DEM Computation of Flood Catchment Areas: Determining the Run-off and Maximum Discharge Time of Concentration in Uyo Urban

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Abstract
Rainfall runoff modelling is a vital and an essential paradigm in flood risk management. This research sought to determine the run-off and maximum discharge time of concentration (T_C) in Uyo Urban to help facilitate adequate and proper flood risk and management plan in the area. The topographic map and 3D surface of the catchment area were generated and the rational method employed to determine the time of concentration of runoff as well as the maximum discharge while Hydrology extension in ArcGIS 10.3 was used to model the river basin from DEM and identify locations. Detailed analysis of 39 years (1977-2015) rainfall data was recorded to determine inter-annual variability, monthly distribution pattern, mean total annual rainfall, mean maximum daily rainfall and standardized anomaly index (SAI). The computed discharge was calculated. The results of the analyses indicate a total discharge of 1573.54m^3/s and takes approximately 40 minutes of runoff time evident of prolonged rainstorms in areas like IBB Avenue as opposed to the short-lived rainfalls that causes flash floods in areas like Brook Street. This means that it takes a longer time of about 2 km to travel to the analysed site to cause flood. The study recommends the need for creation of more risk awareness and flood warning signs to further educate the people.

Keywords: *Flood; Run-off; Maximum Discharge; Time of Concentration; Uyo*

Introduction

Man's quest to recreate himself, improve survival chances and have better control over his environment has continuously and seriously degraded the environment through constant exploration, exploitation and alteration of the natural environment. Though these desires contributes to the development of man, the unwise use of land and its natural resources produce negative impact on the environment which flooding is one of them. Floods are by nature complex event caused by a range of human activities, inappropriate development, planning and climatic variability. These could be attributed to rapid urbanization and land cover change which, according to Cotugno, Smith, Baker and Srinivasan (2021) have resulted in shifting hydrographs. Similarly, Rogger *et al.* (2017) noted that urbanization along river channels without regard for the flood plain impacts the hydraulics of the river and puts infrastructure at significant risk of being flooded. As such, there is need to computing the flood catchment areas to determining the runoff and maximum discharge time of concentration (T_C). The concept of T_C is basically the time required for a water parcel to reach its outlet from the farthest hydrological point of a watershed.

Consequently, most hydrological analyses of rainfall and runoff especially in ungagged catchments by Gericke and Smithers (2014) requires catchment response time parameters as primary input, since these parameters serve as indicators of both the catchment storage and the effect thereof on the temporal distribution of runoff. In view of the aforementioned, Zolghadr *et al.*, (2022) foresaw the necessity of concentration time to estimating discharge rate and volume, generating runoff hydrographs for application in drainage projects, designing spillways and other hydraulic structures, development of flood predicting models and flood alert systems, and much other hydrological analysis and water resources management projects. Hence, surface runoff in particular is an important aspect in hydrological, geographical and engineering research and applications (Vojtek and Vojtekovà, 2016). However, if proper and accurate estimation of time of concentration (T_C) is acquired, the result may lead to accurate design of flood control structures, preparation of flood hazard maps, and enhanced adequate decisions making by the local authorities prior to flooding. Therefore, accurate estimation of T_C is crucial in the management of watersheds since the most severe floods are those caused by rainfalls with durations equal to or greater than the T_C of a watershed (Zolghadr *et al.*, 2022).

Water management projects in small and medium watersheds require the estimation of runoff characteristics. Agbola, Akanji and Tanimola (2012) posited that flooding is mainly caused by heavy and prolonged rainstorm which led to the damage of life and properties Determination of peak flows and water levels at the point of interest are often adequate measures. However, when a comprehensive study of flood routing and reservoir modelling is required, Nagy, Torma and Bene (2016) posited that design hydrographs with different return periods have to be calculated. One of the most often used parameters that describe morphology and runoff from a watershed is the time of concentration (Tc).Using rational method, Chin (2019) estimated the peak runoff rates in urban catchments. The runoff coefficient was determined based on soil and land use land cover (LULC) and the rainfall intensity assumed a constant daily rain divided by 24h.

Zolghadr *et al.*, (2022) used a two-dimensional hydraulic simulation to model the water parcel travel. An estimated T_C values were compared with the measured ones, and the relative error percentage was used to evaluate the accuracy of the result. In the empirical T_C methods, the maximum error was above 300%, and the minimum error was 6.7% for the field studied area. The relative errors of hydraulic simulation outputs were between 3 and 27%. The results showed that only three empirical methods, namely Simas and Hawkins, SCS_{lag}, and Yen and Chow had the least errors respectively equal to 6.7%, 8.660%, and 13.5%, which can be recommended for the studied area and those with similar hydrological characteristics. Moreover, hydraulic simulation was also introduced as an efficient method to determine T_C which can be used in any desired watershed.

Empirically, to improve peak discharge estimates at a large catchment and/or regional level in South Africa, Gericke and Smithers (2014) developed algorithms to estimate the catchment response time since it has a significant influence on the resulting hydrograph shape and peak discharge to incorporate the most appropriate time variables and catchment storage effects into the regressed empirical time parameter equations. In Central Sudan, Babiker and Mohamed (2017) employed Geographical Information system (GIS) and Remote Sensing to model catchment and drainage characteristics with frequency analysis of 100 years rainfall data and construction of Intensity-Duration-Frequency (IDF) curves based on Gumbel distribution. Rational model and contributing area method was used to compute a peak runoff. The result of the peak runoff for the catchment of Khor Shambat was found to be 43.2 and 45 m^3/s for the return periods 10 and 25 years respectively.

Nevertheless, Sharif *et al.*, (2016) acknowledged that remotely sensed elevation data in the form of digital elevation models (DEMs) are used to prepare inputs for hydrologic and/or hydraulic modelling. Based on the aforementioned, Psomiadis, Diakakis and Soulis (2020) used a DEM in HEC-RAS to determine flood extents from trial and error discharge quantities to match their flood maps produced from satellite and radar imagery. Suriya and Mudgal (2012) used a DEM in HEC-GeoHMS to delineate the drainage network and in HEC-RAS to perform hydraulic calculations for a sub watershed in India. Their analysis relied on precipitation gauges, which are often unavailable or unreliable in Less Developed Countries.

In Hungary, Nagy, Torma and Bene (2016) applied 14 empirical equations to determine Tc using geoinformatical tools. HEC-HMS was used to model the runoff. For direct runoff, Clark's unit hydrograph was selected. The estimates from the empirical equations for Tc were compared to the HEC-HMS calibrated values for each sub watershed. The result indicated great variation in the empirical estimates. Cotugno, Smith, Baker and Srinivasan (2021) employed remotely sensed precipitation, LULC, soil properties, and digital elevation model data to estimate peak discharge and map simulated flood extents of urban rivers in ungauged watersheds for current and future LULC scenarios. Three calculation methods for peak discharge (curve number and lag method, curve number and graphical TR-55 method, and the rational equation) were performed and compared to a separate Soil and Water Assessment Tool (SWAT) analysis to determine the method that best represents urban rivers. The analysis indicates that where field data are absent, remotely sensed monthly precipitation data from Integrated Multi-satellite Retrievals for GPM (IMERG) where GPM is the Global Precipitation Mission can be used with the curve number and lag method to approximate peak discharges and input into HEC-RAS to represent the simulated flood extents experienced.

Materials and Methods

Digital Elevation Model (DEM) on 30 by 30 meters resolution was used to extract flood pathways and topographic map of the study area. The DEM was obtained from the United State Geological Surveys (USGS). Spot Image (1 meter resolution) was acquired from GIS laboratory, University of Uyo and it was used to extract features such as roads and buildings. The list of flood prone communities (Aka Offot, Atan Offot, Effiat Offot, Afaha Offot, Ikot Okubo and Nung Oku) within the study area was determined using 2015 Satellite Imagery and the 2015 population of 32,948 being projected from 1991 population census.

Daily records of rainfall for Uyo were used to extract information on maximum daily rainfall in each year for a period of 39years. The average value of maximum daily rainfall was employed as rainfall intensity to compute the maximum runoff (discharge) in the study area (using the Rational Method). The rational formula estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient and means rainfall intensity for duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed).

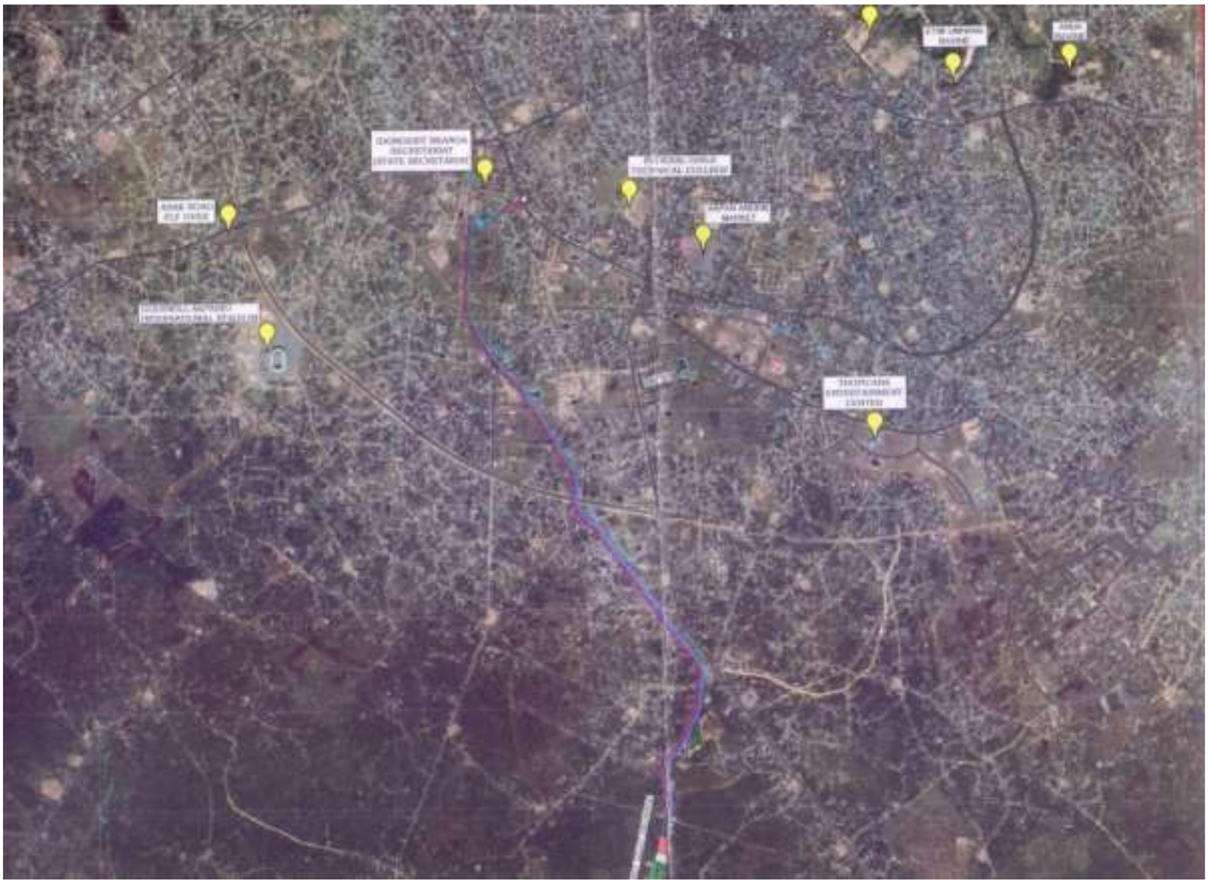

Figure 2: 2015 Satellite Imagery of Uyo Urban

$$Q = CIA \quad (Q = 0.00278CIA)$$

Where,

Q = maximum rate of runoff in m^3/s

C = runoff coefficient representing a ratio of runoff to rainfall.

I = average rainfall intensity for a duration equal to the time of concentration, for selected return period of 50 years, (mm/h)

A = drainage area tributary to the design location, ha (acres)

The maximum discharge at the study area was estimated by first computing the time of concentration of runoff (the time required for water to flow from the remotest point of the basin to the location being analyzed).

$$T_c = 0.00195L^{0.77}S^{-0.385}$$

Where

Tc = time of concentration of runoff

L = maximum length

S = slope

Results and Discussion

In order to identify the causes of flooding in the area, the runoff amounting from the maximum infiltration rate of the soil was calculated to compute the discharge in the study area. The available rainfall data at Uyo, the study area clearly indicates that there is no autographic rain gauge and hence, it was not possible to derive data for rainfall intensity. In view of the foregoing, the maximum daily rainfall for every year was determined for a period of thirty nine years (39yrs). The average value was employed to compute the maximum discharge in the study area.

Table 1: Table of Maximum Daily Rainfall (1977-2015)

Year	Total Annual	Max. Daily Rainfall/Year
1977	3855.6	180.6
1978	3270.7	170.3
1979	3825.6	180.8
1980	2860.4	157.3
1981	2426.8	102.4
1982	2442.5	123.0
1983	1599.4	93.6
1984	1878.7	83.0
1985	2132.6	97.7
1986	1904.2	95.8
1987	2251.4	133.3
1988	2115	82.7
1989	2588.5	124.2
1990	2032.8	120.5
1991	2246.7	120.0
1992	2256.8	144.5
1993	2229.5	118.8
1994	2668.7	110.1
1995	2282.0	70.0
1996	2378.4	60.6
1997	2004.0	49.0
1998	2033.8	100
1999	2945.4	96.6
2000	1904.5	76.0
2001	2317.2	111.0
2002	2341.5	110.0
2003	2194.8	87.7
2004	2221.6	135.5
2005	3030.5	161.2
2006	3373.7	151.0
2007	3513.7	102.0
2008	2505.5	130.0
2009	2725.7	155.0
2010	1934.1	148.4

2011	2782.1	110.8
2012	3879.9	141.4
2013	2951	146.0
2014	3066.9	114.8
2015	2967.6	171.7
Mean	2520.27mm	119.78mm

The first step in applying the rational method was to define the boundaries of the drainage area. A field inspection of the area was also carried out to determine if natural drainage divides have been altered. Rainfall intensity of 119.78m/hr was used. Length of longest axis was computed as 2940m from topographic map. The difference in elevation was calculated as (79-56) =23m, while bare fallow was assumed in this study. The total area was converted to hectares (4495.72ha).

Calculation for the Time of Concentration of Runoff

$Tc = 0.00195L^{0.77} S^{-0.385}$

Where,

Tc = time of concentration of runoff
L = maximum length
S = slope
L = 2940m
S = 0.22
Therefore,

$Tc = 0.0195 \times 2940^{0.77} \times 0.022^{-0.385}$
$= 0.0195 \times 468.411 \times 4.35$
$= 39.73$ mins

To calculate maximum discharge (runoff)
Q = CIA= 0.00278CIA
A= 4495.72 ha
I = 119.78m/hr
C = 1.058 having assumed bare fallow

$Q = 0.00278 \times 1.058 \times 119 \times 4495.72$
$= 1{,}573.54 m^3/s$

Assuming a rainfall duration of 1 hour,
$Q = [1{,}573.54 \times 60 \times 60]\ m^3/s$

Hence, the maximum discharge from the sub catchment is shown above for any rainfall of one-hour duration. If it rains for three hours in a particular rain event, the expected discharge will be multiplied by three. The obvious question to ask is where will this volume of runoff be discharged into? The configuration of the terrain clearly indicates that the concentration runoff in the roadside will aggravate the flood problems along IBB Avenue, Atiku Abubakar road as well as the shallow depressions at Atan, Effiat, Nung Udoe and the Federal and State Secretariat since the available drains have no discharge outlets. This associated flood problems constitute a serious environmental problem, which may include structural and erosional damage, loss of lives and property, contamination of food and other materials. In view of the foregoing, it is recommended that reservoir be constructed to accommodate the excess water.

Furthermore, to analyzing rainfall distribution in Uyo and its relationship with drainage channels, the topographic map of the study area was generated from digital elevation model (DEM). It is more or less an interfluve separating Ikpa River (Cross River Basin) from tributaries of Kwa Iboe River. The relief ranges from 82m above sea level at Ikot Oku Ubo (where the contours appear to be closely packed), particularly at the secondary school before the flyover. Parts of Effiat Offot, Atan Offot, Mbierebe Obio down to Nung Oku in Ibesikpo Asutan LGA are undulating with pronounced depressions at Nung Oku, Atan and parts of Effiat Offot (relief ranging from 29 to 64m). These depressions are particularly susceptible to flooding during rainstorms.

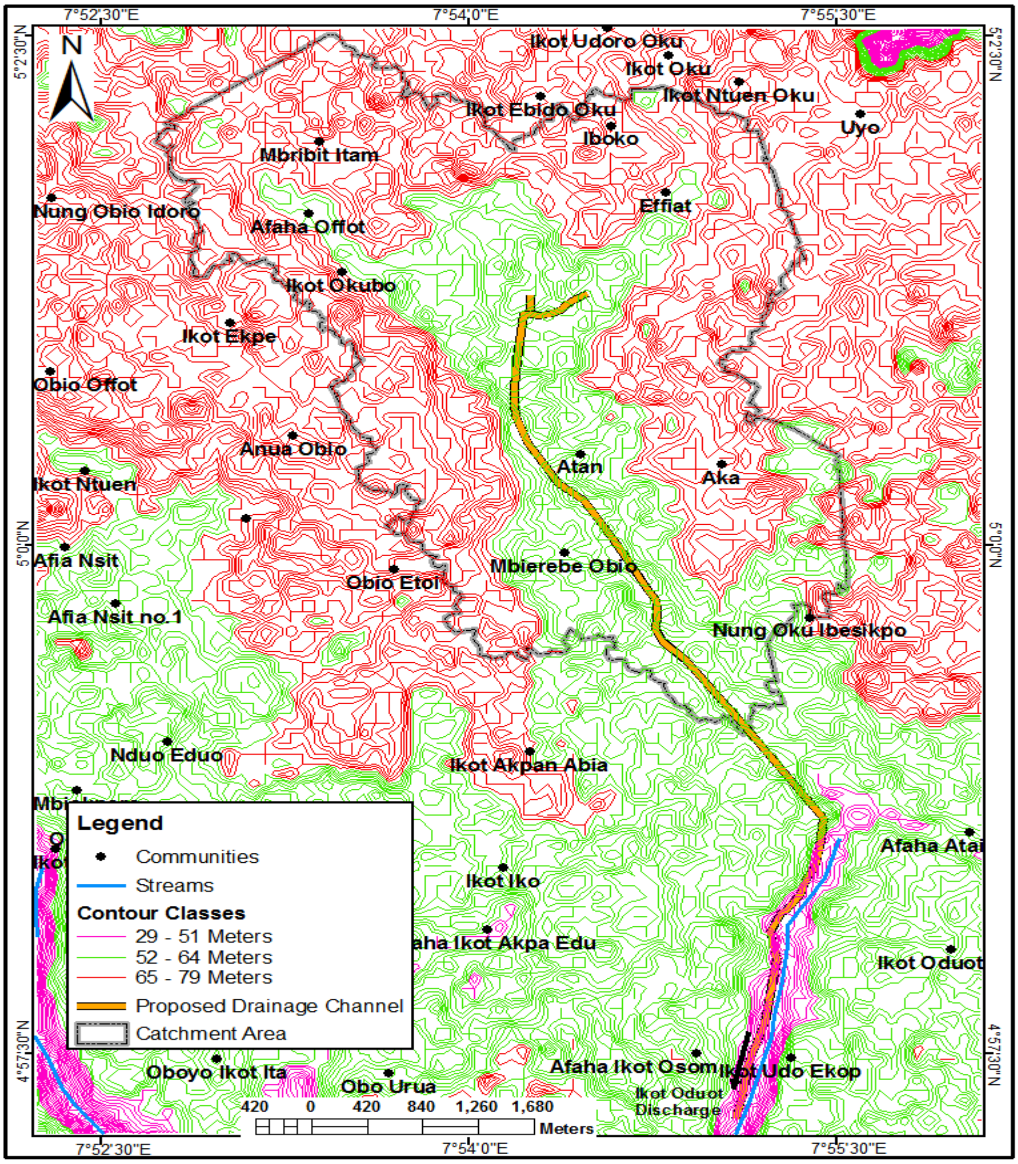

Figure 3: Topographic Map of Uyo Urban

The Topographic map generated from the DEM of the area clearly shows that the water travels at a distance of about 2 kilometres and the area that contributes runoffs to the IBB avenue is quite extensive and this explains why the area is normally flooded during high intensity rainfall particularly the prolonged rainstorms which is common during the peak of the wet season. This is significantly different from the situation in brook street where you have very shallow depression in the middle of the road and the area contributing runoffs is not that extensive as that of the IBB avenue. Most times we experience flash floods in Brook streets from short-lived rainfalls while in IBB Avenue we have the prolonged rainstorm that causes floods due to multiple event rainstorms.

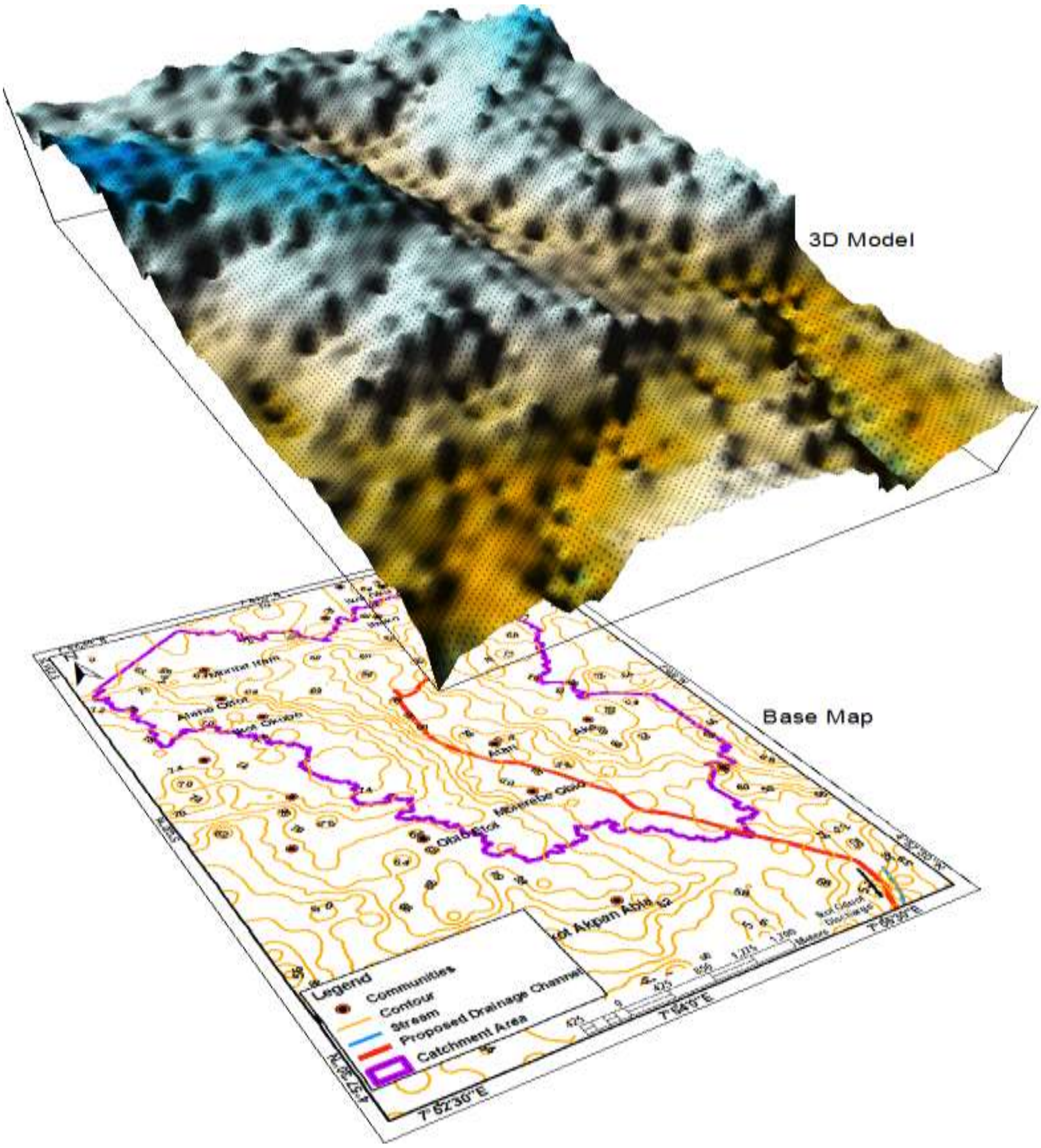

Figure 4: Digital Elevation Model of the Affected Site

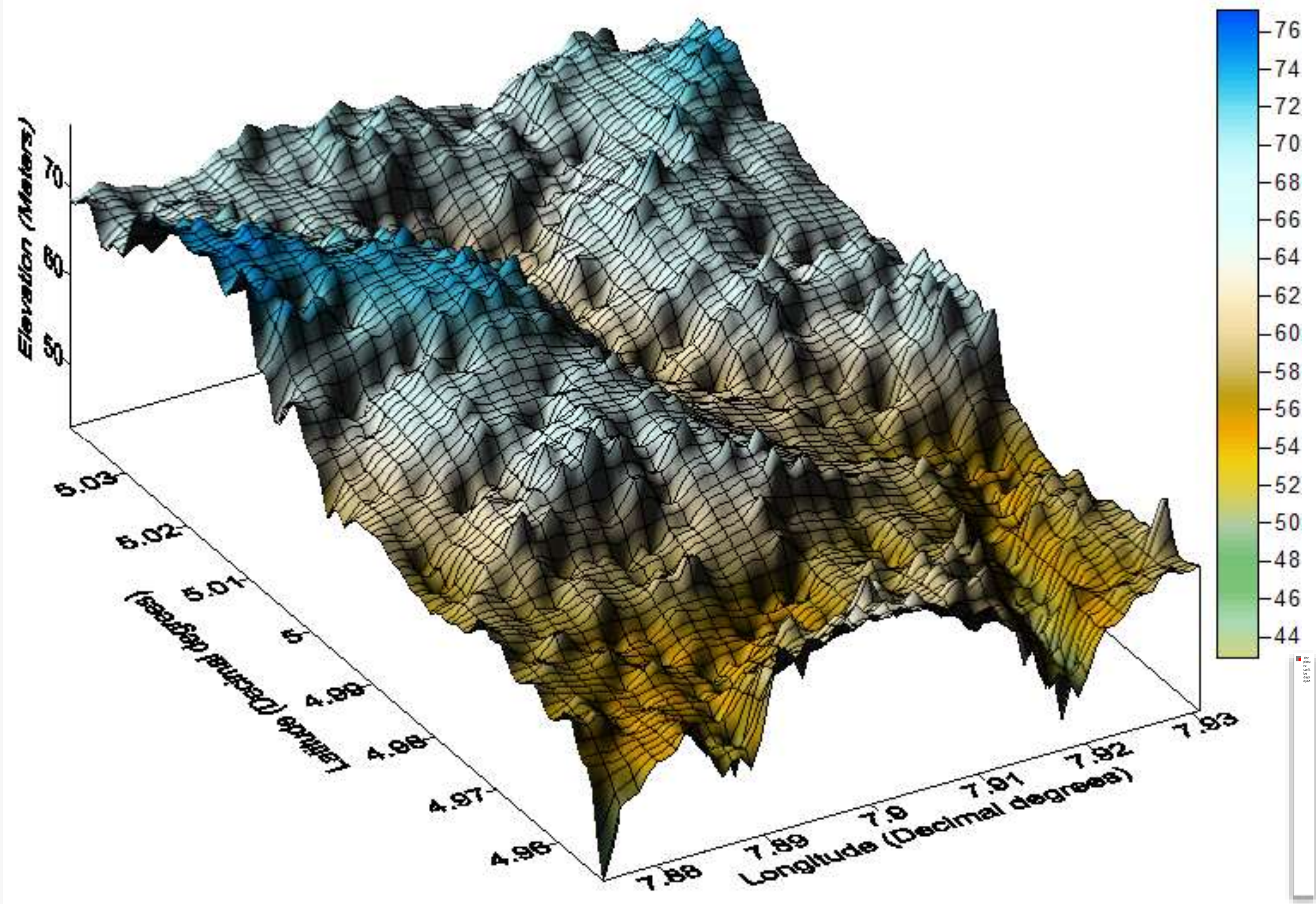

Figure 5: Digital Elevation Model of the Affected Site

The calculated time of concentration shows that it takes approximately 40 minutes of runoff time to the depressed terrain to cause flooding. This clearly states that the causes of major flooding in the study area is as a result of multiple rain events and prolonged rainfall since it takes the runoff water approximately 40 minutes to travel a long distance of about 2 kilometers to cause flooding within the analyzed sites. This affirmed and it is in line with the work of Gericke and Smithers (2014) and Zolghadr *et al.*, (2022) that catchment response time parameters is a primary input, since it serve as indicators of both the catchment storage and the effect thereof on the temporal distribution of runoff and modeling. Also, it affirmed the work of Agbola, Akanji and Tanimola (2012) that flooding is mainly caused by heavy and prolonged rainstorm which led to the damage of life and properties. As clearly stated above, this is because it takes a longer time for the runoff to travel and cause flood, obviously this is not a flash flood as flash floods are short-lived rainstorms and do not have enough time to travel to the analysed sites to cause major flooding in the analysed sites. Furthermore, according to the findings it will depict a broad hydrograph and not a sharp hydrograph as the sharp hydrography depicts flash floods and the broad hydrograph depicts prolonged rainstorms.

Finally, the study showed that the configuration of the terrain clearly indicates that the concentration runoff in the roadside will aggravate the flood problems along IBB Avenue, Atiku Abubakar road as well as the shallow depressions at Atan Effiat, Nung Udoe and the

Federal and State Secretariat since the available drains have no discharge outlets. This is in line with the work of Horton (1954) that floods in urban area occur whenever the rainfall intensity exceeds the infiltration capacity and thus, causes damages to its environment. This associated flood problems constitute a serious environmental problem, which include structural and erosional damage, loss of lives and property, contamination of food and other materials. In view of the foregoing, it is recommended that reservoir be constructed to accommodate the excess water, this was obtained using the rational method of drainage analysis.

Conclusion and Recommendation

Urbanization should come with high consideration of the natural water ways using GIS Models in order to avoid constructions on flood plains thereby causing flooding in the surrounding areas. There is need for a bottom up participation involving all stakeholders in order to aid decision makers more effectively to achieve flood hazard reduction against the top down approach where the government alone feels it has the monopoly and expertise to managing flood.

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