	$K_c = 0.28\left(\frac{P}{A^{1/2}}\right)$	1.6594	1.9446	1.7466	1.6904	1.7535	1.7589	8.80
Concentration time (T_c)(second)	$T_c = \left(\frac{0.886 L^3}{H}\right)^{0.385}$	79.59	33.59	7.04	14.20	0.44	26.97	134.86

where:

L_u = Total stream length of all the orders;
N_u = Total no. of streams of all orders
N_1 = Total no. of 1st order streams;
H = the altitudinal difference (in metres)
L = the length of the main stream (in km);
Π = 3.14

2.4 Estimation of the Peak Runoff for the Sub-Basins

2.4.1 Soil conservation service (SCS) method

Raghunath (2006) reported that the US Soil Conservation Service in 1971 used many hydrographs from drainage areas of varying sizes and different geographical locations to develop a dimensionless unit hydrograph. The peak discharge and the time of the peak can be determined in accordance with (Viessman et al., 1989; Wanielista, 1990; Ramirez, 2000; SCS, 2002; Ogunlela and Kasali, 2002; Raghunath, 2006 & Salami et al., 2013). Equations 1 to 4 were adopted in the analysis.

2.4.1.1 Peak discharge

The peak discharge can be obtained through the equation (Ramirez (2000))

$$Q_p = \frac{0.208 * A * Q_d}{t_p} \tag{1}$$

where
Q_p = peak discharge (m³/s)
A = watershed area (km²)
Q_d = quantity of runoff (mm)
t_p = time to peak (hr)

2.4.1.2. Time to peak (t_p) and lag time (t_l)

$$t_p = \frac{t_r}{2} + t_l \qquad (2)$$

$$t_p = \frac{t_c + 0.133t_c}{1.7} \qquad (3)$$
$$t_l = 0.6t_c$$

where:
t_c = time of concentration (min)

$$t_c = 0.0195\left(\frac{L^{0.77}}{S^{0.385}}\right) \qquad (4)$$

L = length of channel (m)
S = slope of channel

The estimated values for both the peak discharge and time to peak were applied to the dimensionless hydrograph ratios in accordance with SCS, and the points for the unit hydrograph were obtained (Raghunath , 2006) and used to develop the unit hydrograph curve.

2.4.2 Development of the synthetic unit hydrograph

The method of the US Soil Conservation Service (SCS) for constructing synthetic unit hydrographs was based on a dimensionless hydrograph, which relates ratios of time to ratios of flow (Viessman et al., 1989) and Ramirez (2000). This method only requires the determination of the time to the peak and the peak discharge. The calculated values for parameters t_p and q_p were applied to the SCS dimensionless unit hydrograph to obtain the corresponding unit hydrograph ordinates; the estimated unit hydrograph ordinates presented in Tabs 4 to 8 are based on the values of the time to peak discharge (t_p) and peak discharge (q_p) for each sub-basin.

2.4.3 Development of the peak runoff hydrographs

The unit hydrograph ordinates established were used to develop the runoff hydrographs for the actual rainfall events over the sub-basins. The peak runoff hydrographs for the selected return periods (25 yrs, 50 yrs, 75 yrs and 100 yrs) were developed through convolution. The runoff hydrograph was derived from a multiperiod of rainfall excess called "hydrographic convolution". This involves multiplying the unit hydrograph ordinates (U_n) by the incremental rainfall excess (P_n), and adding and lagging in a sequence to produce the resulting storm hydrograph. The SCS type II curve was used to divide the different rainfall data into successive equal short-time events, and the SCS Curve number method was used to estimate the cumulative rainfall for storm depths of 25 yrs, 50 yrs, 75 yrs and 100 yrs return periods as 157.79 mm, 172.71 mm, 181.38 mm and 187.51 mm respectively. The incremental rainfall excess was obtained by sequentially subtracting the rainfall excess from the previous time events. The equations that apply to the SCS Curve Number method are given (SCS, 2002) as presented in equations (5) and (6), while those for the convolution are presented in equation (7).

$$Q_d = \frac{\left(P^* - I_a\right)^2}{P^* + 0.8S} \; for\; P^* > 0.2S \qquad (5)$$
$$Q_d = 0 \; for\; P^* \le 0.2S$$

Tab. 4 *Unit hydrograph ordinates for sub-basin A1*

T(hr)	0.00	6.50	13.01	19.51	26.01	32.51	39.02	45.52	52.02	58.52	65.03	0.00
Q (m³/s/cm)	0.00	96.82	225.17	148.61	72.05	34.90	16.89	8.11	4.05	2.03	0.90	0.00

Tab. 5 *Unit hydrograph ordinates for sub-basin A2*

T(hr)	0.00	3.60	7.30	10.90	14.60	18.20	21.90	25.50	29.20	32.80	36.50	0.00
Q (m³/s/cm)	0.00	94.90	220.80	145.70	70.60	34.20	16.60	7.90	4.00	2.00	0.90	0.00

Tab. 6 *Unit hydrograph ordinates for sub-basin A3*

T(hr)	0.00	0.82	1.63	2.45	3.26	4.08	4.90	5.71	6.53	7.34	8.16	0.00
Q (m³/s/cm)	0.00	55.45	128.95	85.10	41.26	19.99	9.67	4.64	2.32	1.16	0.52	0.00

Tab. 7 *Unit hydrograph ordinates for sub-basin A4*

T(hr)	0.00	1.15	2.30	3.45	4.59	5.74	6.89	8.04	9.19	10.34	11.48	0.00
Q (m³/s/cm)	0.00	95.66	222.45	146.82	71.19	34.48	16.68	8.01	4.00	2.00	0.89	0.00

Tab. 8 *Unit hydrograph ordinates for sub-basin A5*

T(hr)	0.00	0.08	0.16	0.24	0.31	0.39	0.47	0.55	0.63	0.71	0.78	0.00
Q(m³/s/cm)	0.00	121.57	282.73	186.60	90.47	43.82	21.20	10.18	5.09	2.54	1.13	0.00

I_a = initial abstraction $I_a = 0.2S$

$$S = \frac{25400}{CN} - 254 \tag{6}$$

With the CN = 75 based on soil group B, small grain and good conditions, S is estimated as 84.67 mm, while I_a is 16.94 mm. This implies that any value of rainfall less than 16.94 mm is regarded as zero.

where:

$P*$ = accumulated precipitation (mm)

Q_d = cumulative rainfall excess, runoff (mm)

$$Q_n = R_1U_n + R_2U_n + R_3U_n + ------ \tag{7}$$

where:

R = incremental rainfall excess (cm)

U = unit hydrograph ordinates (m^3/s/cm)

Q_n = Peak runoff (m^3/s)

The runoff hydrograph ordinates based on the rainfall depth of the desired return periods were estimated from the unit hydrographs. The storm hydrograph peak flows obtained for the sub-basins A1 to A5 are presented in Tab. 9.

Tab. 9 *Peak runoff for sub-basins A1 – A5 (m³/s)*

Sub-Basins	Storm return periods and peak flows			
	25 yrs, 24 hrs	50 yrs, 24 hrs	75 yrs, 24 hrs	100 yrs, 24 hrs
A1	1287.35	1478.83	1591.74	1672.22
A2	1262.08	1449.80	1560.49	1639.40
A3	737.21	846.86	911.52	957.61
A4	1271.81	1460.99	1572.53	1652.04
A5	1616.42	1856.86	1998.63	2099.68

The runoff hydrograph for the peak flows of various return periods for each sub-basin are presented in Figs. 7 to 11 respectively.

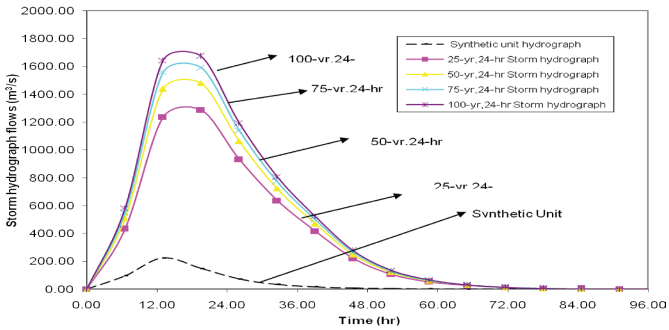

Fig. 7 *Unit hydrograph with generated storm hydrographs of different return periods for sub-basin A1.*

3 RESULTS AND DISCUSSION

3.1 Results

The results obtained from the analyses have been summarized in Tabs. 1 to 3. Tab. 1 depicts the information for the topographic and linear aspects of the channel system; Table 2 depicts the stream length of the sub-basins and basin stream order, while Table 3 presents the summarized morphometrical parameters. The unit hydrograph ordinates generated based on the SCS method are presented in Tabs 4 to 8, while the peak runoffs obtained for the four sub-basins are presented in Tab. 9. The map of Nigeria showing the location of Kwara State is presented in Figure 1, while the map of Kwara State showing the

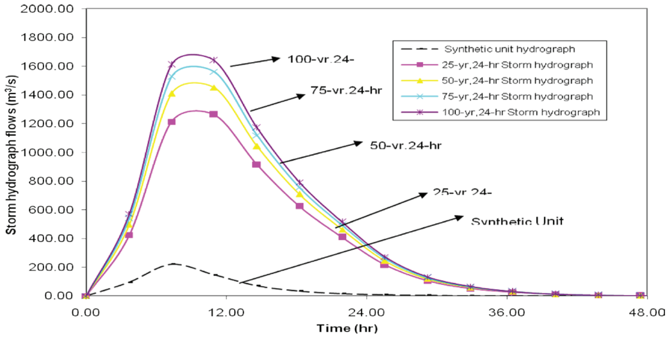

Fig. 8 *Unit hydrograph with generated storm hydrographs of different return periods for sub-basin A2.*

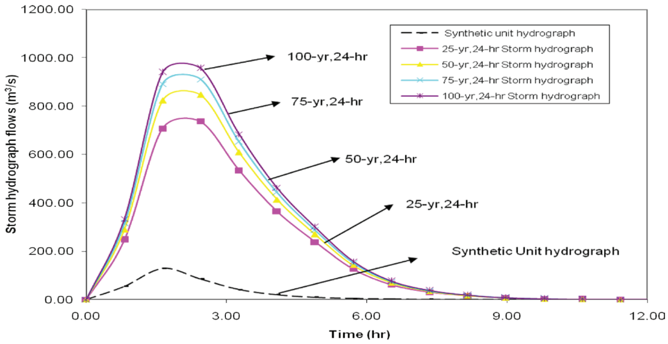

Fig. 9 *Unit hydrograph with generated storm hydrographs of different return periods for sub-basin A3.*

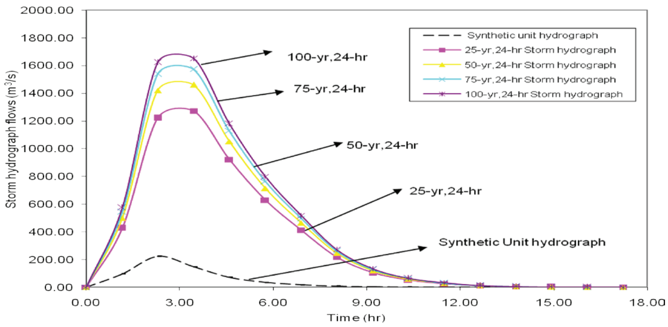

Fig. 10 *Unit hydrograph with generated storm hydrographs of different return periods for sub-basin A4.*

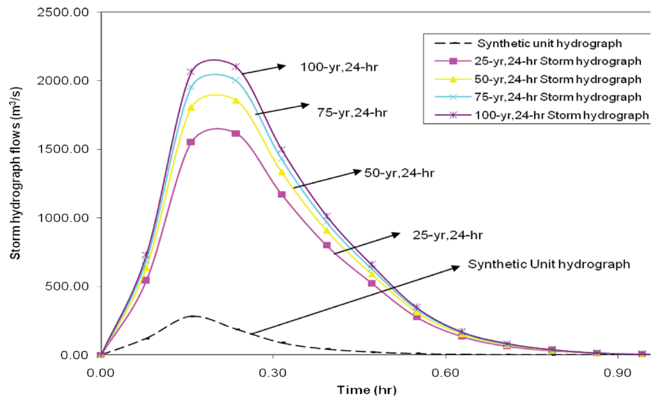

Fig. 11 *Unit hydrograph with generated storm hydrographs of different return periods for sub-basin A5.*

study area is presented in Figure 2. The digital elevation model for the study area is presented in Fig. 3, while Figs. 4, 5 and 6 depict the land slope map, distribution of the land use / cover and stream order / drainage patterns. The synthetic unit hydrographs and peak runoff hydrographs for the various return periods for the five sub-basins are depicted in Figs 7 to 11.

3.2 Topographic and Linear Aspects of the Channel System

As presented in Tables 1 to 3, there are five subbasins in the study area with four stream orders. The 1st order streams total 97 in number with a total length of 308.85 km; the 2nd order streams total 96 with a total length of 179.67 km; the 3rd order streams total 57 with a total length of 66.35 km; and the 4th order stream is only 1 with a total length of 2.75 km. The topographic properties of the watersheds of the sub-basins are as presented in Tables 2 and 3; the sub-basin areas range from 21.34 to 1407.90 km^2, while the basin perimeters vary from 28.93 to 222.37 kilometers. The length of the main stream in the sub-basin, which is a significant morphometrical parameter, varies from 2.34 to 180.12 kilometers, while the sub-basin slopes vary from 0.012 to 0.195. The sub-basin areas, the length of the main stream, and the basin slopes are useful in the SCS method to determine the synthetic unit hydrograph ordinates, which can be convoluted to determine the peak runoff for each of the sub-basins.

3.2.1 Stream order (U)

The stream order (U) expresses the hierarchal relationship between the individual stream segments that make up a drainage network. The first step in drainage basin analysis is the designation of the stream orders.The streams of the Niger River basin have been ranked according to the method described by Strahler (1964). According to Strahler (1964), the smallest fingertip tributaries are designated as order 1; when two first order streams join, a stream segment of the second order is formed; when two second order streams join, a segment of the third order is formed, etc. The stream lengths of the various segments are measured with the aid of GIS software. The study area is a 4th order drainage basin as presented in Figure 6.

3.2.2 Stream number (N_u)

After assigning the stream orders, the segments of each order are calculated to get the number of segments of a given order (N_u). The trunk stream through which all the discharges of water and sediment passes is therefore the stream segment of the highest order. In the study area, the total stream segments present are 251 as presented in Tab 2; the first order streams total 97 segments and account for 38.65%; the second order stream segments total 96 and account for 38.25 %; the third order stream segments total 57 and account for 22.71 %; the fourth order stream segment is 1 and accounts for 0.40%. The drainage patterns of the stream network from the basin have been observed to mainly be a dendritic type, which indicates the homogeneity in texture and the lack of structural control. This pattern is characterized by a tree-like or fernlike pattern with branches that primarily intersect.

3.2.3 Stream frequency (F_s)

The stream frequency or channel frequency (F_s) is the total number of stream segments of all orders per unit area (Horton, 1945). The stream frequency value of the basin is 0.06. The value of the stream frequency for the basin exhibits a positive correlation with the drainage density value of the areas indicating the increase in stream population with respect to the increase in drainage density.

3.2.4 Stream length (L_u)

The stream length is one of the most significant hydrological features of the basin. It reveals streams of relatively smaller lengths that are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is the maximum in first order streams and decreases as the stream order increases.

3.3 Areal Aspects of the Drainage Basin

3.3.1 Texture ratio (T)

The texture ratio (T) is an important factor in the drainage morphometrical analysis, which depends on the underlying lithology, infiltration capacity and relief aspect of the terrain. In the present study the texture ratio of the basin is 1.23 and categorized as moderate in nature.

3.3.2 Elongation ratio (R_e)

The elongation ratio (*Re*) is a very significant index in the analysis of a basin shape and helps to give an idea about the hydrological character of a drainage basin. It is defined as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). Values near 1.0 are typical of regions with a very low relief (Strahler, 1964). The value Re of the study area is 0.039, which indicates the high relief of the terrain and is elongated in shape.

3.3.3 Circularity ratio (R_c)

Nagaswera et al. (2010) defined a dimensionless circularity ratio (R_c) as the ratio of a basin area to the area of a circle having the same perimeter as a basin. He described the basin of the circularity ratios to range from 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geological materials. Catchment No. 4 has the highest circularity ratio (0.35), and catchment No. 3 has a closer value (0.32). This indicates flash floods could reach a great volume over a small area. The circularity ratio values (0.35 to 0.32) of the basin corroborate Nagaswera's range, which indicates that the basin is elongated in shape and has a low discharge of runoff and high permeability of the subsoil's conditions.

3.3.4 Form factor ratio (R_f)

A quantitative expression of the form of the outline of a drainage basin outline was made by Horton (1945) through a form factor ratio (R_f), which is the dimensionless ratio of a basin area's to the square of its length. The basin shape may be indexed by the simple dimensionless ratios of the basic measurements of the area, perimeter and length (Nagaswera, 2010).

The form factor value of the basin is 0.96, which indicates the lower value of the form factor and thus represents an elongated shape. An elongated basin with a low form factor indicates that the basin will have a flatter peak of the flow for a longer duration. Flood flows of such elongated basins are easier to manage than those of circular basin.

3.4 Network Properties

3.4.1 Bifurcation ratio (R_b)

The term "bifurcation" ratio (R_b) is used to express the ratio of the number of streams of any given order to the number of streams in the next higher order (Schumn, 1956). Bifurcation ratios characteristically range from 3.0 and 5.0 for basins in which the geological structures do not distort the drainage patterns (Strahler, 1964). It has been demonstrated that the bifurcation ratio shows a small range of variations for different regions or where different environments dominate. The mean bifurcation ratio value is 4.18 for the study area, which indicates that the geological structures do not have a significant impact on the drainage patterns.

3.4.2 Drainage density (D_d)

The drainage index gives a good idea of the complexity and degree of development of a watershed's drainage system (CEIFI & CRQ, 2003). A rich drainage system has a greater water concentration capacity because the water runs through less of a distance to the streams. Likewise, a poorer system gives place to higher infiltration values; therefore, lower and delayed flow peaks are expected. This indicates the closeness of the spacing of the channels. The calculated value using a stream network shapefile in Arc GIS was 0.193 km/km^2. According to Navarro (2011), this index usually varies between 0.5 km/km^2 in poorly drained basins to 3.5 km/km^2 in exceptionally well drained basins. Following this definition, the obtained value of 0.193 km/km^2 for the Lower Niger River basin indicates a well-developed drainage system. In general, a high (D_d) is characteristic of regions having non-resistant or impermeable subsurface materials, sparse vegetation and a mountainous relief; conversely, a low (D_d) indicates regions of highly resistant rock or highly permeable subsoil materials under dense vegetative cover, where the relief is low.

3.4.3 Shape coefficient (K_f)

This reflects the relation between the average width of a basin and the length of the longest stream. A watershed with a small shape coefficient is less likely to present high runoff peaks (CEIFI & CRQ, 2003); Monsalve,1995). The shape coefficient value obtained for the Niger River Basin was 0.016, which indicates a watershed that is not prone to short concentration times.

3.4.4 Gravelius or compactness coefficient (K_c)

This indicates the relationship between the perimeter of a basin and the perimeter of a circle with the same area of the watershed; it thus gives an idea of the regularity of its shape. The lower the value, the more regular the basin's perimeter and the more prone it is to present high runoff peaks. This is confirmed by the result of the compactness coefficient, which was 0.132 and indicates a not-so-regular watershed; it is therefore prone to high runoff peaks. When equal to 1, a basin is round, and its centroid is closer to the streams. In this case a faster and greater concentration of water during /after rainfall events can be expected (CEIFI & CRQ, 2003; Monsalve, 1995).

3.4.5 Concentration time (T_c)

This expresses the time elapsed since the beginning of the precipitation until the moment in which the total area of the watershed contributes to the runoff at the outlet. It may also be defined as the time that a water drop takes to travel from the farthest point in the watershed to the outlet. This parameter was calculated according to an equation of the U.S. Bureau of Reclamation (CEIFI & CRQ, 2003). A value of 56.5 hours was obtained.

3.4.6 Average slope

A slope has a direct relationship with the infiltration and surface runoff, among other factors. A higher slope produces higher and faster runoff peaks. The average slope was determined through the surface analysis tools of Arc GIS for each of the sub-basins. A basin slope of 14.89° (20%) for the entire watershed was obtained.

3.5 Land use/land cover analysis

The various land use and land cover classes delineated in the five watersheds studied are: water bodies, forests, farm lands, shrubs and grasses, and built-up areas as shown in Figure 5. These results show that A1, A2, and A4 are mostly covered by farm land, while A3 and A5 have the highest percentages of forests. The type and distribution of land cover have a profound impact on a number of hydrological processes (Ballukraya and Geena., 2011). Consequently, A1, A2 and A5, with the lowest amounts of shrubs and grasses, generate less surface runoff compared to the other two watersheds.

3.6 Estimated peak runoff

The peak runoff for various return periods was determined based on the morphometrical parameters obtained for the sub-basins. The values obtained for the various return periods are presented in Table 9. The peak runoff with recurrence intervals of 25 years varies from 737.21 m^3/s to 1616.42 m^3/s, that of the 50 year intervals varies from 846.86 m^3/s to 1856.86 m^3/s, while for the 75 year intervals varies from 911.52 m^3/s to 1998.63 m^3/s, and for the 100 year intervals varies from 957.61 m^3/s to 2099.68 m^3/s. The peak runoff obtained can be used in the design of hydraulic structures within the watershed.

4 CONCLUSION

The basin channel processes as elucidated by the morphometrical studies and then analysis on the River Niger sub-basins highlight how they contribute to flooding problems in these areas. The quantitative analysis of the various parameters is of immense importance in river basin evaluations, watershed prioritizations for soil and water conservation, and natural resources management at a micro level. The results accomplished for the basin areas range from 21.34 to 1407.90 Km^2, while the maximum length of the streams varies from 2.34 to 180.12 Km. The total relief averages range from 333 meters to 769 meters, while the relief ratio ranges between 21.60 and 40.40 m/km. In addition, the relative relief ranges from 4.00 to 13.30 meters, while the ruggedness value varies from 9.13 to 320.94. The results accomplished show that the basin has a low relief of its terrain and is elongated in shape. The drainage network mainly exhibits itself as a dendritic type, which indicates its homogeneity in texture and the lack of structural control. The linear pattern of the topographical representation indicates the weathering and erosional characteristics of the area under study. This result is useful to water resources and environmental managers for the sustainable development and utilization of the water resources in this area. The values of the peak runoff of various return periods can be adopted in the design of hydraulic structures within the watershed under consideration.

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