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THE CURRENT ARTIFICIAL DRAINAGE DENSITY ANDFLOODING PROBLEMS IN CALABAR, NIGERIA

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ABSTRACT

The stream or artificial drainage density of a given catchment, defines how well or poorly a catchment is drained. The Horton number for stream density analysis was adopted to assess the adequacy or otherwise of the artificial drainage density of the Calabar Metropolis catchment. **Rainfall data were obtained using both the recording and non-recording recording rain gauges; Runoff measurements were done witha propeller-type current metre F_4, (A.Ott –Kempten, Bavaria) while G.P.S equipment and Land Dev software (Bentley Systems, Inc. USA)were used for the drainage basin areas, artificial drainage density and degree imperviousness.** The study showed that the artificial drainage density in the catchment was inadequate (68.7%). This explains why land areas become flooded in the Metropolis even with minor storm intensities. Injecting new drains into the ever-expanding Metropolis, legislating against improper refuse dumping and redesigning of major drainage outlets have been proffered as possible permanent solutions to the lingering problems of flooding in the Metropolis.

Keywords: *Runoff, drainage, density, metropolis, evapotranspiration, model, urbanization, catchment.*

I. INTRODUCTION

It is generally accepted that the contemporary trend towards more urbanization in the world today will continue. As a consequence, urban problems associated with the hydrologic aspects of water management should become increasingly more acute. Effective disposal of storm water has become very essential. Urban storm water management is no longer based on the interception, collection and disposal of storm water only, but also on the application of workable rainfall-runoff model approaches in storm drainage designs.

In 2004, the Vision 20/20 Water Quality Planning Group recognized the role sound water engineering design principles and practices play in defining the quality of life for South West Missouri (Storm Water Drainage Criteria Manual, 2008). Sound storm water design practices help to maintain compatible drainage systems, minimize disturbance to existing drainage patterns, control flooding of property, structures, and roadways, and minimize environmental impacts of storm water runoff.Urbanization tends to increase downstream peak flows, runoff volumes, and runoff velocities. These changes can cause the capacity of adequately designed downstream systems to be exceeded and disrupt natural waterways. The impacts of new urbanization must be reduced through the use of structural and non-structural Best Management Practices (BMPs) that usually include storm water detention.

Predictions of stream discharges and groundwater flow with the use of hydrological models have over the years,often proven to be not very satisfactory. This is basically due to the lack of information on the spatial variability for actual rainfall fields. Conventionally, rainfall measurements from raingauges provide relatively accurate estimates at individual point locations. The true rainfall distributions can be estimated by interpolating the available raingauges data to the ungauged areas. This, of course, largely depends on the number of data available for interpolation and the allowable method(s) to be applied-, Thiessen Polygon, Arithmetic Mean or Isotyetal. This is because the approximation of areal rainfall by the interpolation methods suffers spatial sampling errors since they are only representativesof a small range around the instrument (Villarini *et al.*, 2008). Moreover, the quality of the interpolated rainfall fields decreases with the decrease of raingauge network density. A high density raingauge network is required for more detailed areal rainfall estimates, and in many everyday practical cases, this is not often feasible in mountainous regions or remote areas. Such a problem could be severe for tropical regions where most rainfall has convective cells with high spatial variability without a corresponding temporal resolution.

Physically based rainfall-runoff models attempt to link catchment behavior with measurable properties of the landscape, but many properties controlling subsurface flow are only measurable at scales that are many orders of magnitude smaller than the catchment itself (Beven, 2001). Thus, although it seems obvious that catchment models should be ‘‘physically based,’’ it seems less obvious how those models should be based on physics. Many hydrologic models are based on an implicit premise that the microphysics in the subsurface will ‘‘scale up’’ such that the behavior at larger scales will be described by the same governing equations (e.g., Darcy’s law, Richards’ equation), with ‘‘effective’’parameters that somehow subsume the heterogeneityof the subsurface. It is currently unclear whether this upscaling premise is correct, or whether theeffective large-scale governing equations for these heterogeneous systems are different in form, not just different in the parameters, from the equations that describe the small-scale physics (Kirchner, 2006).

Various variables have been shown through careful and painstaking studies to influence either closely or tangentially, the rainfall-runoff processes of a given catchment (Antigha *et al*, 2014). These variables may include the drainage area, its shape, extent and orientation; the rainfall distribution, both spatial and temporal; the length of the overland flow, the slope, etc. Horton, (1945), however argued that by far the most defining variable of a catchment’s rainfall-runoff process is the stream density or the artificial drainage density. Stream density is the length of all channels within the basin divided by the area of the basin. Artificial drainage density is one of the most important characteristics for evaluating potential runoff as it defines not only the area that contributes to stream flow, but how well or otherwise, these contributing areas are drained. It is equal to the reciprocal of the constant of the channel maintenance and equal to the reciprocal of two times the length of the overland flow. Drainage density depends largely upon both the physical characteristics of the drainage basin as well as the climate.
It follows therefore that a drainage basin with a large number of tributaries has a higher stream density than a basin with very few tributary streams. Higher stream density allows the landscape to drain more efficiently following a storm event. More efficient drainage means that water moves into streams and creeks faster, causing peak storm flows to be larger and to occur sooner.

A basin with a lower stream density usually indicates a deep, well-developed soil. In this case, water is more likely to infiltrate into the soil rather than become surface runoff and enter into the channel network.

The objectives of this study are to:
- Discretize the drainage basin by analyzing some of the climatic and hydrologic components of the basin.
- Assess the adequacy or otherwise of the stream or artificial drainage density of the Calabar Metropolis catchment.
- Proffer solutions where necessary to solve existing urban drainage problems in the Metropolis.

II. MATERIALS AND METHODS

2.1 Description of Area of Study

Calabar Metropolis lies between latitudes 04° 45’ 30” North and 05° 08’30” North of the Equator and longitudes 8° 11’ 21” and 8°27’00” East of the Meridian. The town is flanked on its eastern and western borders by two large perennial streams viz: the Great Kwa River and the Calabar River respectively. These are aside from the numerous ephemeral channels which receive water after storm events to drain the area of study (Antigha, et al, 2014).

It occupies an area of about 223.325 sqkm with major clans being Efut Uwanse, Obufa – Esuk, Old Calabar, Mbukpa, Anantigha, Archibong Town, Cobham Town, Henshaw Town, Old Town, Essien Town, Ikot Ansa,

Ikot Effanga, Ikot Omin, Ikot Nkebre, Akim Qua Town, Big Qua Town, Kasuk,Satellite Town, Nyakasang etc.

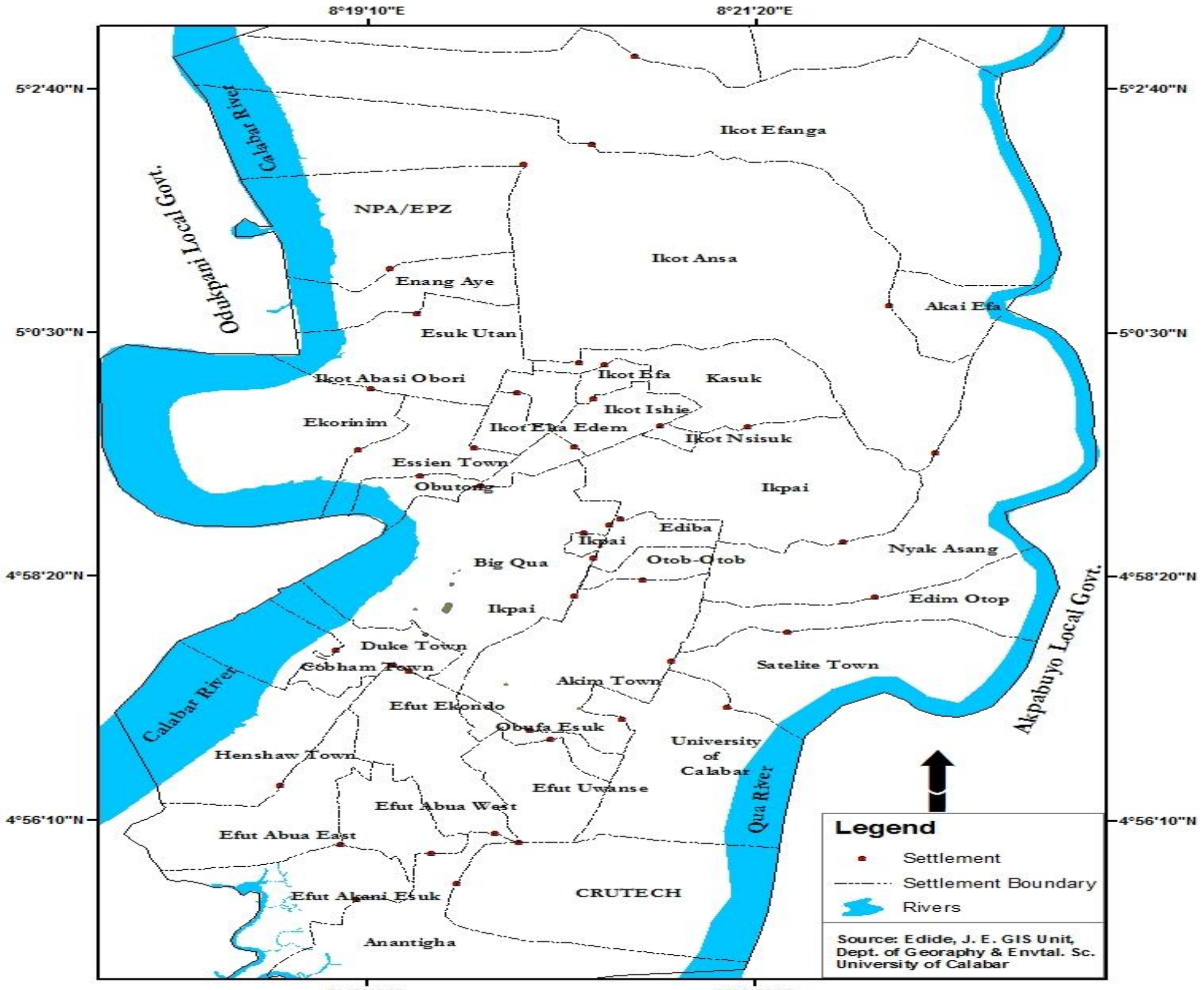

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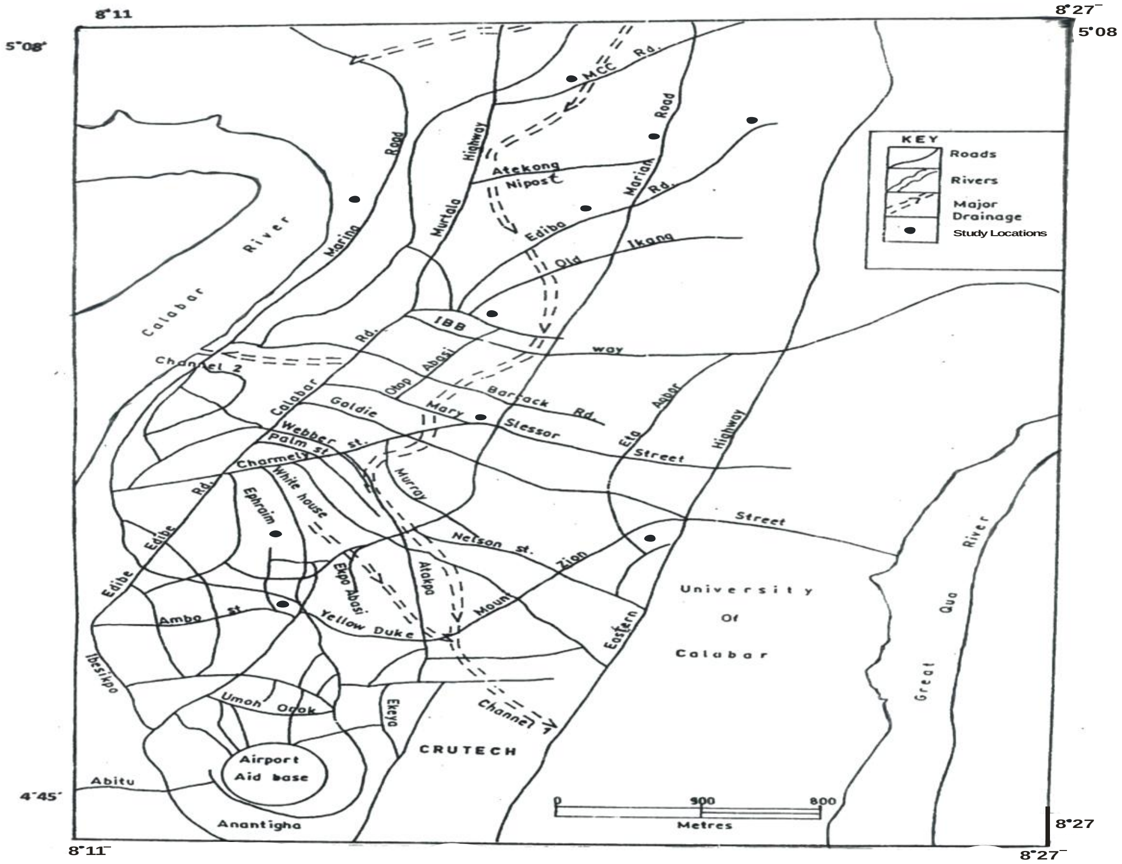
Fig. 3.1: Layout of Calabar Metropolis

As a coastal town in Nigeria, Calabar metropolis has a high relative humidity, usually between 80% and 100%. Relative humidity drops with the rise in temperature to about 70% in the afternoon during the dry season. Vapour pressure in the air averages 29 millibars throughout the year (CRBDA Report, 1995**).**

The Calabar River is about 7.58 metres deep at its two major bands (Tesko-Kutz, 1973). The city lies in a peninsular between the two rivers, 56km up the Calabar River away from the sea. Calabar has been described as an inter-fluvial settlement (Ugbong, 2000).

The present conditions as seen in terms of road network and settlements are as follows: The Calabar Road cum Murtala Muhammed Highway form the main artery of the city's roads network, running from north to south, linking all other major lines. Other major routes are the Ndidem Usang Iso Road, which runs parallel to the Highway, and MCC Road which runs perpendicular to both the Highway and Usang Iso Roads. Other streets spread like branches of a tree throughout the city.



Fg.3.3 Hydrologic Setting of Calabar Metropolis and Study Locations

The urban structure can best be explained in terms of the Hoytes (1939) as captured in Ugbong (2000) sectoral model. Population and settlements are concentrated in zones inhabited by the three ethnic groups-, the Efuts to the south, the Efiks to the west and the Quas to the east.

With a population of 202,585 in 1991, it now has a population of over 400,000, (C.R.S Ministry of Land and Housing, 2008).This shows a growth or an increase in population of 49.4% or an average annual population increase of 2.9%.

All the year round, temperature rarely falls below 19^{0}C and average 27^{0}C. The average daily maximum is above 24^{0}C with a range of 6^{0}C, and a seasonal variation of the same amount, between the hottest month (March) and the coolest month (August). Expectedly therefore, evaporation will be high (Antigha*et al*, 2014).

2.2 Rainfall and Evapotranspiration Data

Rainfall and evapotranspiration measurements for the data were done at the Nigerian Meteorological Centre (NIMET) of the Margaret Ekpo International Airport, Calabar, Cross River State.

Two sets of rainfall data were obtained for the study. The first was a twenty-eight (28) year daily/hourly rainfall data, while the second was a forty-three (43) year yearly/monthly rainfall data. The daily rainfall readings which were personally obtained for twenty-three months from January, 2008 to November, 2009, out of the three hundred and thirty-three (333) months rain fell were subjected to closer scrutiny. (This aligns with Wilson's (2006) 510 rainfall data from 17 different catchments in the U.K). This was because the runoff readings also personally obtained from the area for the study were obtained during some of these storms' event. A total number of three hundred and forty six (346) storm events were recorded. Five thousand, five hundred and eighty seven millimeters (5587 mm) of rain was recorded for the period monitored. Total hours that rain fell were 1084.67hours. This gave an average rainfall of 242.9mm per month of rain, and an average intensity of 5.15mm per hour of rain. Both the cylindrical and self-recording rain guages were used for the rainfall readings.

Evapotranspiration data were measured for 2 years for the project. The class A pan was used for the evaporation data acquisition.

2.3 RunoffData

Flow measurements are critical to monitoring storm water best management practices (BMPs). Accurate flow measurements are necessary for accurate computing of samples used to characterize storm runoff and for the estimation of volumes. A total of ten (10) drainage outlets were selected as points for storm runoff readings. The choice of these ten locations was informed by their vulnerability to flooding, being major flood outlets in the catchment. Twenty (20) storm events were monitoredat each recording point and 80 (eighty) runoff readings were taken fromeach reading point with the propeller- type current metre model A.OTT, Kempton type F_4. The metre had a reading range of $n < 4.67$, $v = 0.0560n + 0.040$; $n \geq 4.67$, $v = 0.0545n + 0.047$ for propeller 1 and $n < 1.28$, $v = 0.0905n + 0.040$; $n \geq 1.2$, $v = 0.1030n + 0.024$ for propeller 2, where v is in m/s and n is the number of revolutions. The readings were taken during the months selected as the wettest part of the year (May to October) for twenty-four (24) months and for storms with duration of not less than 120 minutes (Dayaratne, 1996, 2000).These gave a total of eight hundred (800) runoff readings.

The readings were taken at the five minutes, ten minutes, fifteen minutes up to the one hundred and twenty minutes rainfall intervals. These were recorded as $I_5 I_{10} I_{15}$ toI_{120} respectively (State of New Jersey Urban Storm Drainage Design Manual, 2007).

2.4 Land Use Data

Land use data were obtained from the most recent topo map (2014) of the study area obtained from the State Ministry of Lands and Survey, Calabar. The Land Development software was employed with the application of the polyline approach in discretizing both the total basin area and the area that has become built-up. The degree of imperviousness was obtained by determining from the total area as calculated with the software, the relative percentages of the built-up areas with reference to the total area as scaled,(Ugbong, 2000, Okon, 2012).

2.5 Gradient Data

The gradient data for the sub- catchments were generated from the topo map with the aid of the Land Development software. The profiling approach was equally employed for confirmation. A global positioning system (G.P.S) instrument was used. Mapping was done by marking off 25m interval on ground. This was made to run to cover the whole length of the overland flow of the sub-drainage basins drained by the channels network. The inlet elevation was subtracted from the outlet elevation. The plot of the inlet and outlet elevations was obtained with reference to the overland flow length. The tangent of the angle so formed gave the value of the slope (Uyanah, 2006, Okon, 2012).

III. RESULTS AND DISCUSSIONS

3.1 Basin Area, Sum of channel Length and Artificial Drainage Density

A total of ten (10) sub basins were delineated and considered. The choice was based on the contributions of their total flow to flooding in the Metropolis. The basin measurement was obtained by the application of the polyline approach with the Land Development software version 2010 (Bentley Systems, Inc. USA). Series of regular shapes were generated for each selected sub-basin and their physical sizes were derived to yield the area of each sub-basin. This was achieved by first delineating the divide on a topo-map. The recorded area in square kilometer (km^2) was converted to hectares. A total basin area of 2819.61ha (28.196 sq km) was recorded.

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The sum of the channel length was obtained by measuring the relative length of all drainage systems in all the sub basins considered. This was done by digitizing the most current drainage map of the area. The map showed the main channels and the first laterals. The polyline approach in Civil-3D software was employed. For the second laterals however, the metric tape was employed in obtaining their relative lengths. The total sum of length of channel obtained was 28918.98m.

The artificial drainage density was obtained by dividing the sum of the channel length by the measured basin area in accordance with Horton, (1945) and Ugbong, (2000). This gave a value of 10.3.The length of overland flow was taken as the longest distance from where flow rises to where it is emptied. Horton (1945) observes that for a drainage basin to be considered as well-drained and the facilities adequate and satisfactory, the artificial drainage density should not be less than 15. This result shows that the artificial drainage density of the metropolis is only 0.68666 or 68.7% on the Horton (1945) scale. This is grossly inadequate for an area where the urbanization drive is unparalleled.

The discretization process of the catchment was done by the use of factor analysis. This showed that the pertinent factors considered to influence the Calabar Metropolis catchment's rainfall-runoff processes were the area of the drainage basin, the slope of the basin, the cross sectional area of the existing major channels and first order laterals (as opined by Darayatse, 2000 for medium catchment subdivision approach), the degree of imperviousness, the length of the overland flow, sum of the channel length as well as the depth, duration and distribution of the input, - storm event.

Table 1: Drainage Area,Mean velocity, Depth of flow and Discharge for all locations

S/No.	Code	Area Name	Basin Area (ha)	Sum of Channel Length (m)	Artificial Drainage Density (Dd)	Degree of impervious Area (%)
1	SB1	Ediba One Area	179.4	2978.0	16.6	67.01
2	SB2	Ediba two Area	274.8	3305.24	12.03	65.59
3	SB3	Ibom Layout Area	189.3	2478.92	13.1	69.0
4	SB4	Mayne Avenue Area	280.2	1970.21	7.03	65.4
5	SB5	Big Qua Area	193.6	1579.0	8.16	66.24
6	SB6	M.C.C. Highway Area	559.8	4543.02	8.12	63.0
7	SB7	Yellow-Duke/Inyang Area	221.0	3611.15	16.34	64.9
8	SB8	Marina Road Area	213.5	2195.36	10.28	63.95
9	SB9	Marian Road Area	301.4	2780.01	9.22	72.3
10	SB10	Mary Slessor	406.8	3478.07	8.55	66.2

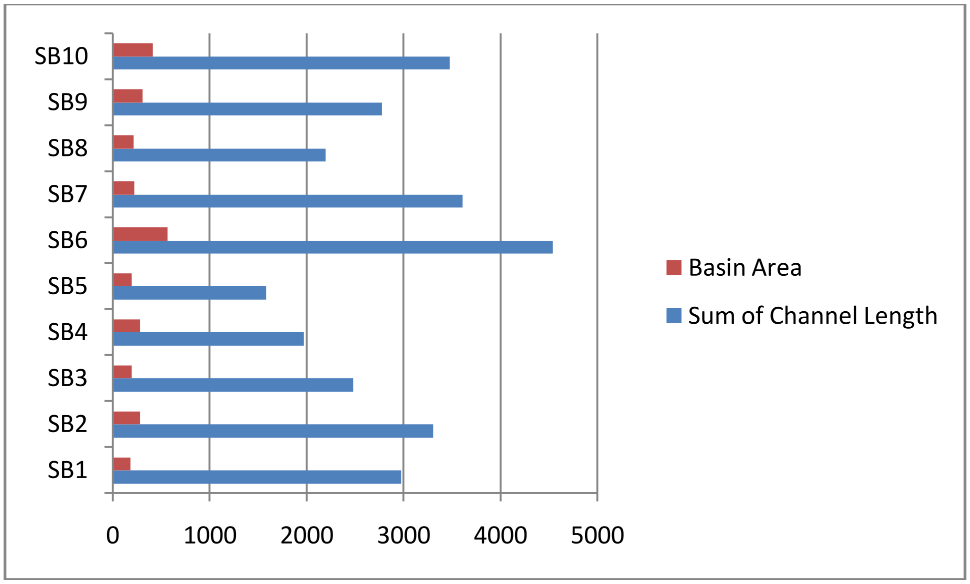

Fig. 3: Relationship between basin area and the stream (artificial) drainage density in the Metropolis.

Table 2: Bivariate Correlation of the catchment variables

	D	BA	SCL	ADD	CSA	DIA	G	LOF	IE	OE
D	1.00									
BA	0.76*	1.00								
SCL	0.67*	0.68*	1.00							
ADD	0.17	-0.46	0.33	1.00						
CSA	0.93**	0.73*	0.59	-0.23	1.00					
DIA	-0.10	0.40	0.37	-0.04	-0.18	1.00				
G	-0.08	-0.03	-0.24	-0.25	-0.10	-0.08	1.00			
LOF	0.68*	0.68*	0.96**	0.27	0.60	0.25	-0.42	1.00		
IE	0.44	0.59	0.50	-0.17	0.28	0.49	0.46	0.46	1.00	
OE	0.23	0.32	0.43	0.12	0.02	0.37	0.09	0.46	0.81	1.00

D = discharge, BA = basin area, SCL = sum of channel length, ADD = Artificial drainage area, CSA = cross sectional area, DIA = degree of imperviousness of the area, G = gradient, LOF = length of overland flow, IE= inlet elevation, OE= outlet elevation.*p<0.05, significant at 95%, **p<0.01.

Table 3

Regression Statistics	
Multiple R	0.983178
R Square	0.966638
Adjusted R Square	0.949957
Standard Error	0.77178
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	103.5503	34.51678	57.94869	8.02E-05

Residual	6	3.573863	0.595644
Total	9	107.1242	

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	9.738964	7.09617	1.372425	0.219024	-7.62474	27.10267	-7.62474	27.102667
X Variable 1	0.004649	0.000418	11.1084	3.17E-05	0.003625	0.005673	0.003625	0.0056726
X Variable 2	-0.03968	0.003113	-12.7443	1.43E-05	-0.04729	-0.03206	-0.04729	-0.0320585
X Variable 3	-0.01584	0.102289	-0.15489	0.881985	-0.26614	0.234448	-0.26614	0.2344477

Residual output

Observation	*Predicted Y*	*Residuals*	*Standard Residuals*
1	15.40294	1.197059	1.899625
2	13.16153	-1.13153	-1.79564
3	12.65858	0.441419	0.700492
4	6.744237	0.285763	0.45348
5	8.348312	-0.18831	-0.29883
6	7.648782	0.471218	0.74778
7	16.72911	-0.38911	-0.61749
8	10.46026	-0.18026	-0.28606
9	9.558232	-0.33823	-0.53674
10	8.718011	-0.16801	-0.26662

Table 4: Factor Analysis of the factors that affect discharge in the study area Total variance Explained for the 3 principal components Extracted

Components	Total variance	Percentage variance	Cumulative
1	3.94	43.8	43.8
2	1.97	21.8	65.7
3	1.60	17.1	83.4

Because of the fact that there could be multicollinearity between each of the variables, factor analysis was performed to investigate which of these variables could explain the variation in discharge. Three components were extracted with components 1 accounting for 43.8% of the total variation in the data set, component 2 accounted for 21.8% of the variation while component 3 accounted for 17.1% of the variation in the data. To really examine the loadings of each of the variables to these three components, their factor loading were obtained and the results as shown in the Table 5 below were obtained.

Table 5: Rotated factor loadings of each of the variables of discharge

	Components		
Variables	1	2	3
Basin area	0.87		
Sum of channel length	0.77	0.42	0.43
Artificial Drainage Density			0.91
Cross sectional Area of drain	0.91		
Degree of impervious Area		0.74	
Gradient		0.46	-0.61
Length of overland flow	0.82		0.46
Inlet Elevation		0.87	
Outlet Elevation		0.82	

Variance explained	**34.69**	**28.88**	**19.81**

Those with loadings < 0.40 were excluded.

Tables 1 and 2 above show both the catchment's flow variables and the bivariate correlation of the catchment's flow variables while tables 3,4 and 5 show the regression model summary output, the factor analysis and the result of the factor loading respectively.

The regression of the artificial drainage density against the sum of channel length, basin area and the degree of imperviousness at 5% significance gave a multiple regression coefficient of 0.983, an R square value of 0.97 a standard error of 0.77 at an intercept of 9.73. This shows that not less than 97% of the variability observed in the Calabar catchments' urban storm system can be explained by the chosen predictor variables. A simple multiple regression equation of the type shown below was generated to explain some of the catchment's components relationship to the stream density or artificial drainage density. Thus,

$$Y = 9.74- 0.04X_1+0.005X_2– 0.02X_3$$

where;

Y = Artificial Drainage Density in (m/m)
X_1 = Basin Area in (m^2)
X_2 = Sum of Channel Length in (m)
X_3 = Degree Imperviousness in (%)

The difference between the best and the worst obtained stream density was 9.57. For the 10 sub-catchments studied, the worst A.D.D. was observed at location 4 with a value of 7.03. Only 2 out of the 10 locations met the acceptable standard. These were locations 1 and 7 with stream density values of 16.6 and 16.34 respectively. The direct relationship between the basin area and the stream (artificial) drainage density is shown in figure 3. The largest sub-catchment (Mayne-Avenue), had the second poorest A.D.D. of 8.12 for an area of 559.8ha.

IV. CONCLUSION AND RECOMMENDATIONS

Every site contains natural features that characterize and contribute to its natural drainage system. Existing features such as natural drainage ways, sinkholes, floodplains, vegetation, soils, geology, and slope affect existing rainfall-runoff processes, drainage characteristics and the morphology of a given drainage basin.

Each development plan of any given drainage basin should include mapping and careful consideration of these natural features. Storm water system design should preserve and enhance natural features to the maximum extent practicable. A well-designed storm water system will improve the effectiveness of the natural system, rather than negate, replace, or ignore it. It is important to note that the amount of storm water runoff present at any given point in time in an urban watershed cannot be compressed or diminished.

Open and enclosed storm systems serve both conveyance and storage functions. If adequate provision is not made for drainage space demands, storm water runoff will normally conflict with other land uses, thereby resulting in damage to public and private property as well as impairment or disruption of other urban systems.

Studies have shown that in urban watersheds that have been developed without adequate storm water planning, there is generally inadequate space available to construct detention storage facilities to reduce peak flows significantly along major waterways. Attempts to create adequate space to construct such storage facilities will generally require the removal of valuable existing facilities and this, of course is often not economically or socially feasible.

Urbanization in the Metropolis, as well as in other areas of the world, tends to increase downstream peak flows, runoff volumes, and runoff velocities. Consideration should therefore be given to the importance of reducing flooding and erosion because of their negative potentials for public and private property damage.Storm water system planning and design for a new development must be compatible with watershed master plans and objectives and must be coordinated with plans for land use, open space, transportation and other community objectives. Based on this, for the metropolis, the six drainage outlets originally designed for the metropolis to cater for the six drainage basins should be put in place to aid flood flow discharge.

V. SUMMARY

The current state of the stream density in the Calabar Metropolis catchment calls for concern with an ever expanding land mass and unparalleled urbanization in recent years. The flood volume generated in the area is over-tasking the drainage facilities in the area. This explains why a storm of minimal intensity results in the flooding of the area as the existing facilities can hardly carry the flow at non-erosive velocity to their outlets.

VI. ACKNOWLEDGEMENT

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