Runoff Coefficient Analytics of Geospatial Catchment Basins in Greater Port Harcourt Development Area, Rivers State, Nigeria

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Abstract: Widespread climate change condition and increasing urban development, which accounts for rainfall-induced flooding in urban locations among other hazards, is a major concern for societies in recent times. This is further compounded with the neglect of critical environmental model indicators such as runoff coefficients in planning for management of urban flooding. It is therefore prudent that such a natural hazard is addressed in a way to reduce the impact it causes on people and the environment. Although the National Emergency Management Agency (NEMA) among other government agencies predicted the occurrence of urban flooding with the attendant distortion in urban flood plains, relevant spatial information and runoff coefficients pertaining the extent of the area was not provided. This study is an attempt to demonstrate the contribution of runoff coefficient of the various geospatial catchment basins in the Greater Port Harcourt Development Area in assessing the urban floods and development imperatives. Geomatics method was used to evaluate the flood-hazard vulnerability areas in terms of terrain characteristics and runoff coefficient. The runoff coefficient of each segment based on their runoff characteristics in addition of each basin were used to compute the percentage runoff for each of the catchment basin. The factors investigated ranges from geospatial terrain model and elevation model of the Greater Port Harcourt City Area, the existing land use/land cover and closeness of creeks and rivers for slope determination.The profile data and area of the various catchment basins needed for the design of the canal was determined.The result shows the criticality of urban development process within the purview of land use classification with an area of 1,161.593 hectares. The summation of individual RC for each of the land-use in the study area is 0.544. In summary, only 23.98% of the water in the entire catchment will result into runoff.

Keywords: Flooding, runoff coefficient, catchment basin, terrain model, geospatial, urban

1. Introduction

With increasing development in major towns and peripheral locations of cities in a developing country like Nigeria, associated infrastructural entities must be designed with the view of functionality and optimization. This objective for built professionals must be hinged on the deployment of relevant geospatial information such as the nature of the topography of the area, the exit point or points to the nearby river, the characteristics of the catchment and sub-catchment areas contributing the surface runoff including the runoff coefficient of the basin, rainfall intensity and duration and peak discharge. However, property and infrastructural developments in urban locations such as the Greater Port Harcourt Development Area in Rivers State and particularly along floodplain of major rivers flowing through urban settlements are progressing unregulated. Urbanization propels the conversion of rural land resources and land-use occupancy through the concentration of people in urban settlements, (Dan Jumbo, et al, 2018). Urbanization increases the surface runoff, by creating more impervious surfaces such as pavements, major car packs, roads and buildings that do not allow percolation of the water down through the soil to the aquifer. (Needhidasan& Manoj, 2013).These natural lands which used to capture large volume of rain have been lost and much rain is now unable to seep into the ground. When runoff flows along the ground, it can pick up soil contaminants such as petroleum products, pesticides, or fertilizers that become discharge or overland flow. Runoff rate and volume generally increase after urbanization and this development alters the characteristics of runoff. If the downstream channel capacity is exceeded, flood will occur over the flood plain. Another related problem is channel erosion which depends on the runoff rate and its duration. Thus, urbanization not only increases runoff rate and volume but also their frequency. The frequency of runoff rate has a direct impact on erosion and sediment transport of river channel(Parkinson, 2003).In view of these phenomena, geo-spatial data has two major components (spatial and attribute)that are critical in relative positioning with respect to the earth surface. The spatial component deals with the location of geographic entities together with their spatial dimensions. It is often represented in form of coordinates. These may include the geographic coordinates system (Latitude and Longitude), Rectangular Cartesian Coordinates System or even assumed Coordinate System; while the attribute component refers to the characteristics of the features under investigation. It is also called as-spatial or non-spatial components of geospatial data. In this work, the aim is to determine the runoff coefficients of the delineated catchment basins of the Greater Port Harcourt Development Area (GPDA) premised on the land use classifications. This information will provide the framework for the appraisal of urban flooding and development activities in the study area. In certain parts of GPDA, the old Port Harcourt city and its environs, buildings are springing up where they are not supposed to or have not been authorised, some of these buildings are placed in water course; while other places have chocked drainage system (Hart and Glory, 2020). These developments have significant impacts on the urban landscape with attendant flood risk implications; hence, the provision of this critical spatial environmental data (runoff coefficients) has become imperative and urgent.

2. The Study Area

The study area is the Greater Port Harcourt City.It is a relatively flat terrain made up of five (5) major basins and 39 sub-basins in Rivers State in the Niger Delta region of Nigeria (Dan-Jumbo et al, 2018). It lies between the projected coordinates of 253549.618mE, 512406.361mN and 301837.893mE, 570943.436mN on UTM Coordinate System (Zone 32N), with an area of approximately 1,900 sq. km. extending over eight (8) Local Government Areas (LGA's). The study area is an increasingly urbanizing location with a hydrologically sensitive coastal plain (see plate 1).The phase 1 component of the new city which is situated within Ikwerre Local Government Area is presently undergoing massive infrastructural development including new roads, sport complex, hospital and numerous residential estates as shown figure 1.

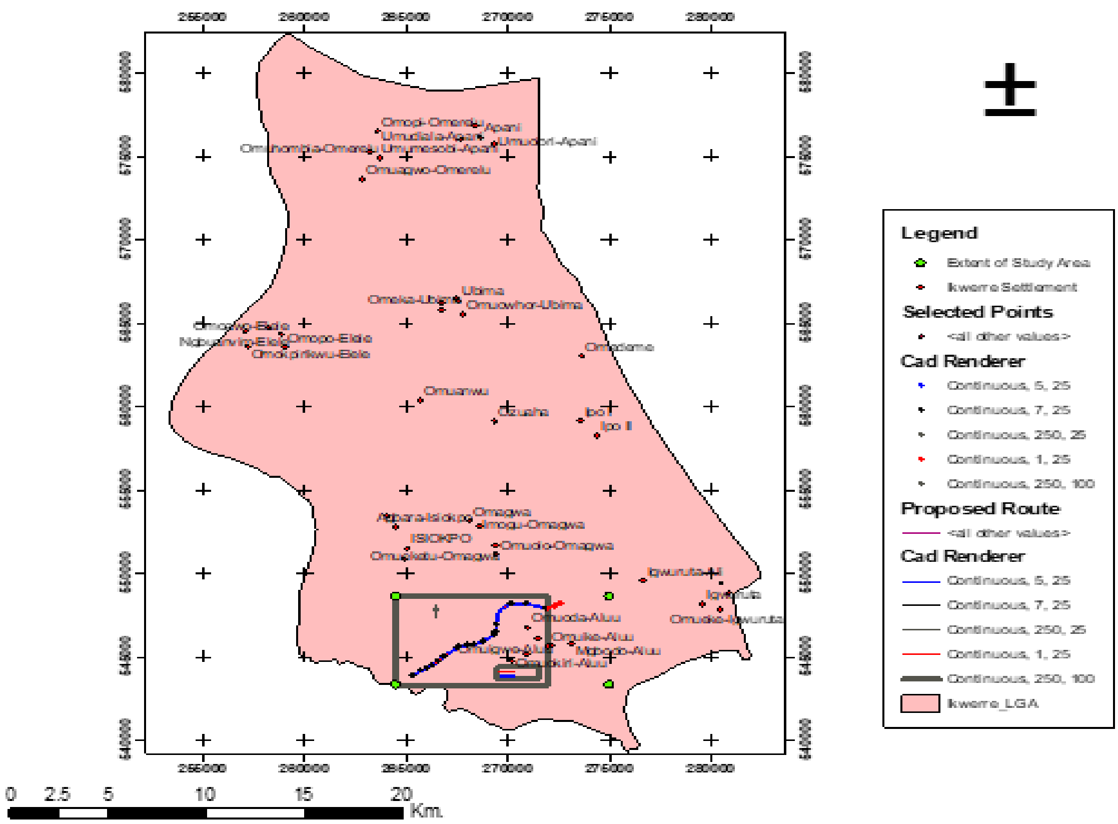

Figure 1. Map Showing Study Area in the Greater Port Harcourt Development Area (Adapted from Victor, 2019)

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

3. Materials and Methods

The rational method of evaluation of the estimate of the peak flow of runoff was adopted in this study. The rational method model relates the catchment area to the rainfall intensity with regards to the optimal time of concentration of flow, connected to the dimensionless runoff coefficients. The model is as shown in equation 1.0. The runoff coefficient depends on the level of impervious surfaces, open spaces, forest (vegetation types). This is typically published in a periodical that underscores the value for various surfaces (Hart & Victor, 2020). The list of elevation for the study area as shown in table 1 was used to develop the terrain characteristics.

$$Q_p = 0.278CiA \qquad (1.0)$$

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 as shown in equation 2.0

$$t_c = \{0.00032L^{0.77}\}/S^{0.385} \qquad (2.0)$$

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, i is given in equation 3.0 as:

$$i = a/t_c + b \qquad (3.0)$$

where a = 760, b=10 for a duration of 5-10 minutes.

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

Table 1. Elevation Values of part of Greater Port Harcourt Phase 1

STN	EASTINGS (m)	NORTHINGS (m)	M.S.L. HEIGHT(m)
GPS001	278562.455	557256.887	29.513
GPS 02	278846.155	551710.235	24.294
GPS 03	272821.85	549949.018	20.63
GPS 04	273770.193	551706.979	23.096
GPS 05	272751.332	550460.253	21.289
GPS 06	272775.056	549525.528	20.218
GPS 07	272361.105	548036.898	16.476
GPS 08	272050.092	547908.448	18.648
GPS 09	274791.688	550581.147	20.165
GPS 10	274952.056	550425.802	21.445
GPS 11	275127.938	550264.88	22.342
GPS 12	272734.325	547834.434	17.181
GPS 13	272998.286	547455.335	16.58
GPS 14	273249.041	547109.461	16.568
GPS 15	273499.642	546712.71	16.592
GPS 16	273562.703	546295.52	16.569
GPS 17	274297.096	541196.432	10.986
GPS 18	274255.236	541295	11.58
GPS 19	274470.211	541211.393	12.024
GPS 20	273322.503	539201.795	14.017
GPS 21	273193.988	539261.914	14.933
GPS 22	273213.351	539061.653	14.742
GPS 23	272972.42	539368.772	15.444
GPS 24	272159.903	534488.939	1.92
GPS 25	272076.681	534486.978	1.275
GPS 26	271991.211	534475.07	2.426
GPS 27	270233.997	534939.438	1.97
GPS 28	270257.604	535040.022	2.73
GPS 29	270325.552	535127.197	5.059
GPS 30	279113.188	546453.446	19.234
GPS 31	279117	546614.919	20.091
GPS 32	279088.722	546803.033	21.279
GPS 33	284069.38	545257.531	22.311
GPS 34	284086.536	545434.445	22.521
GPS 35	284166.382	545805.836	20.393
GPS 36	286653.737	540907.831	16.082
GPS 37	286805.789	541319.937	18.74
GPS 38	288558.597	537810.032	19.542

GPS 39	288755.122	537868.096	19.755
GPS 40	288961.606	537917.284	17.872
GPS 41	292251.127	534385.559	15.906
GPS 42	292350.986	534792.282	13.65
GPS 43	293737.929	527514.543	14.291
GPS 44	293834.291	527453.455	14.515
GPS 45	294012.611	527337.954	15.31
GPS 46	276586.516	543271.151	16.834
GPS 47	276540.516	543468.17	17.227
GPS 48	276420.112	543639.974	16.965
GPS 49	275552.286	531687.035	10.995
GPS 50	275655.398	531661.29	10.798
GPS 51	278849.371	528849.168	9.558
GPS 52	278780.792	528923.472	9.062
GPS 53	278756.697	529031.936	8.824
GPS 54	264917.285	543851.441	2.33
GPS 55	265033.498	543763.687	2.819
GPS 56	265002.797	543528.176	2.488

4. Results and Discussion

GPH Phase 1 Land-Use Classification

The GPH Phase 1 covered a total area of 1,161.593 hectares with various land-use featuring different facilities including residential areas, educational infrastructures, sport complex, golf course etc. (Table 2.). The table also reveals the percentage contribution of the various facilities and their corresponding runoff coefficient (Figure2)

Table 2.Land-Use Classification of GPH Phase 1 and their Runoff Coefficients

S/N	ZONING	AREA HECTARES	AREA KM^2	AREA M^2	PERCENTAGE CONTRIBUTION	RUNOFF COEFFICIENT
1.	SHOPPING CENTRE	21.577	0.21577	215.77	1.85	0.50
2.	HOTELS AND RELATED USES	20.838	0.20838	208.38	1.80	0.50
3.	COMMUNITY HALL	1.898	0.0898	9.8	0.15	0.70
4.	POLICE STATION	2.283	0.02283	22.83	0.20	0.70
5.	FIRE STATIONS	1.520	0.01520	15.20	0.13	0.60
6.	CLINICS	0.856	0.00856	8.56	0.07	0.60
7.	HOSPITALS	5.294	0.05294	52.94	0. 45	0.60
8.	LIBRARIES	1.392	0.01392	13.92	0.12	0.65
9.	CHURCHES	6.333	0.06333	63.33	0.54	0.60
10.	COLLEGES	4.645	0.04645	46.45	0.40	0.40
11.	EDUCATIONAL (PRIMARY AND SECONDARY)	90.535	0.90535	905.35	7.80	0.40
12.	CRECHES	5.636	0.05636	56.36	0.47	0.50
13.	COMMERCIALS	24.178	0.24178	241.78	2.08	0.40

	(30% COVERAGE					
14.	SPORT FACILITIES	6.12	0.06120	61.20	0.52	0.30
15.	GOLF COURSE/ACTIVE OPEN SPACES	87.027	0.87027	870.27	7.50	0.30
16.	PUBLIC OPEN SPACES	80.150	0.80150	801.50	6.90	0.30
17.	WASTE DISPOSAL SITE	6.148	0.06148	61.48	0.52	0.30
18.	MIX-USE (RESIDENTIAL AND OFFICES/BUSINESS)	90.708	0.90708	907.08	8.80	0.40
19.	MEDIUM DENSITY	135.965	1.35965	1,359.65	11.70	0.40
20.	MEDIUM LOW DENSITY	84.802	0.84802	848.02	7.30	0.35
21.	LOW DENSITY	161.126	1.61126	1,611.26	13.90	0.40
22.	PROPOSED NEW ROADS	313.587	3.13587.	3,135.87	27.00	0.80
		1,161.593			100.00%	

SOURCE: -GPH Spatial Development Plan (2009).

Catchment Area from GPH Phase 1

For the purpose of this study and for ease of computation, the GPH Phase 1 was sub-divided into eleven (11) catchment areas (basins).

Figure2 shows the eleven basins and their corresponding exit points, while Table 3 shows the area of each catchment basin, their respective percentage contribution, the maximum distance travelled by water and the average elevation of each of the basin. The runoff coefficient for each of the catchment basin was computed based on the constituents' facilities (land-use) and their percentage contribution to the total area of the basin. Consequently, a single value for each of the basin was determined and used as runoff coefficient based on the level of pervious and imperviousness of the surfaces and the corresponding storm water runoff. (See Table 4). In arriving at the results presented in table 3, the process adopted showed that Area 1 is made up of nine (9) land-use classifications including shopping center, churches, public open space, sport complex etc. with their corresponding areas.The percentage contribution of each land-use was derived from the area of component land-use divided by the total area. (Area 1).That is, for shopping center, area = 4,171.519 sq. mts. The total area = 941,735.568 sq. meters.Therefore, percentage contribution to total area = (4,171.519/941735.568) x100%= 0.44%. Runoff Coefficient for Shopping Centre = 0.50; Actual runoff contribution for shopping Centre = (0.44/100) x 0.50 = 0.002; consequently, the summation of individual RC for each of the land-use within the study area is **0.544**

Table 3.Catchment Basins (Areas) and their Percentage Contribution to Runoff

S/ N	CATCHM -ENT BASIN	AREA (m²)	AREA (HECTAR -ES)	PERCEN TAGE CONTRI B- UTION	MAXIMUM DISTANCE TO EXIT POINT (M)	MAXIMUM DIFF IN ELEVATIO N (M)	RUNOFF COEFFIC I-ENT
1.	AREA 1	941,735.568	94.1736	8.131	1,430.111	2.178	0.544
2.	AREA 2	1,264,248.268	126.4248	10.915	1,999.493	1.986	0.566
3.	AREA 3	1,157,756.248	115.7756.	9.996	1,787.540	2.369	0.528
4.	AREA 4	1,040,316.489	104.0316.	8.982	1,875.064	3.006	0.523
5.	AREA 5	964,061.235	94.6061	8.324	1,945.373	2.517	0.490
6.	AREA 6	947,854.918	94.7855	8.184	1,495.101	1.534	0.516
7.	AREA 7	771,746.565	77.1747	6.663	1,303.024	3.484	0.546
8.	AREA 8	975,958.837	97.5959	8.426	1,583.595	1.718	0.466
9.	AREA 9	521,254.256	52.1254	4.500	1,079.968	2.006	0.501
10.	AREA 10	1,352,830.034	105.2830	11.680	1,978.850	2.498	0.347
11.	AREA 11	1,644,513.000	164.4513	14.199	1,921.472	3.174	0.511
	TOTAL	**1,1582275.417**	**1,158.2275**	**100.00**			

Table 4.Computation of Runoff Coefficient for the Catchment Basins 1 (Area 1)

S/N	ZONING	AREA (m²)	PERCENTAGE CONTRIBUTIO N	RUNOFF COEFFICIE NT	ACTUAL RUNOFF CONTRIBUTIO N
1.	SHOPPING CENTRE	4,171.519	0.44	0.50	0.002
2.	CHURCHES	1,895.994	0.20	0.60	0.001
3.	EDUCATIONAL (PRIMARY AND SECONDARY)	87,244.614	9.26	0.40	0.040
4.	CRECHES	3,640.958	0.39	0.50	0.001
5.	PUBLIC OPEN SPACES	74,064.849	7.86	0.30	0.030
6.	MIS-USE (RESIDENTIAL AND OFFICES/BUSINESS)	218,482.799	23.20	0.40	0.090
7.	MEDIUM DENSITY	102,254.478	10.86	0.40	0.040
8.	LOW DENSITY	112,303.076	11.93	0.40	0.050
9.	PROPOSED NEW ROADS	337,677.281	35.60	0.80	0.290
	TOTAL	941,735.568	99.994		0.544

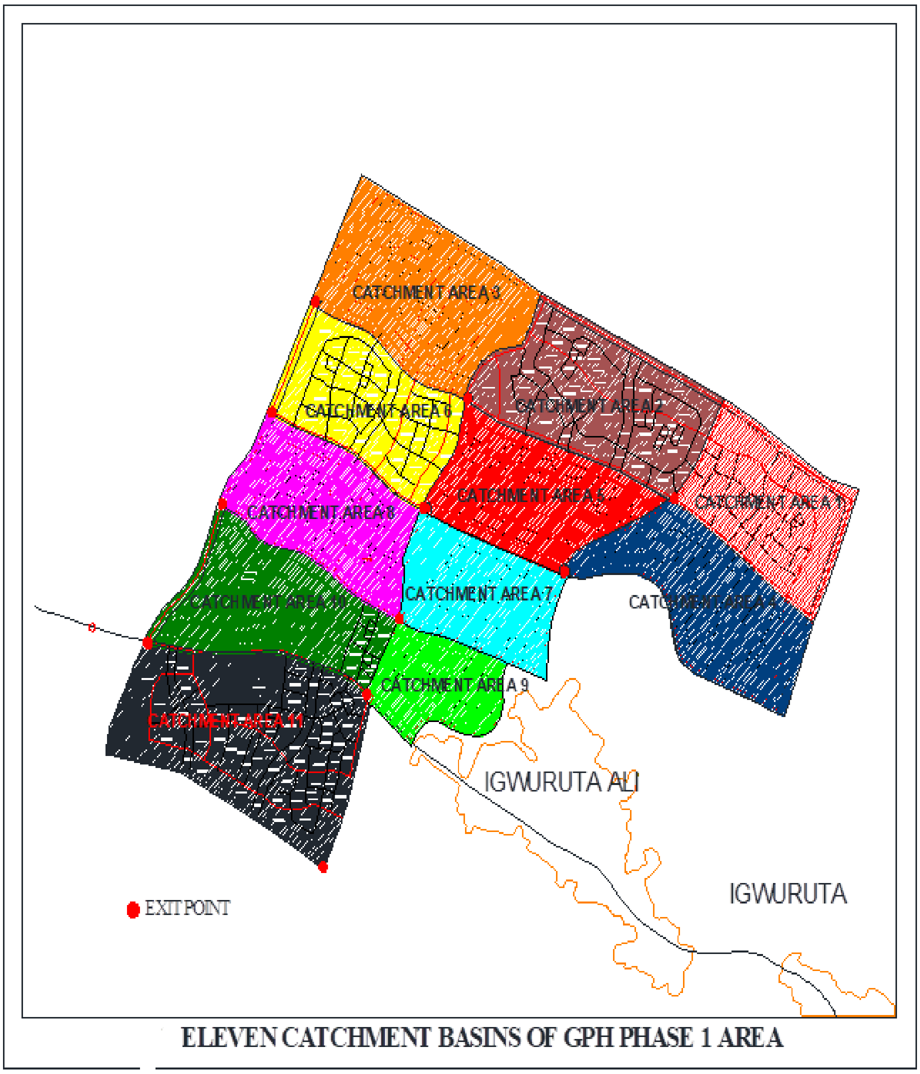

Figure 2. Catchment Basins of the Study Area

Similarly, the terrain characteristics of the study areaas shown in figure 2 expressed in a contour map and the vectorial directional flow of the surface water in the study area as shown in figure 3.It demonstrates the magnitude and direction of the moving fluid throughout the study area.The terrain shows a gentle but steady slope configuration however, it highlights the connect between the sources of flow and direction to the discharge basins. This has necessitated the analysis of the runoff parameters within the geospatially delineated basins for urban drainage design purposes. It is clear that the impact on the study area as a result of land use conversion vary in dimension and spatially. The findings underscore the fact that flood vulnerability may likely increase due to infiltration incapability due to associated paved surfaces thereby leading to increase in surface runoff (Dan-Jumbo, et al, 2018).

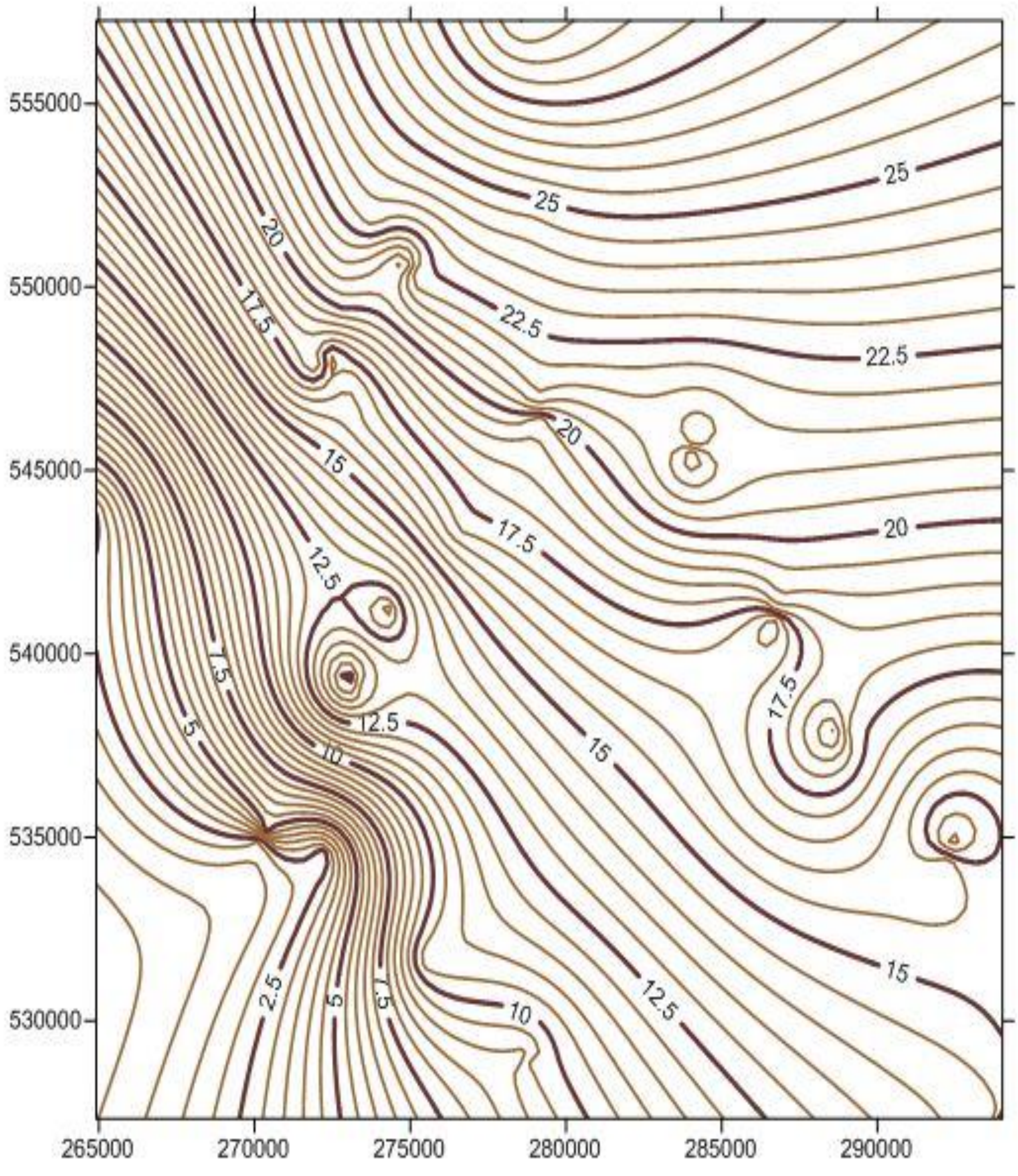

Figure 2. The Contour Map of the Study Area (GPH Area 1)

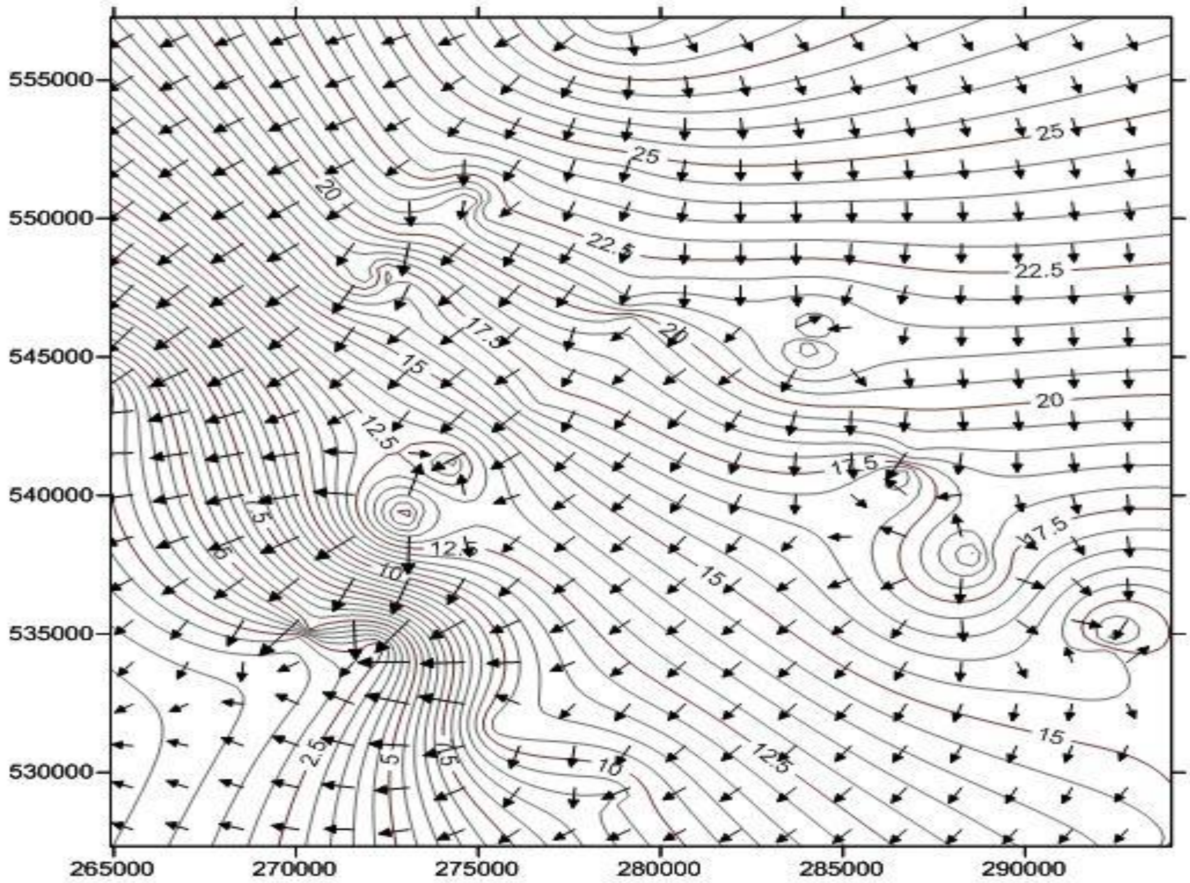

Figure 3. The Directional Surface Water Flow Diagram of the Study Area

5. Conclusion

The study area which is inundated with changes in its urban landscape is constrained with unique, dynamic and delicate wetland environment that is susceptible to flooding (Abam, 2001). The catchment basin of the study area watershed is significantly changing in land use and land cover with the loss of agriculture lands as a critical force of land use. In view of this, the runoff coefficient is important when constructing flood control structures and also for flood zone hazard delineation. A high runoff coefficient value may indicate flash flooding areas during storms as water moves fast on the earth surface to the nearby river channel or a valley floor.

Due to the loss of this land, it is important to note that when constructing flood control structures the runoff coefficient is important as a high runoff coefficient value may indicate flash flooding areas during storms as water moves fast on the earth surface to the nearby river channel or a valley floor. If proper attention is paid to this, the problem of flooding will be greatly reduced if not completely eliminated.

More so, the profiles generated as part of the requirements for the design of the canal and the associated data further confirmed that if proper attentions are paid to adequate study of environment (Malulu, 2016).

With hydrological analysis, the source of runoff water and the expected volume can be readily determined in relation to the bearing capacity of any discharge basin (e.g., the canal). Similarly, with the numerous areas identified as open spaces within the GPH Phase 1, there is a need to create water retention ponds at strategic locations and at sufficient depth to assist in the management of surface runoff. These could also serve as recreational facilities within the new city. There is a need for continuous de-siltation of the canal at regular interval to ease free flow of water and to avoid unexpected flooding.

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