COMPARATIVE EVALUATION OF HYDROLOGICAL STORM WATER DRAINS IN FUTO USING GLOBAL MAPPER 15.0 SOFTWARE

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ABSTRACT

Insufficient and inaccurate hydrological analysis of storm water drains can cause adverse effects such as flooding. This research evaluated and compares hydrological storm water drains at the Federal University of Technology, Owerri to ascertain their adequacy and accuracy using Global Mapper 15.0 software. The Topographical-cadastral survey was carried out for the study area having maximum and minimum elevation of 67 and 44m respectively, and a mean terrain slope of 1.3%. Shuttle Radar Topography Mission data of the study area were downloaded using GPS coordinates of the study area and the Digital Elevation Model of the study area was developed with Global Mapper 15.0 for hydrological analysis. The Intensity Duration Frequency curve of the catchment was developed and a return period of 25 years was used to obtain an average rainfall intensity of 228.73 mm/hr. The hydrologic design was performed and the peak discharge was obtained as 8.71m^3/s. Several hydraulic design parameters such as width b, depth d, flow velocity V, side slope Z, and bed slope S, of the modeled trapezoidal channel were calculated using the peak discharge. The result indicated the depth is 1.43 m, width of the channel is 2.85m, side slope of the channel is 1:4, and bed slope of the channel is 0.017 and a design capacity of 4.382 m^3/s. This was compared to the design parameters of the existing trapezoidal storm water drain which had a depth of 0.77 m, width of 1.03m, side slope of 1:4, bed slope of 0.017 and design capacity of 2.470 m^3/s. The design capacity of the modeled channel was 4.382 m^3/s, 1.5 times higher than that of the existing channel (2.470 m^3/s). This suggest that modeled channel would accommodate higher discharge than the existing channels due to its high design capacity, the existing drains would be insufficient to accommodate the flow discharge of the catchment area when rainfall event is heavy and has a long duration.

KEYWORDS: Digital Elevation Model; Global Mapper15.0; Intensity Duration Frequency Curve; Shuttle Radar Topography Mission; hydrology

1. INTRODUCTION

The rainfall that falls from the atmosphere at a particular location is either intercepted by trees, shrubs, and other vegetation, buildings or strikes the ground surface and becomes overland, subsurface and groundwater flow.

The relative dynamics of the hydrologic cycle in an area are determined, in large part, by the spatial and temporal nature of the rainfall patterns, temperature and atmospheric humidity regimes, soil and topographic features, and vegetative characteristics of the area. Rainfall is the primary source of water runoff (Suresh, 2012).The major task of a hydrological study is to compute design flow. There are conceptual and empirical methods for computational of design flow.

Effective planning and management of water resources requires the use of watershed models that can simulate hydrological processes. Such models, providing a framework for making appropriate decisions for sustainable management of soil and water resources in the watershed, have become an indispensable tool for studying hydrological processes (Ndulue et al., 2018).

Hydrological models are mathematical models that are governed by the laws of conservation of mass and momentum used to describe the temporal and spatial variation of a hydrological system in the field on the basis of information concerning climate, land-use/cover, soil and topography. To improve its effectiveness in terms of data representation and quality of modeling results, hydrological models are usually interfaced with Geographical Information System (GIS) environment to simulate various parameters attributed to a selected catchment (Ndulue et al., 2018).

Geospatial analytical techniques (GIS and remote sensing) are powerful tools for computation, quantitative description and assessment of morphometric parameters, thematic mapping of morphometric variables, and the application of morphometric analysis in different fields of research such as: hydrology and appraisal of environmental hazard (Ali et al., 2018). Morphometric analysis helps to infer the hydrological characteristics of drainage basins; therefore, it facilitates hydrological prospecting, assessment of the potential of groundwater recharge, and mapping of flood prone areas (Ali et al., 2018). Demarcation of flood prone areas in a catchment is carried out by drainage analysis. For a proper understanding a terrain, DEM is always developed.

Global Mapper 15.0 software is used to develop and analyze the DEM of the terrain because of its accuracy and low cost. Global Mapper 15.0 has notable benefits because it provides: (1) access to hundreds of spatial data file formats and numerous free online datasets, (2) a variety of drawing tools for creating and editing map features, (3) the ability to carry out several analysis including watershed delineation and flood zone modeling and (4) the ease of operating just at the right level of GIS functionality to satisfy both GIS professionals and mapping novices.

Hydrological data of a place can be affected over time by climate change and anthropogenic activities such as improper land use, urbanization and infrastructural installations. Such effects caused by climate change and anthropogenic activities can result in insufficient and inaccurate hydrological data. Insufficient and inaccurate hydrological data would have an adverse effect on watershed management, flood prospecting and control because hydrological data is the basic requirement for hydraulics design in the control of flood or erosion menace and water resources management.

As a result of occasional flood events that occur within the FUTO environs the need to ensure accuracy in the hydrological data of the FUTO catchment area became necessary. This is to validate any existing information on hydrological data of the drainage basin and help assess the cause(s) of hydrological extremes such as the case of occasional flood events in the environment.

2. MATERIALS AND METHODS

2.1 Study Area Description

The study area is watershed at the Federal University of Technology Owerri, Imo state, 5^0 23'11.66" N and 6^0 59'29.87 " E. It covers an area of about 24.88 kmsq. The with an annual rainfall of 1900-2900 mm and monthly minimum and maximum temperature of 25 and 35°C, respectively. Owerri is located in the rain forest zone. The rainfall is characterized by high rainfall in most of the rainy months of the year (Ogbomida and Emeribe, 2013).

Figure 1. Aerial imagery of the study area.
Source: Google-Earth pro 6.2.1.6014

2.2 Digital Imagery of the Catchment Area

To obtain an accurate description of the catchment area, the drainage area and other relevant morphometric data.

This was obtained from Google earth software, it can also be obtained through the use of Drones (Unmanned Aerial Vehicles) or any source of photogrammetric or satellite imagery. It was done by searching the location of study area with the use of its coordinates or typing in the address or location of the area in the Google-earth software and carefully mapping the out the study area.

2.3 Shuttle Radar Topography Mission (SRTM)

Using the handheld GPS (Global Positioning System) gadget, some coordinates of the catchment area were taken in terms of latitude and longitude. These coordinates were used as a base to obtain the SRTM data of the catchment area. The SRTM data was downloaded from U.S. Geological Survey's (USGS) website, the website explores the world's largest civilian collection of images of the Earth's surface.

The SRTM data was used in imported into Global Mapper 15.0 software to generate DEM of the catchment area.

2.4 Hydrologic Design

From the generated DEM the watershed delineation (dividing the watershed into sub-catchments) was further carried out using Global Mapper 15.0 software. This is to assist in the estimation of the exact runoff discharging in the drains along a drainage line or road.

Morphometric parameters of the drainage basin were also estimated with the aid of Global Mapper 15.0 software. The morphometric parameters include; area of the catchment, length of channel flow, length of overland flow, slope of channel flow, slope of overland flow. The time of overland flow and the time of channel flow were estimated on the basis of Kerby-Hatheway Method and Kirpich method respectively.

2.5 Kerby-Hatheway Method for Time of Overland Concentration

$$T_{ov} = K(L_{ov} \times N)^{0.467} \times S_{ov}^{-0.235} \quad (1)$$

Where,

T_{ov}= time of overland concentration (min)

N = Kerby roughness parameter (dimensionless)

S_{ov} = overland ?ow slope (dimensionless)

L_{ov}= Length of Overland flow

2.6 The Time of channel Concentration Using Kirpich Method

$$T_{ch} = KL_{ch}^{0.77} \times S_{ch}^{0.385} \quad (2)$$

Where,

T_{ch}= time of channel concentration (min)

L_{ch} = length of main channel flow (m)

K = Units conversion coefficient = 0.0195

S_{ch} = The dimensionless main channel slope flow (%)

Overland flow rarely occurs for distances exceeding 1200 feet (365.76 m), such as the study area with a watershed length of 527.304 m. Then a combination of Kerby's equation and the Kirpich equation may be appropriate. Certainly, the combination of overland flow and channel flow is an appropriate concept (Thompson, 2006).

Hence, to obtain the accurate time of concentration for the catchment area, Equations (1) and (2) were added together.

Thus, $$T_c = T_{ov} + T_{ch} \quad (3)$$

Where:

T_c = time of concentration (min)
T_{ov} = time of overland flow (min)
T_{ch} = time of channel flow (min)

The time of concentration thus calculated from Equation (3) was used to obtain the rainfall intensity from the Intensity Duration Frequency (IDF) curve as shown in Figure 2.

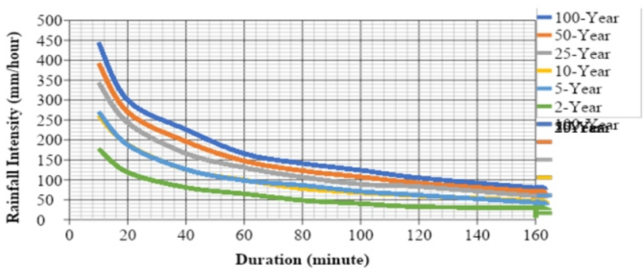

Figure 2. The developed intensity duration frequency curve for Owerri

2.7 Hydraulics Design Equations

Theses design equations were used to determine the hydraulic parameters of the modeled channel.

$$Q = \frac{CIA}{360} \quad (4)$$

Where,
Q = peak discharge (m^3/s)
C = runoff coefficient
I = average rainfall intensity (mm/hr)
A = drainage area (hectares)

From the above equation, the peak runoff of each sub-catchment was calculated.
To obtain the dimension of the structure, the Manning's formulae is employed, which is given as:

$$V = \frac{R^{2/3} \times S^{1/2}}{n} \quad (5)$$

Where,
V = minimum permissible velocity of storm water in the hydraulic structure in (m/s)
R = hydraulic radius of the hydraulic structure in (m),
S = bed or land slope of the catchment area (%), and
n = manning's coefficient corresponding to the lining material used in the hydraulic structure (obtained from standard chart for hydraulic design).

The hydraulic radius of channel, R is given as:

$$R = \frac{A}{P} \quad (6)$$

Where,
R = hydraulic radius (m)
A = cross sectional area (m^2)
P = wetted perimeter (m)

Area of trapezoidal channel is given as:

$$A = bd + Zd^2 \quad (7)$$

Where,
b = the bottom width of the channel (m)
d = depth of the channel (m)

For a trapezoidal channel, the wetted perimeter is given as:

$$P = b + 2d\sqrt{Z^2 + 1} \quad (8)$$

Where,
P= wetted perimeter (m)
b = the bottom width of the channel (m)
d = depth of the channel (m)

The discharge capacity of the channel, Q is given as:

$$Q = A \times V \quad (9)$$

Where,
Q = discharge capacity of channel (m^3/s)
V = velocity of flow (m^2/s)
A = cross sectional area of channel (m^2)

3. RESULTS AND DISCUSSION

3.1 Topographical Survey

From the topographical survey, it was obtained that the maximum elevation is 67 m, minimum elevation to be 44m, mean slope of the area as 0.013 (1.3%). The maximum length of overland flow, L_{ov}, and Length of channel flow, L_{ch} were determined for each sub-catchment using the Global Mapper software as presented in Table 1. Area of the watershed was obtained to be 40.84 ha which is the summation of the various sub-catchments that make up the watershed (Table 1).

3.2 Hydrological Analysis

Table 1. Summary of Hydrological Analysis of each sub-catchment

SC	Area (ha)	L_{ch} (m)	L_{ov} (m)	H_1 (m)	H_2 (m)	H_3 (m)	Tov (mins)	Tch (mins)	Tc (mins)	I (mm/hr)	Q (m3/s)
SC1	0.4334	60.96	85.24	62.387	62.323	60.671	16.2	3.18	19.40	250	0.12
SC2	0.2368	47.47	23.68	64.505	62.501	61.843	13.3	1.11	14.43	294	0.08
SC3	1.224	49.79	154.10	63.858	63.46	60.894	11.5	4.63	16.15	272	0.37
SC4	0.777	60.43	164.84	62.279	60.305	59.671	14.4	6.74	21.18	234	0.20
SC5	0.555	58.18	40.92	63.142	61.611	60.664	16.0	1.99	18.02	255	0.16
SC6	12.561	39.13	492.89	63.142	63.05	61.514	29.9	19.28	49.15	148	2.07
SC7	9.395	76.38	853.66	63.821	62.959	61.041	19.6	14.04	33.65	184	1.92
SC8	7.646	90.24	635.36	63.833	62.721	60.787	18.5	10.27	28.78	205	1.74
SC9	6.054	49.09	570.96	63.766	62.698	61.828	12.5	9.28	21.73	235	1.58
SC10	1.041	74.57	46.59	63.877	62.516	61.845	31.8	0.88	32.73	190	0.22
SC11	0.919	95.18	193.28	63.83	62.909	61.227	15.1	4.37	19.50	249	0.25
Total	40.8										8.71

The results of hydrological analysis of the catchment area done using Global Mapper 15.0 software can be seen in Table 1. The peak discharge obtained as 8.71 m^3/s was used in the hydraulic design of the modeled channel. This peak discharge was divided into two for the two the both sides of the road, the peak discharge used for the design evaluation becomes 4.355 m^3/s.

3.3 Hydraulic Design

Table 2. Hydraulics design parameters of modeled channel

Trapezoidal Channel for FUTO Back Gate	Units	Values
Parameters		
Channel flow depth, d	m	1.1
Channel Base Width, b	m	0.65
Mannings roughness coefficient, n		0.015
Acceleration Due to Gravity, g	m/s^2	9.81
Channel Side Slope, Z		0.25
Designed land slope, S		0.017
Wetted Area of Channel, A	m^2	1.0175
Wetted Perimeter, P	m	2.917708
Hydraulic Radius of Channel, R	m	0.348733
Channel Flow Velocity, V	m/s	4.305638
Channel Discharge Capacity, Q	m/s^3	4.381902
Froude Number, Fr		1.310984
Free Board of the Channel feet, Fb		1.541699
provided depth of channel, D	m	1.43
Free Board of the Channel in meter, Fb		0.469887
Estimated discharge, Q (one side)		4.355
Estimated discharge, Q (both sides)		8.71
Top width of the channel, T	m	2.85

The adequate dimensions of the drains were obtained using the manning's formula, hydraulic radius, area and the wetted perimeter formulas for a trapezoidal channel, adopting the trial-and-error approach.

3.4 Design Comparison

Table 3. Comparison of Existing and Designed Channel Parameters Provided both Sides of the Road

Existing Channel Parameters		Calculated Channel Parameters	
Shape	Trapezoidal	Shape	Trapezoidal
Width (top) (m) T	1.03	Width (top) (m) T	2.85
Width (bottom), b (m)	0.65	Width (bottom), b (m)	0.65
Bed slope (%)	0.017	Bed slope (%)	0.017
Velocity (m/sec)	3.57	Velocity (m/sec)	4.31
Area (m^2/sec)	0.65	Area (m^2/sec)	1.02
Peak Discharge, Q (m^3/sec)	2.470	Peak Discharge, Q (m^3/sec)	4.397
Side slope (z)	0.25	Side slope (z)	0.25
Depth (m), d	0.77	Depth, d (m)	1.43
Manning's coefficient, n	0.015	Manning's coefficient, n	0.015

From the hydraulics design, using the same parameters from the existing channel such as, the side slope, Z = 0.25, the bottom width, b = 0.65 m, the bed slope of the Channel estimated at an average of S = 0.017, and manning's coefficient of n = 0.015, there was a discrepancy between the channel depth. The existing channel has a depth of, D = 0.77 m while the calculated channel has a depth of, D = 1.43 m, and a minimum permissible velocity to avoid sedimentation of 3.57 m/s and 4.31 m/s respectively. This is evident in the difference between the estimated surface runoff of the study area of Q = 4.397 m^3/s compared with the capacity of the existing channel of Q = 2.470 m^3/s.

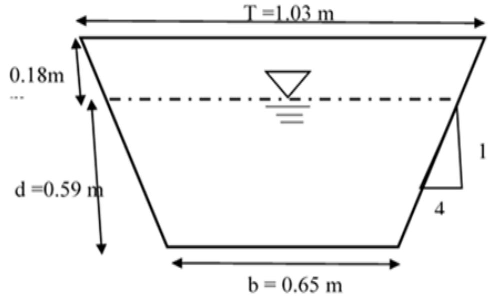

Figure 3. Existing trapezoidal channel

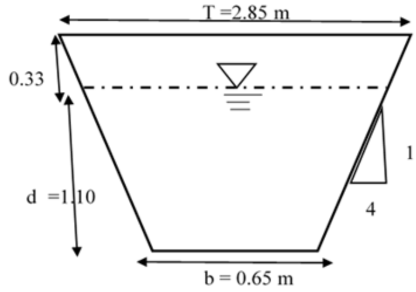

Figure 4. Calculated trapezoidal channel

4. CONCLUSION

From the field research study on the comparative evaluation of hydrological storm water drains in Federal University of Technology, Owerri using Global Mapper 15.0, the following conclusions were drawn:

The topographical survey of the study area was carried out, the results of the survey shows that the maximum elevation is 44 m, minimum elevation is 67m and the mean slope of the area is 1.3%.

Watershed analysis of the study area was also carried out using the Global Mapper15.0. From result the parameters obtained such as the mean area of the sub-catchments, the mean length of channel flow, the mean length of overland flow, mean upstream elevation for overland flow, mean downstream elevation for overland flow and mean downstream elevation for channel flow were 3.71 ha, 63.77 m, 296.50 m, 63.49 m, 62.46 m and 61.09 m, respectively.

The intensity duration frequency curve of the study area was developed. The average rainfall intensity of all the sub-catchments using a return period of 25 years was obtained as 228.72 mm/hr.

The kerby-kirpich formula was used to obtain the time of concentration of all the sub-catchments. The result shows that the mean time of concentration is 24.97 mins.

Furthermore, the results from the hydrological analysis of the study area were used to determine a peak discharge of 4.355 m^3/s on both side of the catchment using the rational formula.

Also, the hydraulic analysis was carried out using the peak discharge of $3.08 m^3/s$ to design for a trapezoidal channel section having a top width of 2.85 m, bottom width of 0.65 m, depth of 1.43 m, bed slope of 0.017 and side slope of 1:4.

The hydraulic parameters of the modeled channel were compared to that of the existing channel. It was observed that the design capacity of the existing channel which is 2.470 m^3/s did not meet up to the demand of the flow discharge which is 8.71 m^3/s. The insufficiency of the existing storm water drain is accountable for the occasional flood event that occurs within that environment.

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