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Morphological Studies of the Calabar Metropolis Catchment, South-South Nigeria

Antigha[1], Richard E.E, Ayotamuno[2], M.J., Akor[3], A.J. and Fubara-Manuel[4], I.
[1]*Dept. of civil Engineering, Cross River University of Technology, Calabar.*
[2,3&4]*Dept. of Agric & Environmental Engineering, Rivers State University of Science & Technology, Port Harcourt.*

Abstract: *Morphology of the Calabar Metropolis catchment was understudied in order to assess the contributions of the urban drainage systems to the protracted flooding in the catchment. Rainfall data were obtained using raingauges; The propeller-type current metre, (A.Ott –Kempten, Bavaria) was used for runoff readings, 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.* ***Contour crenulations approach was adopted for the morphological analysis of the catchment. The study revealed that stream density was inadequate. Revisiting the original arrangement of six drainage outlets is recommended as well as delineating the catchment into its natural basins and sub basins and ensuring that the discharge of the generated flow is done in line with the existing natural alignment***

Keywords: *Alignment, morphology, crenullations, drainage, runoff, density, metropolis, catchment*

I. Introduction

In the present precarious nature of the world, everyone, professionals and lay people alike, is curious about the future of the hydrological systems. This curiosity may not be unconnected with the recent global turn of events in the hydrological and hydraulic environments of our world.

Over the last one hundred years, man's need to protect himself and his possession from the threat of flood and erosion has remained one of the most important considerations in his water conservation efforts.

In many parts of the world, and especially in the humid tropics, this arises not only from storm runoff, but from other water related interactions (Ragan, 1961).

Historically, most cities of the developing world sprang up along the coastal regions as ports, often on the estuaries of rivers which served as commercial arteries. These coastal regions of the tropics in which Calabar Metropolis is one of such, have the highest average rainfall. However, due to the flat terrain and often alluvial soils, drainage is difficult (Antigha, *et al*, 2014).

Large areas of impermeable surfaces and sparse vegetation in the urban centres, coupled with inadequate drainage facilities, cause excessive run-off to form within minutes of a storm event. This, of course often results in damage to lives and property.

Acknowledging the enormity of this problem, the United Nations Environmental Programme UNEP, (1991) had indicated that communities in developing countries should consider uncontrolled storm water drainage to be their most urgent problem as far as the preservation of urban infrastructure is concerned.

The inadequacy of drainage is particularly serious where the ground is either steeply sloping or very flat. On very steep sites, as in parts of Luanda, Rio de Janeiro and Hong Kong, storm water flows fast and violently downstream, damaging buildings, eroding the land and sometimes causing landslides (UNEP, 1991; Ugbong, 2000).

In some parts of Calabar Metropolis, roads have been built by filling in channels. This has resulted in serious flooding. Where the natural drainage channels are not filled or obstructed by buildings, they often become blocked by domestic refuse. On the other hand, drainage improvements in one area are closely linked with drainage problems elsewhere. Better drainage in one neighbourhood means that surface run-off flows faster, thereby imposing burden on the capacity of the drainage system downstream if it is insufficient, (UNEP, 1991).

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.

In Calabar Metropolis, rapid and largely unplanned urban growth has, over the years, resulted in land use changes and modifications, which have resulted to changes in the hydrological fluxes in the urban watershed.

Over the past thirty-eight years, the area of impervious surfaces in Calabar Metropolis has significantly increased. This has resulted from the several activities of man to foster urbanization and expedite development. In 1972 for instance, the city had an area of about 120.8sqkm. At the end of 2006 however, the area had expanded to encompass not less than 223sqkm, (Tezko-Kutz , 1973, Ugbong, 2000).

As urbanization continues, there is increased population density. This means that more areas have been devoted to housing and businesses. This, in turn results in an increase in the area of ground covered with impervious surfaces. This should also mean that a good portion of the right-of-way of water, specifically overland flow, would have been tampered with. Accordingly, as there are more impervious surfaces in the ever-spreading urban area, threat of flooding is bound to increase during any major storm event. This should be expected because water runs off quickly and there is an increase in peak discharge rates. This, of course overwhelms the various hydrological structures and systems across the entire metropolitan area.

The objectives of this work is to:

- analyse the morphology of the catchment,
- from the analysis, delineate the basins and the sub-basins in the metropolis
- based on the crenullations, identify the areas in the metropolis where flooding regularly occurs and proffer solution on how to curb it.

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). (Fig.1)

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 (Antigha *et al*, 2014).

The urban structure can best be explained in terms of the Hoytes (1939) sectoral model as quoted in Ugbong (2000). 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%. The Metropolis occupies an area of about 223.325 sqkm. 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.

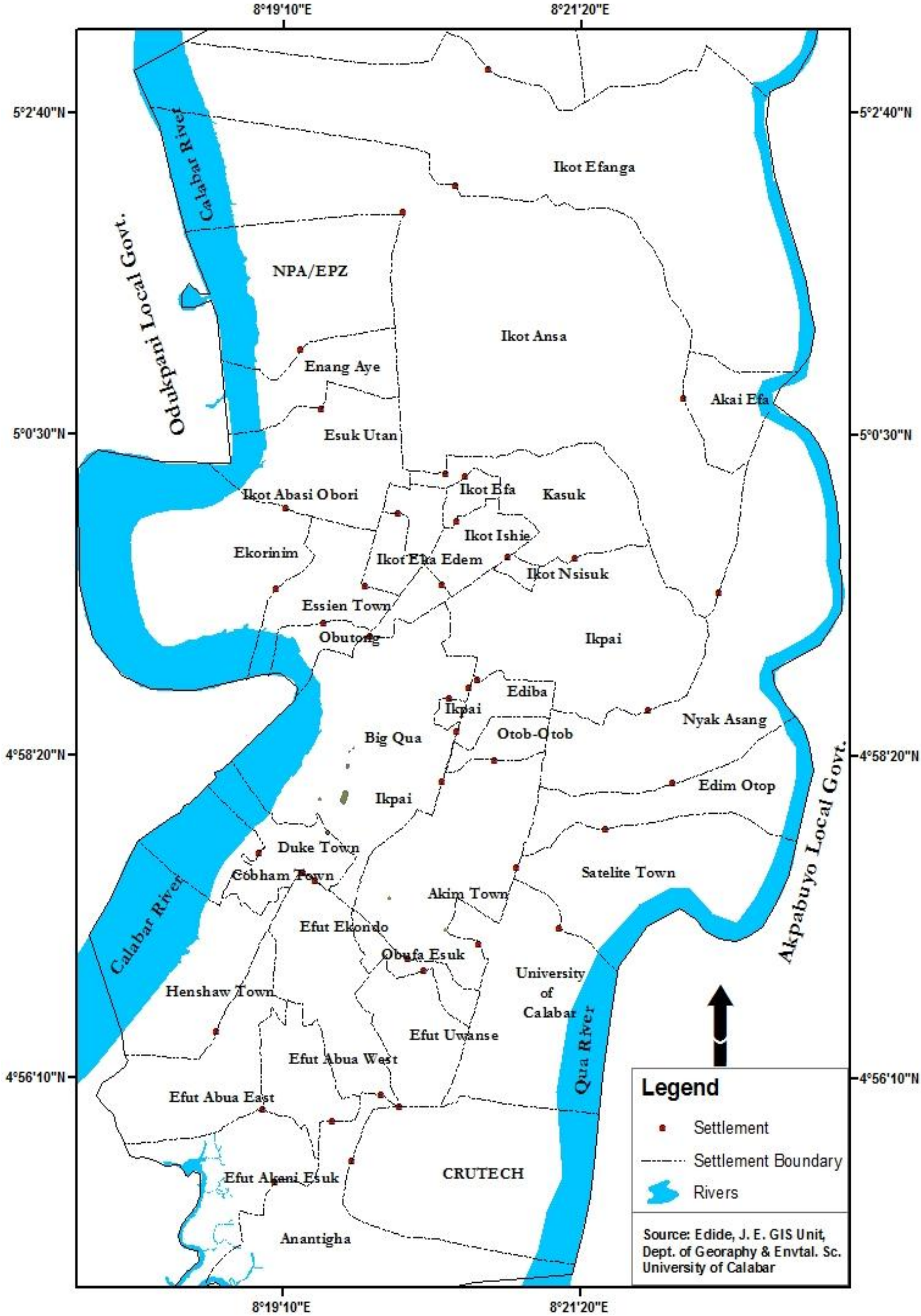

Fig. 1: Map of the Study Area

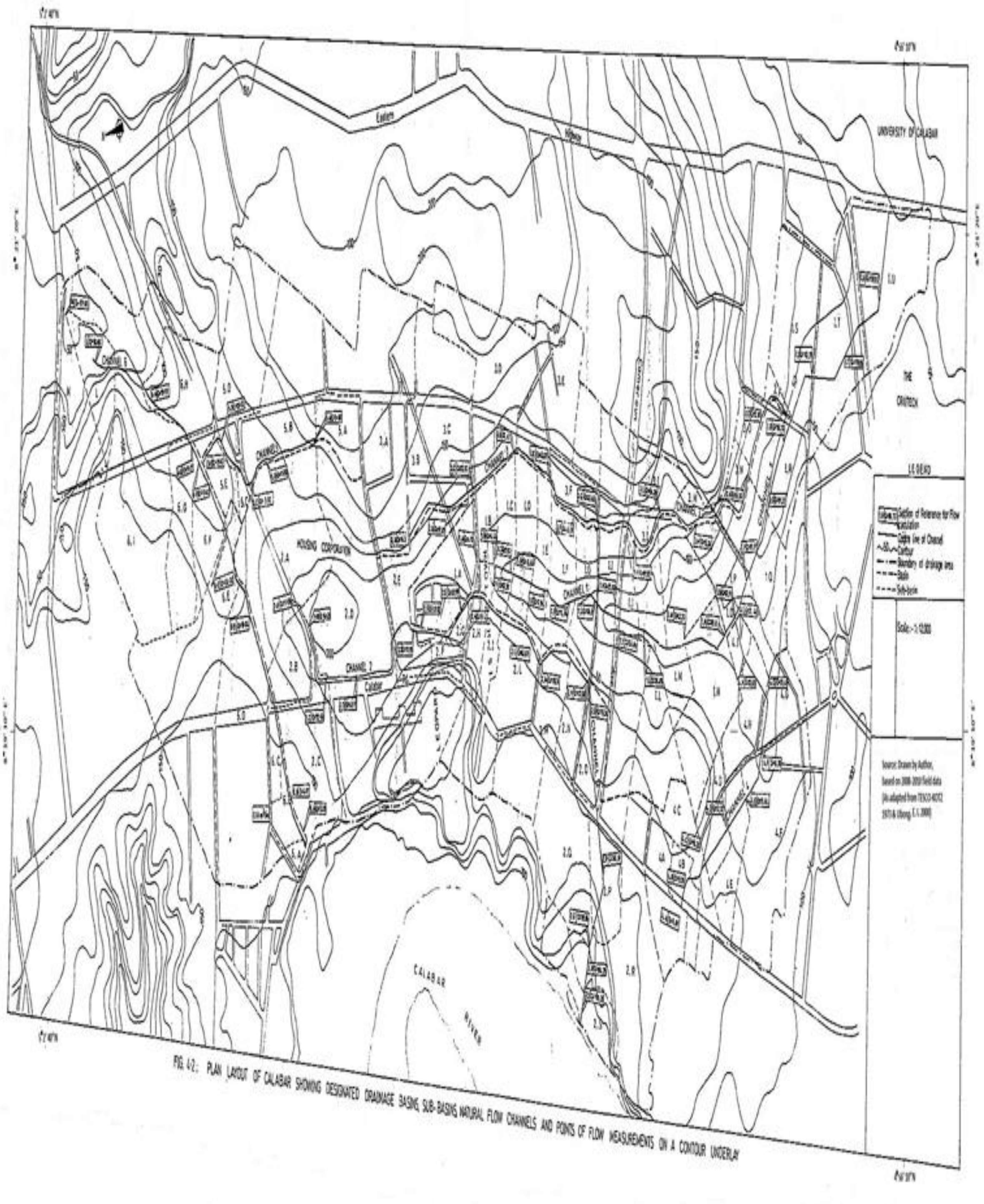

Fig. 2: Contour Crenullations of the Metropolis

Vapour pressure in the air averages 29 millibars throughout the year (CRBDA Report, 1995)

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

2.2 Runoff Data

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 monitored at each recording point and 80 (eighty) runoff readings were taken from each reading point with the propeller- type current metre model A.OTT, Kempton type F_4. The metre had a reading range of nv = 0.0560n + 0.040; n 4.67, v = 0.0545n + 0.047 for propeller 1 and nv = 0.0905n + 0.040; n 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).

2.3 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).

2.4 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).

III. Results And Discussions

Morphology defines the structure and shape of a drainage system. The most important parameters in any morphological analysis of a drainage network include the drainage areas, lengths, and the slope characteristics of the landscape (Linseley et al,1982)

All these parameters have been recognized as important factors in estimating overland flow processes, especially in small catchment areas like the Calabar Metropolis. A detailed topographic map of Calabar was prepared. From the map, runoff channel networks were derived through contour crenulations (Fig.2) while Table 1 shows the catchment's hydrologic characteristics as obtained in the study region.

Two distinct forms of the basin area were recognized viz: the apparent and the inapparent. The apparent structure consists of the two main perennial river channels which are fed by the numerous dry channels, gullies and rills. These form the apparent network structure.

According to Ugbong, (2000), the drainage system of the Calabar Metropolis is hinged around the two main rivers which, he asserts, run in a North-South direction on both sides of the city. The numerous ephemeral lower-order channels however remain the building block of the entire drainage system.

Effiong-Fuller, (1988), stated that one of the most important operations in a drainage basin morphology is network delimitation, which requires extraction of the drainage network. Therefore to identify the inapparent network structures in the Calabar Metropolis basin, Fig. 2 was used. The figure shows the detailed morphology of the Metropolis' drainage system, with an outlay of basins, sub-basins and channel networks as adapted from Ugbong, (2000).

The contour crenulations method was used in defining the trend of surface water flow based on the topography. The following features were observed: Two main watersheds trending north to south were found within the Metropolis. The western one lies on the left flank of the Calabar River and parallel to the river. The eastern one lies along the Great Kwa River. With these two watersheds, five main drainage basins were delineated. They included the South eastern basin, the Eastern basin, the North western, the Western as well as the Central Basins. The Eastern and the Western drainage basins are delineated by the slopes which directly drain into the two main rivers. The Central larger basin is defined by two converging slopes whose natural drainage discharges downstream into the Great Kwa River.

This Central basin is undoubtedly where 75% of the drainage problems in the Metropolis are observed. For the purpose of analysis, all the basins and sub basins were coded.

Basin1 is the Central basin defined by the deep crenulation of contours of the central zone in a South-North direction. The main channel here passes through the central topographic trough at the centre of the Metropolis. This then runs southwards and discharges into the Great Kwa River. It receives almost all the storm runoff from the other four basins.

Basin 2 trends in a North-Western direction. It receives flows from the outer and North-point limits of basin 1 and should have discharged same into the Calabar River. However, due to urbanization, right-of-way of storm water has been intercepted and therefore, runoff converge mid-way in the basin centre and diverts into the main channel in Basin 1

Ugbong, (2000), confirmed that Basin 3 is found in the north-eastern section of the Metropolis. It drains in a southerly direction. All flows along this basin were expected to be directed towards the south to join the channel at approximately two kilometers downstream. But just like the flow channels in basin 2, urbanization has truncated the flow path therefore forcing a convergence at the north-eastern border of basin 1 and so diverting the flows into the headwater of basin 1.

Ugbong, (2000), argued that basin 4 stretches from the 150th contour at the south-western flank beginning at the crenulation between the two top slopes of Henshaw Town area and the Mbukpa area. It trends south-eastward and joins basin 1 at the lowest segments. Unfortunately, development has pushed flow upward causing discharge into the trunk channel at the Mayne Avenue/ Atu street stretch. The crenulation shows that basin 5 covers the stretch enclosed by the hilltop area of Sacramento and the Parliamentary Village with a central trough at Efio.Ette junction.

Under natural conditions, the runoff discharge is supposed to be eastwards, coinciding with a 6th basin at the north-east point. However, due to urban road network, a diversion of flows into Marian Road extension segment tends to carry the flow into basin 2 through the lower segment of M.C.C. Road. As also observed by Ugbong (2000), the ponding experienced around the Effio- Ette round about and the environs is as a result of the disruption of flow which results from loss of gradient and massive sediment yield.

The northern limits of basin 2 and 5 defines basin 6. This basin's flow is directed from the Ikot Ishie Hill northwards towards the Ikot Ansa axis.

Table 1: Various locations and the Measured Variables

S/N	Area Name	Basin Area (ha)	Sum of Channel Length (m)	Artificial Drainage Density (Dd)	Cross Sectional Area of drain(	Measured Discharge ()	Degree of impervious Area (%)	Gradient (m/m)
1	Ediba One Area	179.4	2978.0	16.6	0.88	4.85	67.01	0.010
2	Ediba two Area	274.8	3305.24	12.03	2.125	13.0	65.59	0.010
3	Ibom Layout Area	189.3	2478.92	13.1	0.63	1.80	69.0	0.017
4	Mayne Avenue Area	280.2	1970.21	7.03	0.63	1.94	65.4	0.006
5	Big Qua Area	193.6	1579.0	8.16	0.33	0.69	66.24	0.010
6	M.C.C. Highway Area	559.8	4543.02	8.12	6.075	32.2	63.0	0.011
7	Yellow-Duke/Inyang Area	221.0	3611.15	16.34	0.556	1.94	64.9	0.005
8	Marina Road Area	213.5	2195.36	10.28	3.08	9.7	63.95	0.0114
9	Marian Road Area	301.4	2780.01	9.22	0.22	0.66	72.3	0.023
10	Mary Slessor	406.8	3478.07	8.55	1.4	4.40	66.2	0.016

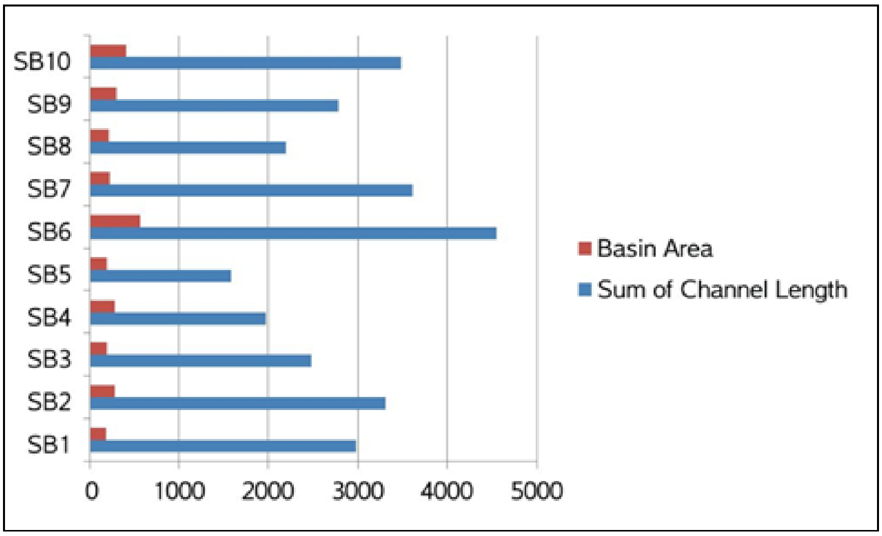

Fig. 3: Relationship between basin area and the sum of channel length in the Metropolis.

From the analysis, it can be observed that out of the six basins (five major natural basins and the sixth developed by human interference), and more than twenty-five sub basins in the Calabar Metropolis catchment area, four of them direct their storm water either directly or indirectly into the trunk or main channel (channel one) in basin 1. This, of course, has grossly over tasked the design capacity of the channel. This results in the multiple storm water drainage problems often experienced along the entire stretch of basin 1. Fig 3 shows the relationship that exists between the basin area and the sum of the channel length.

When the basin area was regressed against the discharge at the 5% degree of significance as shown on Table 2 above, a negative intercept of -10.219, a standard error of 6.725 and an r^2 of 0.57 were obtained. This shows that the combination of these two variables could only explain 57% of the catchments variability. A simple linear regression of the form below was obtained.

$y = -10.219 + 0.06149x_1$

where y = Discharge , in m^3/s

x_1 = Basin Area , in m^2

Table2: Summary Output

Regression Statistics	
Multiple R	0.757083
R Square	0.573175
Adjusted R Square	0.519822
Standard Error	6.72566
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	485.9561	485.9561	10.74304	0.011227
Residual	8	361.876	45.2345		
Total	9	847.8322			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95 %*	*Lower 5.0%*	*Upper 5.0%*
Intercept	-10.2192	5.701093	-1.7925	0.110815	-23.366	2.92751	-10.5881	-9.85037
X Variable 1	0.06149	0.01876	3.277658	0.011227	0.018229	0.104752	0.060277	0.062704

IV. Conclusion And Recommendations

The Calabar drainage basin has been discussed earlier as having been designed originally with six drainage outlets (Calabar Master Plan, 1972). The design for these numbers of outlets was done to accommodate the drainage basins in the watershed. At the time of construction, only one outlet out of the six was put in place. This explains why 65 percent of the CRUTECH staff quarters is always inundated even with an average storm event of average intensity and duration not exceeding 30 minutes. This equally explains why the outskirts of the southern part of the metropolis experience unparalleled flash flooding.

A lot of useful land areas have been lost to flood water around this axis, and yet, a lot of land also has been wrongly and forcefully recovered (seemingly) from the flood by some crude land reclamation processes. These processes adopted for the reclamation of these flooded areas have not helped matter at all. Some of the resultant effects have been loss of gradient on some parts which, in effect have forced some flows from some drains to be truncated prematurely.

In addition to these, there has been uneven compaction of some land areas where, on a patch of land not exceeding 1acre, as much as four gradient values with difference in excess of 10m/10000m have been recorded.

According to observations from the contour crenulations study, which has shown four, out of the six drainage basins emptying their flow into one outlet thereby grossly over -tasking it, Ugbong (2000) equally agreed that not less than 60 percent of the runoff generated in three-fifth part of the metropolis, is emptied either directly or tangentially into this outlet. This outlet, on its own was constructed to terminate abruptly within the western axis of the Cross River University of Technology (CRUTECH) and its surrounding neighborhoods. This abrupt termination has not allowed the trunk to empty its content directly into the Great Kwa River which, originally, was the targeted receptor of this flood water.

It is recommended that more drainage facilities be injected into the over-tasked drainage system in the Metropolis in order to curb the incidence of flooding.

Additionally, the drainage design consideration should embrace the delineation of each sub-basin into its major mother basin.

Designers should endeavour to ensure that the watershed boundary is tenaciously adhered to such that each basin carries its discharge to a safe outlet without a cross-carpet.

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