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Modelling of Basic Environmental and Spatial Parameters: An Imperative for an Optimal Design of an Urban Storm Water Canal in Greater Port Harcourt (GPH) Development Area

Hart Lawrence[1,*], Victor Glory Ukwoma[2]

[1]Department of Surveying and Geomatics, Rivers State University, Port Harcourt
[2]Department of Surveying and Geoinformatics, Captain Elechi Amadi Polytechnic, Port Harcourt
*Corresponding author: Lawrence.hart@ust.edu.ng

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Abstract The traditional way of handling storm water runoff from cities has always been to drain it as fast as possible by means of drainages. Thus, in urban areas the natural water cycle is been influenced by infrastructures that hinders infiltration and concentrates storm water flows. This approach has been shown to cause several environmental problems as storm water from urban areas can be polluted by heavy metals, organic materials, suspended materials and nutrients when discharged to the nearest receiving river. The main thrust of this work is to modelled basic environmental and spatial parameters for the design of storm water canal that will serve as a means of collecting and conveying the urban runoff of the Greater Port Harcourt City. Consequently, the methodology deployed was terrestrial surveying techniques, bathymetric mapping and hydrological models in other to identify the optimal route for the canal, determination of the topography/configuration of the area, generation of the mathematical parameters of the proposed storm water design location in relation to the adjourning communities and to ascertain the proximal impact of the canal on the neighbourhood. The identified route for the canal covered a total distance of 6.47kms with 100m right of way/corridors in addition to a total of 14 transect lines at 700m on both side of the proposed route with no feasible development outside farmlands. Similarly, the receptacle river, covered a total distance of 750m while the width of river varies from 7.21m to 11.34m. The profile of the identified route presents a continuous gradual decrease in elevation data of 21.94m at SC 19 to 1.89m at SC 5 so also the 700m transects with elevation data decreasing gradually from 16.96m to 2.07m at the centre of the proposed canal. The average time of concentration, rainfall intensity and peak discharge for the various basins along the route were 10.719mins, 49.824mm/hrs and 0.826m^3/s respectively, while for the GPH Phase area, the average time of concentration, rainfall intensity and peak discharge were 72.728mins., 13.001mm/hrs., and 1.824m^3/s respectively. These are the basic and essential data required for the design of the storm water canal.

Keywords: *storm water, elevation, modelling, Urban, hydrological models, spatial*

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1. Introduction

The process of urbanization with all its benefits and handicaps seem to be unstoppable in Rivers State and the country at large. Urbanization has from time to time required a lasting approach to runoff water management. The influence of human activities on the physical and biological systems of the earth’s surface is not a recent manifestation of modern society as it is a natural event throughout human history, [1]. Most of the time when there is need for any development, the government only focuses on health, sanitation, provision of water, markets and schools without any consideration to the problem of urban flooding. However, urban flooding which occurs as a result of sustained development and inadequate drainages poses one of the greatest threats to human settlements today. Regrettably, and from time to time, this issue had been sidelined, particularly in the Port Harcourt City. The traditional drainage systems focus on making surfaces smoother to increase runoff to the nearest water course, while storm water drainage have essentially been regarded as a technical intervention linked to road works to handle destructive surface water [2]. Besides the inadequacy of drainages, lack of relevant design parameters based on geospatial acquisition of relevant data models has made existing drainages not to be optimal and suitable to manage urban floods especially storm water in the study area. These have adversely impacted on the natural environment resulting in increased flooding of the study area, associated land neighborhood with attendant impact and losses on properties and livelihood. In addition, increases water ways erosion, transport of sediments and pollutants with detrimental impacts on aquatic and riparian life, [1]. Consequently, there is a need to construct a storm water canal to collect surface runoff based on scientifically determined parameters from the phase 1 area of Greater Port Harcourt City and the surrounding communities for subsequent discharged into a river.

The main thrust of this work is to model and highlight basic environmental and spatial parameters necessary to design an optimal storm water drainage for urban storm water and flooding. This underscores the concept of best management practice (BMP) as discussed by [3,4], it hinges on the modalities of an appropriate drainage design strategies based on determination of various parameters and associated information for the particular design. In most cases they include the determination of the various surface runoff of catchment and sub-catchment areas within the location, assessment of rainfall data for the determination of rainfall intensity, runoff coefficient of various catchment basin leading to the determination of peak discharged for the entire study area. The width, depth and peak discharged of the proposed drainages were equally determined using appropriate drainage design models. Developing parameter for the design of storm water canal requires direct and in-direct observation of earth's surface features and their inter-relationship as a consequence of the terrain characteristics, [2]. Without doubt, within the Port Harcourt City and its immediate environs, major roads, government residential estates, and some neighborhoods have drainage facilities that are not functioning and as such, flooding after rainfall is still a usual occurrence. Some of the identified factors responsible for the non-functionality and inefficiency of these drainage facilities include inappropriate depth, width, and lack of identified flow direction amongst other design deficiency, [1].

2. The Study Location

The study area is the Greater Port Harcourt City. It lies between the geographical coordinates of 253549.618mE, 512406.361mN and 301837.893mE, 570943.436mN on UTM Coordinate System (Zone 32N), with an area of approximately 1,900sq.km. extending over eight (8) Local Government Areas (LGA's). These include the whole of Port Harcourt City Local Government Area, and part of Okrika, Oyigbo, Eleme, Ogu/Bolo. Obio/Akpor, Etche and Ikwerre LGAs. Characterized by different languages and cultural values, with a population of about 1.9 million, [5] the people are predominantly farmers and fisher men and women. The proposed route for the storm water canal is located in Aluu community in Ikwerre Local Government Area as a constituent of the Greater Port Harcourt City as shown in Figure 1. The communities are characterized by both low land and upland that make flooding a serious problem especially for those parts of the communities that are at the lowland.

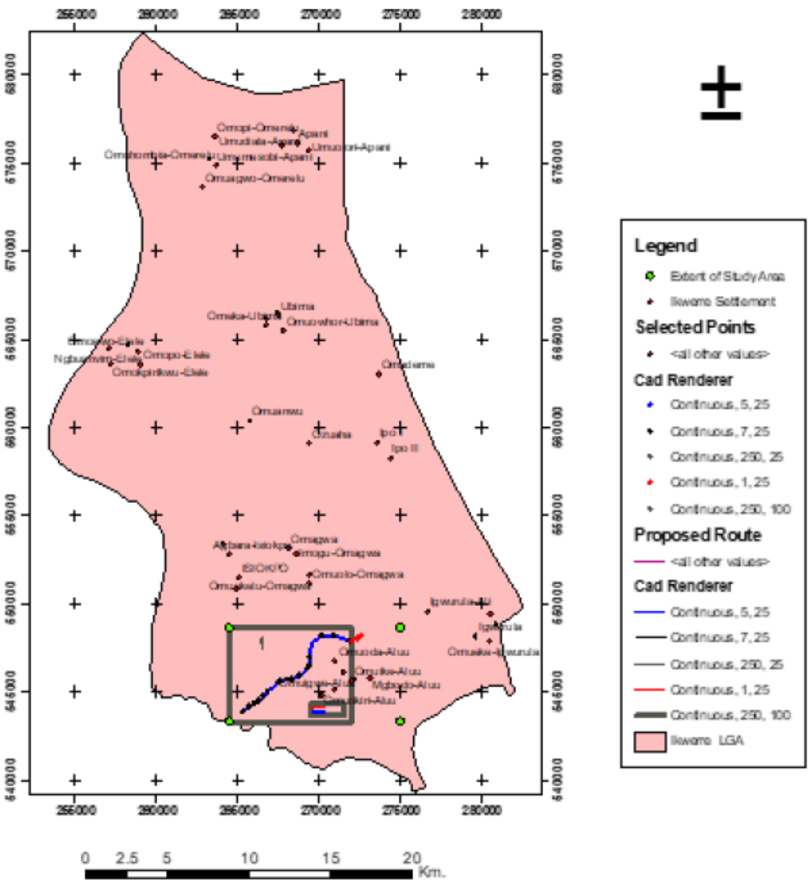

Figure 1. Map of Ikwerre Local Government Area (LGA) Showing the Study Area

3. Theoretical and Conceptual Framework

3.1. Flood and Storm Water: Issues and Perspectives

Floods are caused by many factors and can be human induced or as a natural factor. Natural factors include heavy rainfall, highly accelerated snowmelt, severe winds over water, unusual high tides, tsunamis, while human factors include; failure of dams, levees, retention ponds, or other structures that retained the water [6]. Urban flooding is the inundation of land or property in a built-up environment caused by storm water overwhelming the capacity of drainage system such as storm sewers. Although triggered by single event such as flash flooding or snow melt, urban flooding is a condition characterized by its repetitive, costly and systemic impact on the communities as depicted in plate 1. Without doubt, a lot of studies have been carried out on the design of Storm Water Canal especially in developed countries, [7] However, in developing countries like Nigeria, there have not been any developmental efforts towards management of Storm Water or how it can be harnessed to better the life of the people. In the recent past, major cities and towns in the country have witnessed tremendous rainfall with unimaginable destruction of lives and properties resulting from the corresponding flooding. As development continues unabated, the percentage of impervious surfaces will continue to increase with corresponding increase in surface runoff, [8]. Within Port Harcourt metropolis, the famous Ntawogba Creek was a natural drainage system along with numerous wetlands within and around the city center which in the past served as retention ponds.

Plate 1. Flood Effect in part of Port Harcourt. (Source: Author's Field Survey, 2018)

Consequently, a storm water drainage system is a system of receiving, conveying, and controlling storm water runoff in response to precipitation. These include ditches, culverts, swales, sub-surfaces interceptor drains, roadways, curb and gutters, catchment basins, manholes, pipes, attenuation ponds and service lateral lines [9]. These drains are designed to convey runoff from frequent rainfall.

4. Methodology

The methodology deployed in this work within the context of developing parameters for the design of storm water canal, was the classical approach of geospatial data acquisition which involve topographic surveying of the entire study area and hydrographic surveying of the river which will serve as the discharge point or ultimate destination of surface runoff. The use of relevant hydrological mathematical models forms the framework for the determination of relevant environmental parameters necessary for any meaningful design, [10]. Plate 2 and Plate 3 shows the survey team in the process of data acquisition and assessing the suitability of the receptacle river using bathymetric approach. The entire area (corridor) was covered with grid lines at 20m interval for loop 1 and 2, while some part of loops 3 and 4 and loop 5 and 6 were leveled at 50m interval due to the nature of the terrain. The method of differential leveling was adopted in the study and it commenced from the control pillar (GPH 10). The sounding of Creek channel commenced after the calibration of the echo sounder and tide gauges, [11]. The sounding was carried out along the center line of the channel and fixes of depth was done at 20 meters interval. The approximate width of the rivers was 10.2m, while the sounding exercise covered a distance of 750 meters. In this work the rational method was employed in the computation of the peak discharge or runoff from storm water. The mathematical models associated with the methodology is as shown. The values of the coordinates of the boundary points of the study area is determined using equations 1-4 [12].

Plate 2. Researcher and other Members of the Survey Crew for Data Acquisition Operations

Plate 3. The Proposed Route for the Canal terminating at Mgbuogidi River (2016)

Latitude,

$$\Delta N_{AB} = LCOS\theta \quad (1)$$

Departure,

$$\Delta E_{AB} = LSin\theta \quad (2)$$

While,

$$N_B = N_A + \Delta N_{AB} \quad (3)$$

$$E_B = E_A + \Delta E_{AB} \quad (4)$$

Where, NA = Northing coordinate of station A; EA = Easting coordinate of station A; NB = Northing coordinate of station B; EB = Easting coordinate of station B; ΔNAB = Difference in Northing from A to B; ΔEAB = Difference in Easting from A to B.

4.1. Parameters for the Design of Storm Water Canal

There are two basic analyses are required for the design of storm water canal. These include the hydrologic aspect of estimating runoff and the hydraulic aspect of sizing the components which comprises runoff coefficient, peak discharge, rainfall data (to determine rainfall intensity and time of concentration).

i. Runoff Coefficient: This depends on the level of imperviousness (built and un-built area), paved and unpaved roads, open spaces, forest and grasses. However, there is a standard published manual that expresses the value for various surfaces.

ii. Peak Discharge: This can be obtained for the various catchment and sub-catchment areas using the expression as shown in equation 5

$$Q_p = 0.278CiA \quad (5)$$

where, Q_p = peak discharge,
C = dimensionless run-off coefficient whose value depends on catchment characteristics.
i = rainfall intensity in mm/hr.
A = Catchment area in Km^2.

More so, in determining the catchment rainfall-runoff response, the time of concentration in each of the catchment must be determined using Kirpich's formula in equation 6.0:

$$t_c = \left\{0.00032L^{0.77}\right\} / S^{0.385} \quad (6)$$

where tc = time of concentration (hrs.)
L = Maximum length of water travel (m)
S = Surface slope given by H/L, where H is the difference in elevation between the remotest point in the drainage basin and the outlets (m). Therefore, rainfall intensity, which is the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period was determined for each of the basin using equation 7.

$$i = a / t_c + b \quad (7)$$

Where a = 760, b=10 for a duration of 5-10 minutes. a = 1020, b= 10 for a duration of 20 -100 minutes.

iii. Area of the Catchment Basin; This can be obtained from the contour map of the study area and where there is a digital map of the study area, the area of catchment basic can be computed using the AutoCAD Software area computation module or tool. Furthermore, for the proposed canal, the Discharge can be computed using Cheezy-manning equation in [10] as demonstrated in equation 8:

$$Q_c = \left\{A_c R^{2/3} S^{1/2}\right\} / n \quad (8)$$

Where: Q_c = Discharge
A_c = Cross-sectional area of the canal.
R = Hydraulic radius
S = Slope of drain or hydraulic gradient
n = manning's roughness coefficient. (This is a function of the surface material of the canal).

4.2. Volume Computation for the Various Catchment Area

The catchment areas or catchment basins are those areas that may serve as water retention pond or basin for onward discharged into the canal. The percentage contributions from the various catchment areas are determined by the volume of water retained by each basin multiply by the run-off coefficient which is a function of the catchment characteristics. The volume contribution is obtained from the expression in equation 9:

$$V1 = A \times \Delta h \quad (9)$$

Where, V1 = Volume (m^3)
A = Area(m^2)
Δh = Difference in elevation.

For example, computation of volume using the above expression for the first segment, SC 19 to SC 18, we have, Area = 500,145m^2; Difference in elevation = 1.92m; Volume, V1 = 960,278.4m^3. The percentage runoff as given in equation 10 is thus:

$$V2 = V1 * RC \quad (10)$$

Where, V2 = Percentage runoff; RC = Runoff coefficient; the value of V1 = 960,278.4m^3; RC= 0. 3. Therefore, V2 = 960,278.4 x 0.3 = 288,083.52m^3.

4.3. Design Parameters for the Route Corridor of Storm Water Canal

The parameters required for the design of the route corridor for the storm water canal is shown in equation 11.

$$V = Axhxd \quad (11)$$

Where; V = Volume (m^3), A = Cross-sectional area (m^2), h = elevation, d = depth

5. Results and Discussion

Peak Discharge for The Canal Using Manning's Equation,

$$\frac{AcR^{2/3}S^{1/2}}{n} \quad (12)$$

where A_c =Cross Sectional area, R= Hydraulic Radius, S = Slope or Hydraulic Gradient, n = Manning's Coefficient for Concrete Channels (0.013). Therefore, hydraulic radius R = A/P, where A = cross sectional area (378.000$m^{2)}$, P =wetted perimeter (73.412m), therefore, R = (378.000/73.412) m = 5.1487414m.

$$S = \Delta h/L \quad (13)$$

Where, Δh = difference in elevation, L = Maximum distance of water travel, S = Slope.

Therefore,

$$Slope = \left(\frac{1.92}{1008.550}\right)m = 0.0019181m,$$

$$Q_C = 378 \times \frac{5.1487414^{2/3}}{0.013} \times 0.0019181^{1/2}$$

$$= 378 \times \frac{11.682926 \times 0.0437961}{0.013} = \frac{193.41006}{0.013} = 14877.697.$$

Therefore Qc=14,877.697 for the first area:

$$Q_C = 650 \times \frac{7.222222^{2/3} \times 0.0019181^{1/2}}{0.013}$$

$$= \frac{650 \times 19.40913 \times 0.0437961}{0.013}$$

$$\frac{552.52875}{0.013} = 42502.212;$$

Q_c = 42,502.212 m^3/s for the second area.

Table 1. Specimen of Proposed Route Corridors and Elevation Data

FROM	ELEVATION DATA		DIFFERENCE IN ELEVATION (Metres)	DISTANCE (METRES)			TO
	HIGHEST VALUE(Metres)	LOWEST VALUE(Metres)		LEFT CORRIDOR (Metres)	CENTRE CORRIDOR (Metres)	RIGHT CORRIDOR (Metres)	
SC 19	21.94	20.02	1.92	993.407	1000.979	1008.550	SC 18
SC 18	20.39	18.27	2.12	729.455	751.058	772.661	SC 17
SC 17	19.68	5.84	13.84	591.450	622.446	653.441	SC 16
SC 16	7.30	3.98	3.32	516.999	542.627	568.255	SC 15
SC 15	5.59	3.66	1.93	390.711	397.279	405.943	SC 14
SC8	4.06	3.44	0.62	160.860	150.813	170.907	SC 7
SC 7	3.94	2.05	1.89	805.746	808.598	811.448	SC 6
SC 6	2.62	1.89	0.73	406.780	408.821	410.862	SC 5
SC 5	(END OF THE PROPOSED ROUTE)						SC 4
	TOTAL			**7,193.415**	**7,186.927**	**7,266.672**	

Table 2. Elevation Data for Catchment Basins

FROM	ELEVATION DATA		DIFFERENCE IN ELEVATION (Metres)	TO
	HIGHEST VALUE (Metres)	LOWEST VALUE (Metres)		
SC 19	21.94	20.02	1.92	SC 18
SC 18	20.39	18.27	2.12	SC 17
SC 17	14.39	5.84	9.09	SC 16
SC 16	12.44	3.98	8.46	SC 15
SC 15	12.92	3.66	9.26	SC 14
SC 14	8.71	3.25	5.46	SC 13
SC 13	9.41	3.73	5.68	SC 12
SC 12	11.88	3.07	8.81	SC 11
SC 11	14.82	2.90	11.92	SC 10
SC10	12.95	1.68	11.27	SC 9
SC 9	8.46	2.60	5.86	SC 8
SC8	7.82	3.29	4.53	SC 7
SC 7	9.76	2.05	7.71	SC 6
SC 6	7.47	1.89	5.58	SC 5
SC 5	(END OF THE PROPOSED ROUTE)			SC 4

Table 3. Specimen Result of Expected Volume from the Various Catchment Area for the Expected Runoff.

From	Area in Hectares	Area in m^2	Difference in elevation	V1=area(m^2)* diff in elevation	Runoff coefficient (RC)	V2=V1* RC	To
SC 19	50.0145	500,145	1.92	960.2784	0.30	288,083.52	SC 18
SC 18	37.5164	375,164	2.12	795.43768	0.30	238,631.30	SC 17
SC 17	31.1584	311,584	9.09	2,832,298.56	0.25	708,074.64	SC 16
SC 9	19.6309	196,309	5.86	1,150,370.74	0.20	230,074.15	SC 8
SC 8	8.2115	82,115	4.53	371,980.956	0.20	74,396.19	SC 7
SC 7	40.3628	403,628	7.71	3,111,971.88	0.20	622,394.38	SC 6
SC 6	20.5690	205,690	5.58	1,147,750.20	0.30	344,325.06	SC 5
			TOTAL	**22,559,053.72**		**5,409,525.20**	

Table 4. Specimen Expected Volume on the Canal Catchment Basin

From	Length of segment, L (m)	Vol.1 = (a1 x L) m^3 (a1 = 378.000m^2)	Vol.2 = (a2 x L) m^3 (a2 = 650.000m^2)	To
SC 19	1000.979	378,370.062	650,636.350	SC 18
SC 18	751.058	283,899.924	488,187.700	SC 17
SC 17	622.446	235,284.588	404,569.900	SC 16
SC 16	542.627	205,113.006	325,707.550	SC 15
SC 15	397.279	150,171.462	258,231.350	SC 14
SC 9	393.158	148,613.724	255,552.700	SC 8
SC 8	150.813	57,007.314	98,028.450	SC 7
SC 7	808.598	305,650.044	522,588.700	SC 6
SC 6	408.821	154,534.338	265,733.650	SC 5

Table 5. Specimen Results of Determination of Peak Discharge on the Proposed Canal Using Two Different Areas

From	Peak discharge using Area 1 (378.000m^2)	Peak discharge using Area 2 (650.000m^2)	To
SC 19	14,877.697m^3	42,502.212m^3	SC 18
SC 18	18,048.143	51,559.482	SC 17
SC 17	51,964.756	148,450.74	SC 16
SC 16	27,222.313	77,768.023	SC 15
SC 15	23,876.844	68,206.597	SC 14
SC 9	16,547.024	47,271.132	SC 8
SC 8	21,781.064	62,223.635	SC 7
SC 7	21,350.591	46,918.371	SC 6
SC 6	14,354.635	41,008.00	SC 5

Table 6. Specimen of Basic Data of the Catchment Area for the Storm Water Design.

Segment (SC)	Area (hectares)	Area (km2)	RC	Diff in elevation	Length (m)	Slope	T_c (mins)	i (mm/hr)	Q_P (m^3/s)
19- 18	50.0145	0.500145	0.30	1.92	430	0.0019	16.4394	38.2305	1.5530
18 -17	37.5164	0.375164	0.30	2.12	430	0.0027	15.8795	39.5051	1.2361
17 -16	31.1584	0.311584	0.25	9.09	430	0.0211	9.0346	53.5865	1.1604
16 -15	27.1775	0.271775	0.25	8.46	430	0.0197	9.2879	52.8828	0.9989
15 -14	19.8609	0.198609	0.20	9.26	430	0.0215	8.9704	53.7680	0.5937
9 -8	19.6309	0.196309	0.20	5.86	430	0.0136	10.6983	49.2793	0.5379
8 -7	8.2115	0.082115	0.20	4.53	430	0.0105	11.8130	46.7612	0.2135
7 -6	40.3628	0.403628	0.20	7.71	430	0.0179	9.6259	51.9721	1.1663
6 -5	20.5690	0.20569	0.30	5.58	430	0.0130	10.9019	48.7993	0.8371

Note: Tc - Time of Concentration, RC: -Runoff Coefficient, i – Rainfall Intensity, Q_p-Peak Discharge.

The results have provided required data for the design of proposed route for the storm water canal and the environmental parameters of the catchment basins within the neighbourhood of the route. Table 1 shows the specimen computed elevation data for the various segments of the canal from SC 19 to SC 5, the length of the left, center and right corridor of each segment and the corresponding difference in elevation. A close examination of the various segment and the lengths of the three corridors for each segment show slight differences in the measured distances due to the non-collinearity of the various segment that define the route for the proposed canal because the route was design to align with the natural drainage pattern of the area. For instance, from SC 19 to SC 18, the length of the left corridor was 993.407m, center corridor was 1000.979m and the right corridor was 1008.50m respectively. In Table 2 the differences in height between the lowest point and the highest point within each segment of the route was highlighted. While the lowest elevation for the entire route was 1.89m, the highest elevation value was 20.02m; this implies that the difference in height from the beginning of the route up to the end was 18.13 meters. The profile of the center line from SC 19 to SC 5 reveals a gradual decrease in elevation data from 21.94m at SC 19 to 2.62m at SC 5. (See Table 1) This decline in elevation continues to the end of the route as it links the existing Ngbuogidi river with the depth of the sea bed ranging from 0.2m to 0.6m for the major part of the river. In the same vein, Table 3 shows the water volume capacity for the expected runoff of the different catchment areas basins delineated in the study area. Table 4 gives a graphic representation of the capacity of various segment of the canal based on the cross-sectional areas of 378.000 sq. meters and depth of 6.0 meters and 650.000 sq. meters and the corresponding depth of 10 meters respectively. More so, Table 5 gives the peak discharge on the proposed canal using the two cross-sectional areas. In analyzing the terrain characteristics of the catchment basin which serves as water retention pond that eventually discharged into the canal as runoff. The following parameters and coefficient was adopted, a distance of 215 meters on both side of the canal, giving a total distance of 430 meters as catchment radius was used, while a runoff coefficient of 0.2 to 0.3 were adopted due to the varying vegetation of the route from dry land (farm land) to thick forest and deep swamp forest. The runoff coefficient of each segment based on their runoff characteristics in addition to the capacity of each basin were used to compute the percentage runoff for each of the catchment basin. In summary, only 23.98% of the water in the entire catchments will result into runoff. This clearly revealed that the identified or selected route is the most appropriate and optimal route for the canal.

Table 6, provides the basic data for each catchment basin and their corresponding runoff coefficients, difference in elevation within each segment, slope, time of concentration, rainfall intensity and peak discharge of various catchment basins. These constitute a significant part of the basic data required for the subsequent design of the canal.

6. Conclusion

Without doubt, the issue of flooding in most of the cities in developing countries and the corresponding destruction to lives and properties cannot be under-estimated [13]. The emerging development of geospatial, environmental engineering and modelling techniques as demonstrated in this work addresses the gap that exist in the optimal determination of relevant parameters and associated information in urban storm water design process. To have a sustainable city in this 21st century that is resilient and adaptable concerted efforts and joint participation of all stakeholders from government at various level, community leaders and ordinary citizens to promote scientifically approached designs and geospatial analysis. This study has significantly examined the critical factors that are often neglected in urban drainage design and environmental modelling required for city planning and development which in most cases resulted into preventable disasters occasionally experienced in these urban locations. The issue of adequate understanding and access to real time information about the topography/configuration of our cities and communities are necessary essentials to the control and prevention of flooding in our communities. As already highlighted by the various computations and analyses carried out in this work, an optimal route for the storm water canal was identified, as Table 1 clearly revealed a continuous decrease in elevation data (height) from 20.02 meters at SC 19 to 1.89 at SC 5 respectively. Consequently, in other to avoid the mistakes of the past, there is a need for adequate planning and provision for sustainable drainage network system, monitoring and control of development and proper channelization of storm water runoff to the designated exit points.

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