ASSESSMENT AND OPTIMIZATION OF DRAINAGE CHANNEL EFFICIENCY IN URBAN ROADWAYS: A CASE STUDY OF ZARIA CITY, KADUNA-NIGERIA

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ABSTRACT
This research presents an analysis of the adequacy of drainage channels of Zaria City, Kaduna to identify areas constantly affected by flood every year and hence put forward measures that will adequately cater to the incessant flood problems bothering the community. Field survey and geometrical measurement of the drainage channels were carried out and data obtained from the measurement were used for the analysis of runoff from drainage channels. There are 10 sub-catchments from which the catchment areas, composite runoff coefficients, lengths of the farthest points to the outlets, and elevations were obtained by Global Positioning System (GPS) for the computation of slopes. The parameters obtained were used as input parameters into the computer package, Federal Highway Administration's (FHWA) Hydraulic Toolbox Version 5.1 Software Program; the capacities of the existing drainage channels and the peak discharge generated in each sub-catchment were computed. The results of the study revealed that; the existing drainage have the discharge ranging from 0.15 m^3/s to 1.22 m^3/s. Also, the minimum and maximum rainfall intensities of area are 2.99 mm/hr and 281.72 mm/hr with corresponding duration of 24.00 hr and 0.08 hr respectively. This study suggests that; proper design analysis, construction, and maintenance of drainage channels be made.

Keywords: Drainage, Flooding, Erosion and Pavement Failure

INTRODUCTION
A drainage system is a series of interlinked components that conduct surface or subsurface water away from sensitive structures such as tracks, pavement, and earthworks. According to (Muhammad, 2018) the general purpose of a drainage system is similar for all transport infrastructures, however how this is achieved and the consequent risks to the transport operations are different. The principal drivers for highway drainage systems are flood and pollution prevention, and longevity of the pavement. For railways, the drivers are effective in track support and performance, and associated earthworks safety (Spink et al., 2014). The waters of the natural channels usually empty into artificial channels. In essence, all the materials constitute a nuisance as loads of the natural drainage systems empties into the artificial drainage systems. The performance of these functions depends primarily on both the competence and capability of the overland flow (Alamsyah, 2020). Urban environments are faced with major challenges of improper drainage systems which result in the flooding of many cities in Nigeria, particularly the overcrowded areas that experience rainfalls that overwhelm the capacity of the drainage systems. The system must be properly designed, built, and maintained to properly collect water, avoid disruption of the road's transportation function, maintain safe travel conditions, and sustain infrastructure. Poor drainage can direct water back into the road

and keep it from draining away (Lukman and Abdurrasheed, 2013). Too much water remaining on the surface, base, and subgrade combined with traffic action will cause potholes, cracks, and pavement failure. Even on roads built with all the proper drainage elements, neglecting periodic maintenance is likely to result in flooding, washouts, and potholes. Regular annual evaluation of drainage systems is an important part of maintaining and managing roadways (Muhammad et al., 2017).

Many areas and streets in Zaria lack proper and adequate drainage systems that can drain the increasing stormwater volume due to the rapid urbanization of the city causing flooding of the streets and roadways in many areas of the metropolis. This paralyzes traffic mobility and damages private and public properties. The state of drainage systems in Zaria has received little or no attention regarding research.

The major aim and objectives of this study include; appraising the condition of the existing storm sewers to identify areas of improvement; providing methods of solving the problems associated with the storm drains to achieve self-cleansing velocity even with the minimum dry weather flow; analyzing the working conditions of storm sewers in Zaria with the help of FHWA Hydraulic Toolbox. The Hydraulic Toolbox significantly extends the basic functionality of the historic version of the FHWA DOS Hydraulic Toolbox and Visual Urban Programs. The program allows a user to perform and save hydraulic calculations in one project file, analyse multiple scenarios, and create plots and reports of these analyses. The computations can be carried out in either CU or SI units. Twelve Analysis calculators are available for project development such as Channel, Channel Lining Design, Weir, Curb and Gutter, Median/Ditch Drop-Inlet, Rational Method Hydrologic, Detention Basin, Riprap, Rock-Sediment Gradation, Culvert Assessment, Bridge Scour and Horizontal Grade Inlet Analysis Calculator. Some modules represent a project graphically and save notes and reports with the analysis results. These results can be printed at the user's discretion (Veronica et al., 2021).

The Channel Analysis Calculator offers five channel types to choose from; Trapezoidal, Rectangular, Triangular, Circular, and User Defined Cross-Section. Each type of channel requires slightly different variables. When you select a channel type, an input window will appear. The Channel Analysis Calculator can compute the full range of hydraulic parameters for trapezoidal, rectangular, triangular, circular, or user-defined (irregular) channel shapes for a given depth or discharge. For a selected cross-section, the user is prompted for necessary input including channel side slopes, bottom width, diameter, channel slope, and Manning's n value. Hydraulic parameters are computed using the Manning Equation (Veronica et al., 2021).

Description of The Study Area

The figure 1 shows below is a study area within Zaria City, Kaduna State, Nigeria. It is approximately 670m above mean sea level. It is located on latitude $11^0 02' 57''$ to $11^0 03' 46''$N and longitude $7^0 41' 18''$ to $7^0 44' 10''$ E. It has two distinct seasons the arid season (October to March) and the soaked season (April to September). Mean annual rainfall is about 1,000mm, but inter-annual fluctuations may be high. The mean monthly temperature is about 27^0C but it is highest between the months of March and May, which represent the hot dry period. It is lowest in December/January reaching about 18^0C.

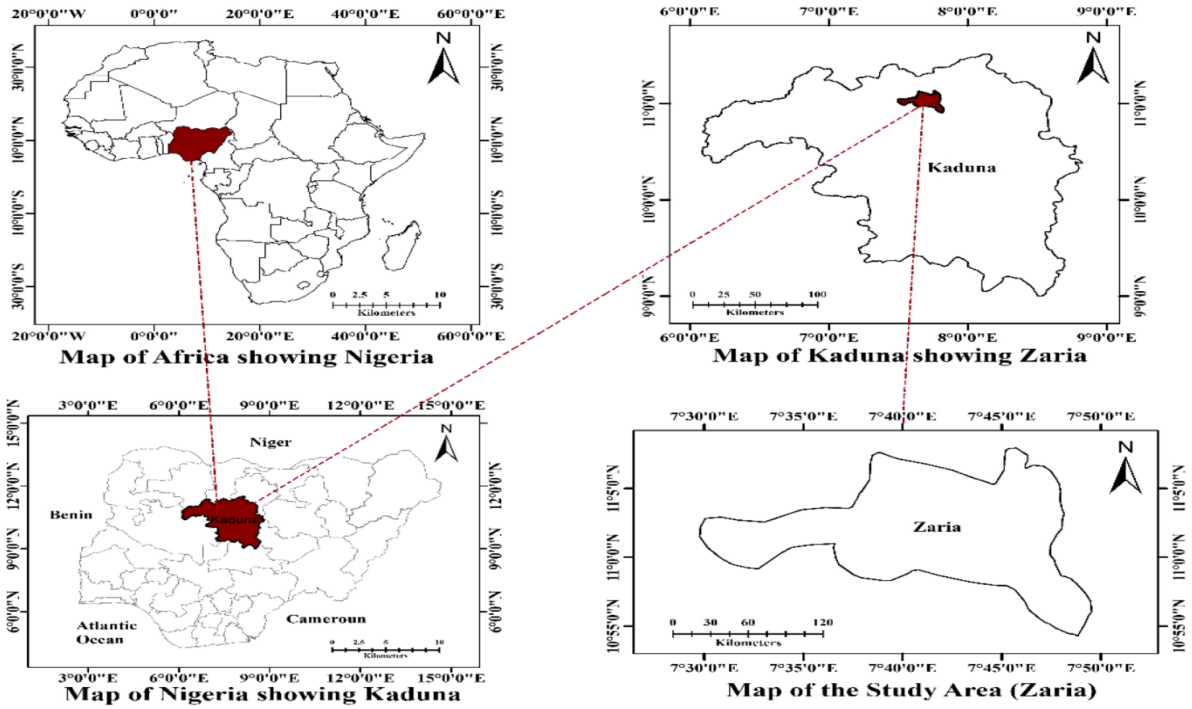


Figure 1: Study Area Map, Source: Google Earth Map

MATERIALS AND METHODS

The materials used were topographical map, location map, stopwatch, book and pen, 5m and 100m tape, iron pegs, harmer, white paint, rainfall data for period of 25 years using rain gauges (Secondary Source obtained from Department of Geography Federal College of Education Zaria) and a GIS based software. The network of drainage channels and their locations were identified using the topographical map. Thereafter, the geometric measurement (width and depth) of the existing drainage channels were measured with a tape. The length and slope parameters are determined from the topographical map and this was imported on a GIS based software which shows the drainage network and their outfalls. Observed time of concentration for channel flow was obtained through field measurement by estimating the slope and distance from the catchment, by estimating the velocity of flow from drainage channels and by calculating the time it takes to travel that distance. The selected catchment was divided into ten (10) sub areas; this was done such that the time of concentration increases from one sub-area to another. The empirical model result of time of concentration was calculated using Kirpich equation.

For a rainfall record containing several years of data, the following computations lead to the IDF curve:

1) For a given duration of time, starting with Δt, the maximum rainfall amount of each duration in each year were determined

2) The precipitation amounts, one for each year were ranked in order of magnitude and the return period T, for each precipitation amount were estimated using the Weibull formula T= n +1/m.

Where n is the number of years of data and m is the rank of the data corresponding to the event with return period.

3) Steps 1 and 2 were repeated with the duration increased by Δt. A maximum duration of 5mins was used in this study.

4) For each return period, the precipitation amount was divided by the duration in order to obtain the average intensity, this was plotted against the duration for each return

period using Microsoft excel to yield the IDF curve.

Theoretical Approach

The existing drain capacities were computed using the FHWA Hydraulic Toolbox Program; which is a standalone suite of calculators that performs routine hydrologic and hydraulic computations.

The following steps were used for the design of drainage channel analysis. Therefore, average runoff coefficients were calculated using Equation 1 below:

$$\mathbf{C_{avg.}} = \frac{\sum CnAn}{An} \quad \text{..... (1)}$$

Where;

C = Runoff coefficient

A = Catchment area

n = Number of successions

The time of concentration was determined with Equation 2:

$$T_c = 0.0195 L_{\max}^{0.77} S_{av}^{-0.383} \quad \text{..... (2)}$$

Where;

T_c = Time of concentration (min)

$L_{\max}$ = Maximum length of flow in the catchment (m)

S_{av} = Average gradient of the catchment area

Intensity Duration Frequency (IDF) curves describe the relationship between rainfall intensity, rainfall duration, and return period. IDF curves are commonly used in the design of hydrologic, hydraulic, and water resource systems (Yabin et al., 2019). According to (Ewea et al., 2016) to know which value to take from the IDF curve, the time of concentration has to be calculated.

This daily rainfall record is a result of the close organization of the Department of Geography Federal College of Education Zaria for 25 years from 1996 to 2020.

The rainfall analysis was done via data from 1996 to 2020 using the Gumbel (Type I) distribution method. Also, with analyzed rainfall data the IDF curve relationships were developed in Figure 3 below, and the intensity was estimated from the curve.

The amount of stormwater the catchment will produce was determined by the FHWA Hydraulic Toolbox software program, based on the well-known rational method analysis. That is equation 3 shown below:

$$\boldsymbol{Q = \frac{CIA}{360}} \quad \text{..... (3)}$$

Where;

Q= Design peak runoff rate (m^3/s),

C = Runoff coefficient,

I =Rainfall intensity (mm/hr.),

A =Surface area of the catchment area (hectare).

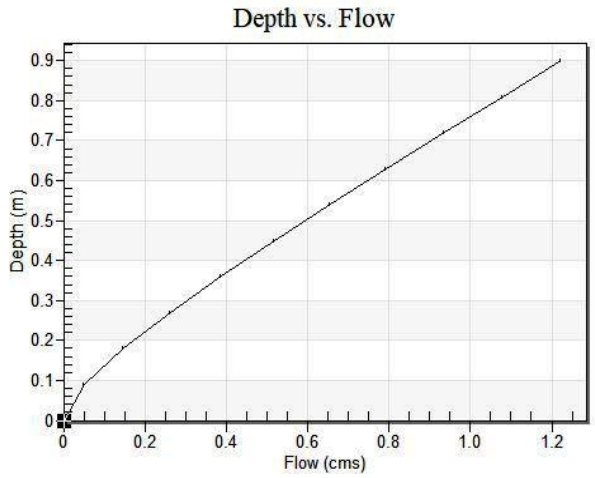
RESULTS AND DISCUSSION

RESULTS

The capacities of the existing drains were computed after analyzing the dimensions using the FHWA Hydraulic Toolbox and the result is as shown in Table 1 below:

Table 1: Summary Table of Existing Drainage Analysis

Drainage Line	Type	Top Width TW(M)	Bottom Width BW(M)	Depth D (M)	Length L (M)	Slope	Discharge (m^3/s)
Line 1	Rectangular	0.7	0.7	0.9	4700	0.0040	1.2
Line 2	Rectangular	0.7	0.7	0.4	2400	0.0042	0.5
Line 3	Trapezoidal	0.9	0.3	0.3	2700	0.0067	0.3
Line 4	Rectangular	0.5	0.5	0.4	1200	0.0100	0.4
Line 5	Rectangular	0.6	0.6	0.5	600	0.0250	1.2
Line 6	Rectangular	0.6	0.6	0.5	1775	0.0045	0.5
Line 7	Trapezoidal	0.8	0.5	0.4	2300	0.0087	0.9
Line 8	Trapezoidal	0.9	0.4	0.3	2200	0.0009	0.1
Line 9	Rectangular	0.4	0.4	0.2	800	0.0363	0.3
Line 10	Rectangular	0.6	0.6	0.4	300	0.0067	0.5



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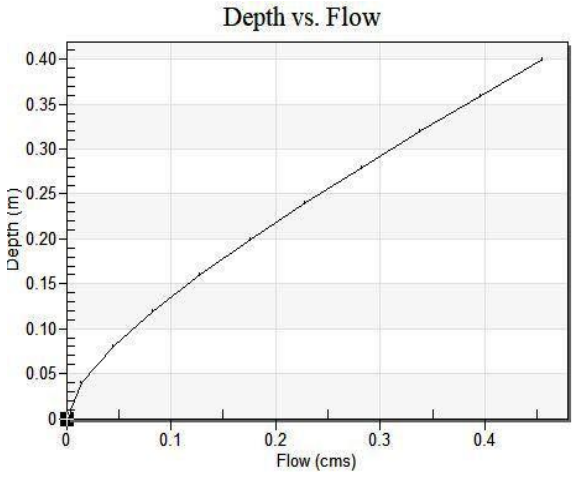

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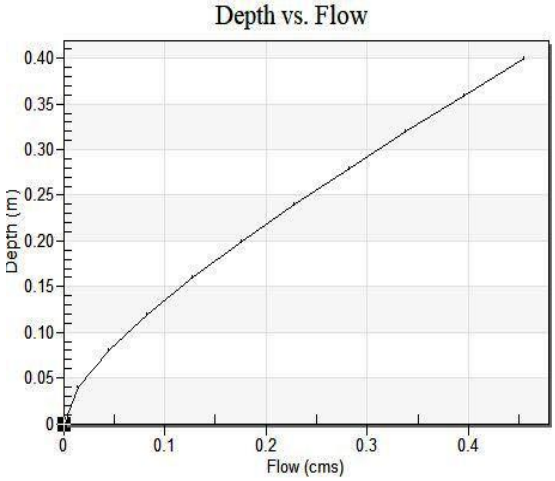

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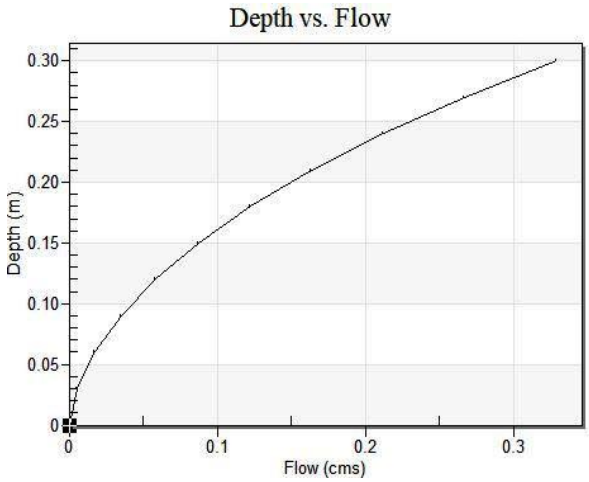

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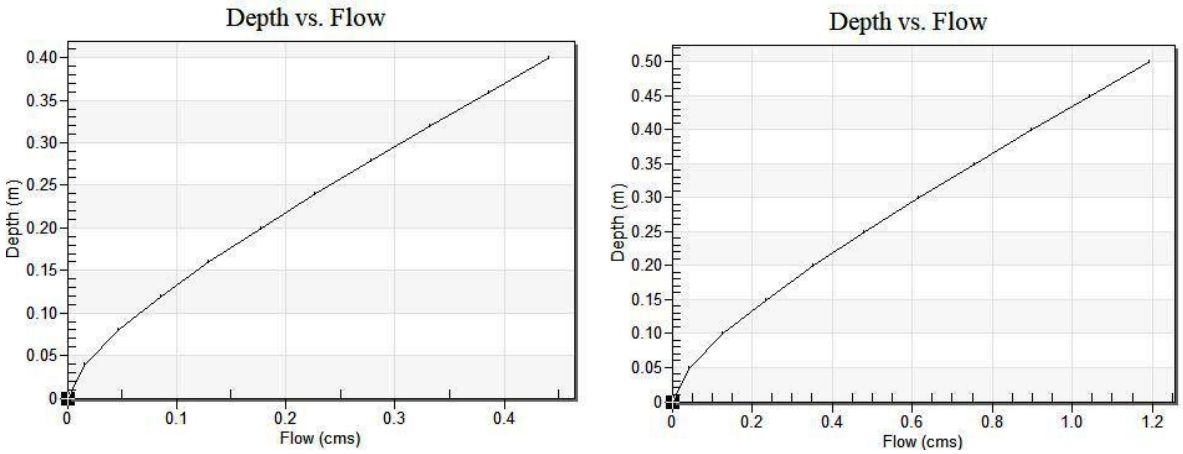

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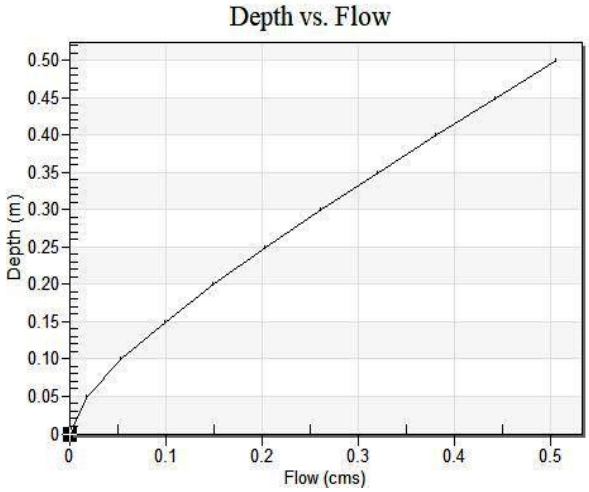

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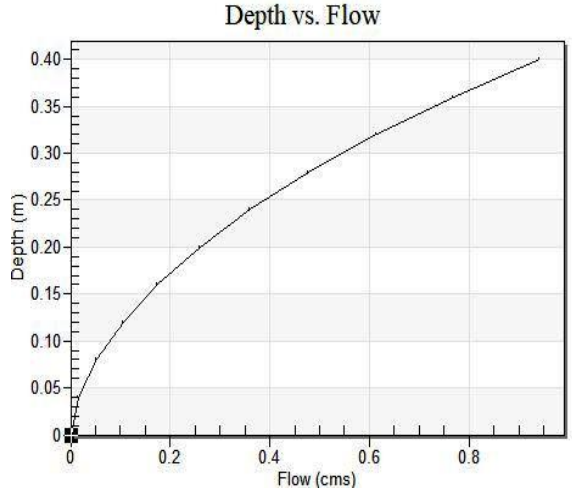

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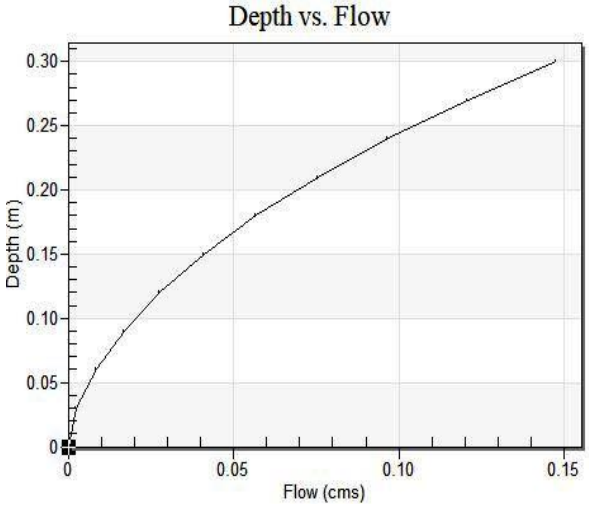

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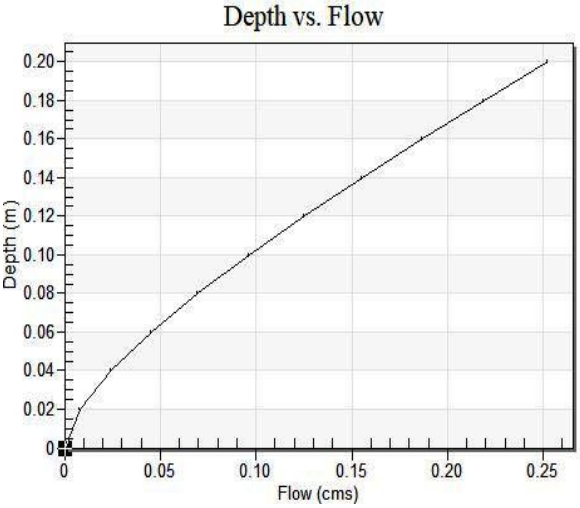

(10)

Figure 2: Depth vs. flow curve for existing drainage line 1-10

Figure 2; shown above is the curve plotted of depth versus flow curve for the existing drainage for all ten (10) Lines. Then, from the curve shown, as the depth increases the flow will also increase.

Table 2: Intensity Duration Frequency Curve Development

Duration (min.)	Duration (hr.)	Intensity for given return periods (mm/hr.)					
		2years	5years	10years	25years	50years	100years
5	0.08	124.76	158.71	181.19	209.59	230.66	281.72
10	0.17	104.97	133.54	152.45	176.35	194.07	232.38
15	0.25	90.34	114.93	131.21	151.77	167.03	204.00
30	0.50	64.53	82.09	93.72	108.41	119.31	145.72
60	1.00	41.66	52.10	60.50	69.98	77.02	94.07
120	2.00	24.95	31.74	36.24	41.92	46.13	56.34
360	6.00	10.07	12.82	14.63	16.92	18.63	22.75
720	12.00	5.52	7.02	8.01	9.26	10.20	12.45
1440	24.00	2.99	3.80	4.34	5.02	5.52	6.75

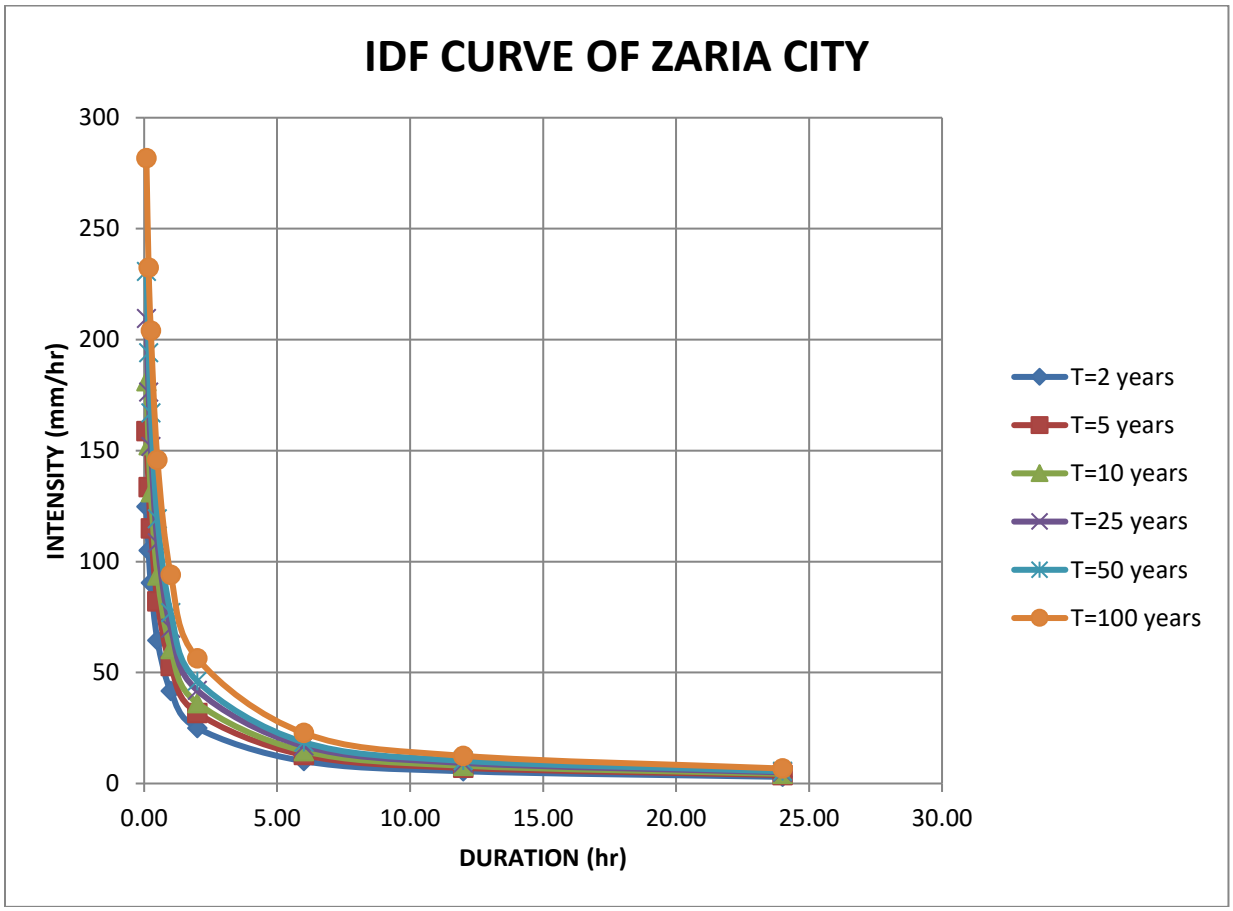

Figure 3: Developed IDF Curve of Zaria Rainfall (1996 – 2020)

Table 3: Summary Table for Calculation of Peak Discharge

Sub-Catchments	Time of Concentration T_c(min.)	Runoff Coefficient C	Rainfall Intensity $I_{25Years}$(mm/hr.)	Area A(ha)	Area A(km^2)	Discharge Q(M^3/S)
S_1	108.62	0.53	40.00	21.00	0.210	1.2
S_2	65.55	0.50	60.00	13.00	0.130	1.1
S_3	58.20	0.51	65.00	10.40	0.104	1.0
S_4	26.70	0.50	100.0	14.00	0.140	1.9
S_5	11.04	0.41	120.0	16.50	0.165	2.3
S_6	49.06	0.50	70.00	12.20	0.122	1.1
S_7	46.53	0.48	75.00	15.00	0.150	1.5
S_8	107.21	0.56	40.00	9.00	0.090	0.6
S_9	11.94	0.55	120.0	10.50	0.105	1.9
S_{10}	10.72	0.48	120.0	12.00	0.120	1.9

DISCUSSION

In this study, the rational method was adopted in estimating the volume of runoff. Manning's equation was adopted in assessing the stormwater drains for a catchment area. The area was divided into ten (10) sub-catchments as Lukman and Abdulrrasheed (2013). The capacities of existing drainage were evaluated as 1.2 m^3/s, 0.5 m^3/s, 0.3 m^3/s, 0.4 m^3/s, 1.2 m^3/s, 0.5 m^3/s, 0.9 m^3/s, 0.1 m^3/s, 0.3 m^3/s and 0.5 m^3/s. Then, table 2; presented the Intensity Duration Frequency Curve Development of annual 24 hours heaviest rainfall data for twenty-five years in Zaria. It was observed that the average rainfall intensity of Zaria and its environs over the twenty-five years was calculated to be 87.66 mm/hr. Then, for the purpose of analysing the effects of precipitation in the catchments area in respect to erosion and floods, the mean monthly rainfall of the months of July, August and September over a period of twenty-five years (1996 to 2020) was used as adopted by Yabin et al., (2019).

Also, the estimated flow for the sub-catchment areas are 1.2 m^3/s, 1.1 m^3/s, 1.0 m^3/s, 1.9 m^3/s, 2.3 m^3/s, 1.1 m^3/s, 1.5 m^3/s, 0.6 m^3/s, 1.9 m^3/s and 1.9 m^3/s as compared to other researchers on the literatures review. They are designed such that the drain capacity will be adequate and economically sufficient at peak discharge.

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This study considered the working conditions of drainage channels along selected roadways in the Zaria metropolis. It was observed that most of the existing drainages were not properly designed and constructed.

The capacities of the existing drains were computed after analyzing the dimensions using the FHWA Hydraulic Toolbox Version 5.1 Program; it computes flows based on the well-known formula Manning's equation.

The results of the study revealed that;

1. All the ten (10) existing drainage lines have a discharge range from 0.15m^3/s to 1.22m^3/s.
2. Also, the minimum and maximum intensities of the study area are 2.99mm/hr and 306.00mm/hr respectively with the corresponding time of concentration.

3. It has been evident from the findings of this research work that the estimated flow for the various sub-catchment areas are $1.2m^3/s$, $1.1m^3/s$, $1.0m^3/s$, $1.9m^3/s$, $2.3m^3/s$, $1.1m^3/s$, $1.5m^3/s$, $0.6m^3/s$, $1.9m^3/s$, and $1.9m^3/s$.
4. As runoff rates exceed the conveyance capacity of the drainage system, then street flooding and erosion will eventually happen. Stormwater drainage are part of the essential infrastructure of a modern town.

RECOMMENDATIONS

The field studies and engineering analysis of the stormwater problems have indicated that engineering structural control measures are the only feasible solution to the problems. Consequently, to ensure a sustainable and efficient drainage system.

The following recommendations were made;

1. All the drainage channels shall be re-design as rectangular shape

2. The drainage channels shall be constructed of concrete with wire mesh reinforcements

3. The channels are to be interconnected down to the main stream (final discharge point)

4. Proper and frequent maintenance of the drainage facilities shall be considered.

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