Assessment of Existing Drainage Facilities with an Intensity Duration-Frequency Curve for the Purpose of Storm Water Management in Ilorin Metropolis

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Abstract:

Drainage channels are critical facilities necessary for the conduit and proper transportation of surface run off, with its effectiveness comes storm water management, this is because without the drains the water can become a major hazard as flooding instead of a blessing inform of rainfall precipitation. This study has evaluated the existing drainage facilities in Ilorin metropolis for the purpose of storm water management. The approach used are; preliminary data collection, reconnaissance survey, field work and data computation. This was followed by a desk study of fall data to produce an IDF curve, analysis of the drains based on the intensities obtained and report writing. Results obtained revealed that most of the existing drainage facilities in Ilorin metropolis were functioning below capacity hydraulically, in terms of discharge, area and velocity. And this makes the surrounding environment prone to flooding. Area and velocity are two of the most seriously affected hydraulic parameter in the study area with percentage difference of 10% in most study area.

Keywords:
Evaluation, Drainage, Storm water management, Intensity Duration Frequency Curve (IDF)

1. Introduction

Drainage network is the pathway in which storm water or runoff follows flow path before getting to a receiving water body (Raji et al. 2017) it serves as the

conduit for channeling and moving storm water under a time of concentration to a given outlet. Rainfall intensity is a measure of the amount of rain that falls over time. The intensity of rain is measured in the height of the water layer covering the ground in a period of time i.e. If rain stays where it falls, it would form a layer of a certain height (Floodsite Project, 2008). Intensity-Duration-Frequency (IDF) curves describe the relationship between rainfall intensity, rainfall duration, and return period (or its inverse, probability of exceedance). IDF curves are obtained through frequency analysis of rainfall observations and are commonly used in the design of hydrologic, hydraulic, and water resource systems (Collins, 2008).

The principal characteristics of storm water are its intensity, duration, total amount and frequency or recurrence interval. The intensity is an important characteristic of rainfall because soil erosion is caused by rainstorm of high intensity. Rainfall duration is the period that rain falls at a particular rate or intensity, for every storm the rainfall intensity may vary from high to very low; generally, the high-intensity portion of a storm has a shorter duration than the low-intensity portion (Okonkwo and Mbajiorgu, 2010). The runoff been utilized in the intensity duration frequency process represent that portion of the rainfall that is not evaporated, it is the portion of rainfall that runoff into river or ocean as surface or subsurface flow.

The generation of runoff and its distribution from a drainage basin is affected to a great extent by precipitation, infiltration, evaporation, transpiration, interception, and depression storage. Storm water is water from rain and melting snow and ice (Bobbi et al. 2014), According to the United States Environmental Protection Agency (EPA) Storm water management is the effort exercised to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality. It means to manage surface runoff.

Flooding occurs when the amount of rainfall exceeds a certain amount normal for a given region, and is capable of causing significant environmental consequences. Flooding remains the most common of all environmental hazards worldwide. Flooding can be reduced by studying and plotting of an intensity duration frequency (IDF) curve (Nwachukwu et al, 2018). The occurrence of flooding is due to the lack of storm water management. This study attempts to evaluate drainage facilities and prevent for the purpose of storm water management.

1.1 Description of Study Area

Ilorin is the state capital of Kwara state, as of the 2006 census, it had a population of 777,667 making it the 6th largest city by population in Nigeria. Ilorin is located at latitude $8^0$30'N and longitude $4^0$33'E. Ilorin comprises of three local government areas namely; Ilorin East, Ilorin South, and Ilorin West. It has a humid tropical climate which is characterized by wet and dry seasons. Rainy season in the region begins towards the end of March and ends around October with two peak periods in June and September (Iroye K.A 2017).

2. Materials and Methods

This research is based on assessing existing drainage facilities in Ilorin metropolis with an intensity duration frequency (IDF) curve for the purpose of storm water management. The assessment involved field and desk works. The field work involved a preliminary survey which lead to acquiring a first-hand information about the drainage condition. A tape rule was used to measure the hydraulic characteristics (breadth and depth) of the drainage channels through which the drainage area was evaluated. The d This research is based on assessing existing drainage facilities in Ilorin metropolis with an intensity duration frequency (IDF) curve for the purpose of storm water management. The assessment involved field and desk works. The field work involved a preliminary survey which lead to acquiring a first-hand information about the drainage condition. A tape rule was used to measure the hydraulic characteristics (breadth and depth) of the drainage channels through which the drainage area was evaluated. The desk study involved the analysis of rainfall data using IDF curve and rational method to obtain the expected discharge and area of the drainage facilities

The methodological tools for this project consist of a Tape rule, Arc Gis software, Microsoft excel and Google Earth software. A tape rule was used in measuring the depth, width of the drainage facilities. Google earth is a virtual globe, map and geographical program. It maps the earth by superimposing of images obtained from Satellite Imagery, Aerial Photography and Geographic Information System (GIS) 3D globe it was used in obtaining satellite imagery for all the study area. Arc GIS is a geographical information system for working with maps and geographic information. It is used for creating and using maps, it was used in delineating the watershed shed area for the drains in the study area. Microsoft Excel is a spreadsheet software developed by

Microsoft windows, macOs, Android and iOS, it features calculation graphing tools, was used to display and obtain the rainfall intensity and to report obtain and accurately reflect rainfall data and for the final development of the IDF curve.

2.1 Reconnaissance Survey

A reconnaissance survey was carried around Ilorin metropolis to identify namely Ilorin east, west and south region. Ilorin east which is on latitude $8^0$34' 16.3'' (8.5712^0) North and longitude $4^0$43'41.8'' (4.72838^0) East and Ilorin south which is on latitude 8.4347^0 N and longitude 4.6657^0E. Identification of drainages with faulty and weak condition which could be evaluated. In studying the location and getting information three mediums were utilized under both primary and secondary sources, for the primary source the following methods were used.

2.2 Collection of Relevant Data

Rainfall data particular to Ilorin metropolis was gotten from first the Nigerian Meteorological Agency (NIMET) office in Kwara state to plot the intensity duration frequency (IDF) curve and obtain the rainfall intensity that was used in computing the expected discharge with the rational formula. Data concerning the drainage standard dimension were obtained from Kwara State ministry of works which was used in obtaining the percentage difference in the drainage channel (standard dimension for drainage network is given as 0.6m by 0.6m). The measured area was gotten from the multiplication of the depth with the width because it was a rectangular channel.

2.3 Computation of IDF Curve

The Intensity Duration Frequency Curve was gotten by plotting the rainfall intensity against the time duration which was for a forty years period, on two years return period. The selection of a two years return period is used because drainage channels are constructed on two years return period (Needhididasan et al,2013). The IDF curve was generated from the following stages

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I. Rainfall data for 40 years was obtained from NIMET and displayed in Microsoft Excel. Forty years data was chosen to have a wide range of data to work with at various possibilities
II. The annual maximum daily rainfall from each year was obtained, and the peak rainfall for each year was identified.
III. The empirical plotting method was used to obtain the frequency analysis curve based on exceedance probabilities and Time of concentration (Collins 2008)
IV. The hourly rainfall at different hours (0.03hrs, 0.06hrs, 0.08hrs, 0.5hrs, 1hr, 2hrs, 4hrs, 6hrs and 24 hrs were chosen to understand the rainfall pattern under various time of occurrence. According to Bhatt and Gohil (2014) the formula for obtaining hourly rainfall which was used in the project is given below in Equation 1

$$P_t = P_{24}\left(\frac{t}{24}\right)^{\frac{1}{3}} \quad (1)$$

(Bhatt and Gohil, 2014)

Where, P_t = the required rainfall depth in mm at t-hr duration, P_{24}= the daily rainfall in mm, t = the duration of the rainfall for which the rainfall depth is required in hr

i. The rainfall duration in hrs was plotted against the rainfall intensity in mm/hr
ii. The rainfall intensity was obtained from the hyetograph based on the time of concentration which is given in Equation 2

$$T_C = 0.02\, L^{0.77} S^{-0.385} \quad (2)$$

Where Tc is the time of concentration, L is the length of drainage channel, S is the slope. The rainfall intensity obtained provide a base and intensity as a function that can be utilized in the rational it serves as "I" which is needed to obtain Q as discharge from C I A

Computation of the Expected Discharge

The Rational method was used in computing the expected discharge, which is given by Equation 3. the discharge serves as a product of the intensity (I) Coefficient (C) and Area (A). This is the discharge that is expected from the precipitation

$$Q=CIA \quad (3)$$

Where; Q is the discharge in m^3/s. C is the runoff coefficient. I is the intensity of the rainfall for the given time of concentration T_c. A is the area of the drainage channel. The rational formula was used for drainage channel less 200 arces or less than 8000sq.meters (OBOT 2014). The runoff coefficient, C, is expressed as a dimensionless decimal that represents the ratio of runoff to rainfall. Except for precipitation, which is accounted for in the formula by using the average rainfall intensity over some time period, all other portions of the hydrologic cycle are contained in the runoff coefficient. Coefficient of Runoff for the Rational Method and for Various Areas and types of Surfaces is given in the table 1(Boumen 2009).

Table 1: Runoff coefficient for Rational Formula..

Description	Coefficient
Business areas depending on density	0.70 to 0.95
Apartment- dwelling areas	0.50 to 0.70
Single- family areas	0.30 to 0.50
Parks, cemeteries, playgrounds	0.10 to 0.25
Paved streets	0.80 to 0.90
Watertight roofs	0.70 to 0.95
Lawns, depending on surface slope and character of subsoil	0.10 to 0.35

(Boumen 2009)

Hence the drainage area A, was determined from the satellite imagery map which includes the drainage area of interest, namely drainages in two Ilorin east, two in Ilorin West and four in Ilorin south. Boundaries determined for the drainage areas to be evaluated and was done by using the map scales on Arc GIS software from satellite imagery. Therefore with the intensity, coefficient and area the discharge can be computed as in Equation 3 **(**Q= C I A)

2.4 Computation of Observed Discharge drainage

Observed discharged was gotten from the product of the flow velocity of the drainage channels and the area using Equation. 4;

$$Q=VA \quad (4)$$

Where, Q is the discharge in m^3/s, V is the velocity in m/s and A is the area in m^2 The area already obtained via the reconnaissance survey as a product of

the depth y and width b due to the rectangular nature of the channel (Needhididasan et al, 2013) in Equation 5

$$A = by \tag{5}$$

While the velocity was obtained using manning's equation in Equation 6,

$$V = \frac{1}{N} S_2^1 R_3^2 \tag{6}$$

Where V is velocity in m/s, N is Roughness coefficient, S is Slope of the drainage channel and R is hydraulic radius.

$$R = \frac{Area}{Wetted\ Perimetet} \tag{7}$$

The area is a product of the depth and width in Equation 5.
The wetted perimeter in Equation 8;

$$\text{Wetted Perimeter} = 2y+b \tag{8}$$

Where y is the depth of the channel and b is the channel width in meters The Table 2 shows the recommended surface roughness value;

Table 2 Surface roughness for manning's equation

Surface Description	**N**
Smooth, impervious surface	0.02
Smooth, packed bare soil	0.1
Poor grass, cultivated row crops of moderately rough bare soil	0.2
Pasture or average grass	0.4
Deciduous Timberland	0.6
Timberland with deep forest litter or dense grass	0.8

(Watershed Modelling System WMS 2O17)

2.6 Analysis of Result

The observed area obtained via measurement on the study area site will compared to the area obtained via the delineated map. The discharge obtained

from the measured area will be compared with the discharge gotten from the rational formula. The velocity gotten from the measured study areas via manning's also will be compared with the velocity obtained as a result of the discharge obtained from the map and the velocity

The purpose of the analysis is to establish the capacity of the drain system in terms of velocity, area and discharge which reveals if the drain functions within, below or above capacity.

3. Results And Discussion:

3.1 Collection of Relevant Data

The hydraulic features tells and completely describes the drainage system hydraulically. For this research work a rectangular channel was used and their hydraulic parameters comprises of the depth y and the width b that generates its area given by Equation 9

$$A=b*y \tag{9}$$

Where, A is area in m2, b is width in m and y is depth

The area obtained from the various study area are given in Table 3 to show the difference from the standard area dimension gotten from Kwara State Ministry of works. A standard of 0.6m by 0.6m was obtained with area of 0.36m2 obtained and used in comparison. The measured hydraulic feature was done during the reconnaissance survey. A reconnaissance survey was carried out in four point in Ilorin South, two points in Ilorin West and Ilorin East

Ilorin South

Table 3: Measured hydraulic data Ilorin South

Tipper Garrage Tanke Ilorin South			Standard Dimension			% Difference
Depth y(m)	Width b (m)	Area b*y (m^2)	Depth y(m)	Width b (m)	Area y*b (m^2)	%Difference
0.530	0.625	0.331	0.6	0.6	0.36	7.986

Sanrab Tanke Ilorin South			Standard Dimension			%Difference

Depth y(m)	Width b (m)	Area b*y (m^2)	Depth y(m)	Width b (m)	Area y*b (m^2)	% Difference
0.570	0.620	0.353	0.6	0.6	0.36	1.833
Tipper Garrage Tanke Ilorin South			Standard Dimension			% Difference
Depth y(m)	Width b (m)	Area b*y (m^2)	Depth y(m)	Width b (m)	Area y*b (m^2)	% Difference
0.530	0.625	0.331	0.6	0.6	0.36	7.986
Pipeline Road Ilorin South			Standard Dimension			% Difference
Depth y(m)	Width b (m)	Area b*y (m^2)	Depth y(m)	Width b (m)	Area y*b (m^2)	% Difference
0.61	0.62	0.378	0.6	0.6	0.36	5.0356

Ilorin East

Table 4: Measured hydraulic data Ilorin East

Basin Road By Office Of Survey Ilorin East			Standard Dimension			% Difference
depth y(m)	width b (m)	area b*y (m^2)	depth y(m)	width b (m)	area y*b (m^2)	% difference
0.610	0.580	0.354	0.6	0.6	0.36	1.722
Farte Tanke Road Ilorin East			Standard Dimension			% Difference
depth y(m)	width b (m)	area b*y (m^2)	depth y(m)	width b (m)	area y*b (m^2)	% difference
0.605	0.580	0.351	0.6	0.6	0.36	2.528

Ilorin West

Table 5: Measured hydraulic data Ilorin West

ASA DAM Road Ilorin West		
Width b (m)	Area b*y (m^2)	Depth y(m)
0.59	0.354	0.6
Obo Road Ilorin West		
Width b (m)	Area b*y (m^2)	Depth y(m)
0.6	0.348	0.6

From the Table 3- 5, it was observed that the measured dimension were different from the original standard dimension of the drain when constructed with the percentage difference rising up to 8% and minimum of 1.33% difference. This shows how most of the drainage are having reduced areas due to the accumulation of solid waste which reduces the width and the depth of the drains and thus The area of the drainage channel are lesser than the standard area which makes the drains function below capacity and prone to flooding. The Figure 1 gives the comparison between the standard and measured areas graphically which displays the difference in their areas as measured and as standard areas.

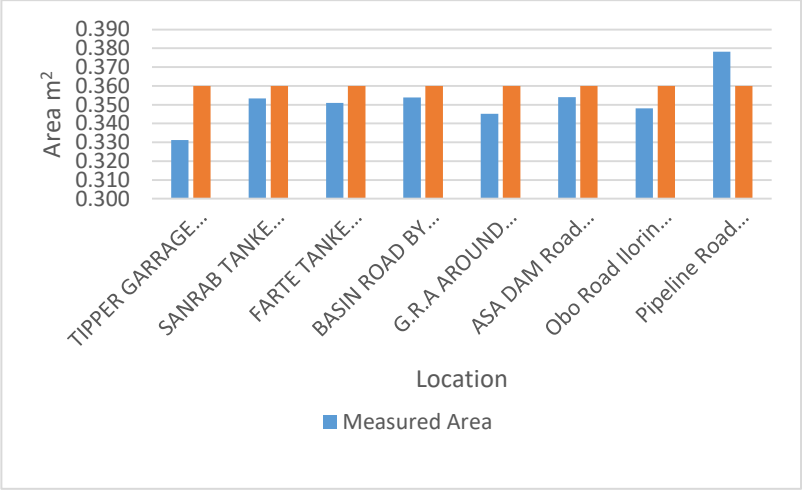


Figure 1: Graphical representation of measured area and standard area

The figure 1 shows the description of the difference in areas only Pipeline area of Ilorin had a measured area above the standard area which is also faulty due to excessive expansion of the drains beyond the standard dimension which causes failure of the drain channels.

3.6 Computation Of Intensity Duration Frequency Curve

Empirical plotting position approach was used in generating exceeding probability p and T which is the corresponding return period, however for the purpose of this research 2 minute return period was adopted because most

drain channels are constructed with 2 years return period (Neehidasan .S.et.al 2013)
. The empirical plotting position is utilized using the Equation 10
Where rainfall intensity

$$P=\frac{I}{T} \tag{10}$$

Where T is the Return Period in years and P is the Exceeding probability

$$T=\frac{M+1}{N} \tag{11}$$

Where M is the number of observation and N is the Rank of the observation.
With the rainfall intensities obtained a frequency analysis curve was developed to show the graphical relationship between the rainfall intensities and its return period in Figure 2.

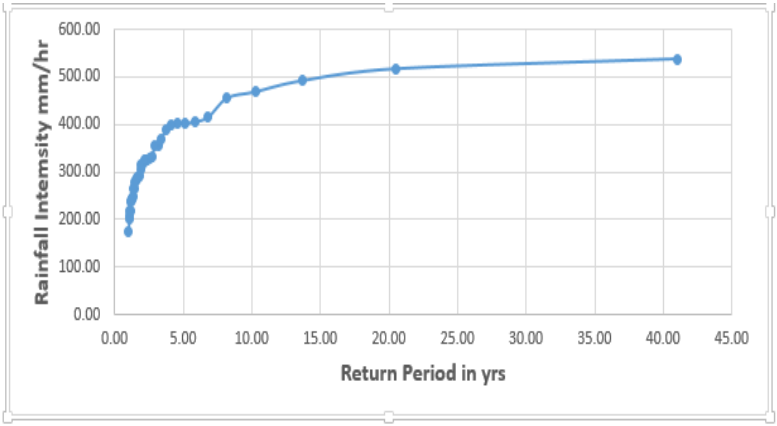


Figure 2: Frequency analysis for 2 years return period.

The figure 2 shows the rainfall intensity high up to about 531mm/hr. This is one of leading factors leading to flash flooding. If the rainfall intensity for 2 minute return period occurs there would be occurrence of flash flood. Flash flood occurs as a result of non-forecasted and unexpected raise in the amount of rainfall (National Weather Service 2015).

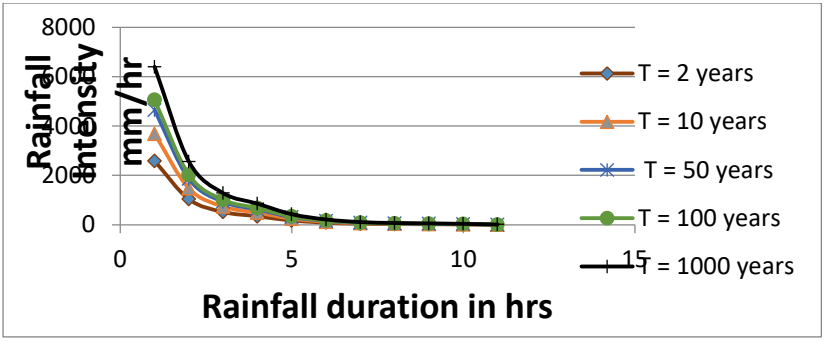


Figure 3: IDF curve for various return periods

The IDF curve in Figure 3 shows the rainfall distribution pattern for various return period which are 2 years, 10 years, 50years 100 years and 1000 years. This gives a futuristic view into the rainfall characteristics for further years. This is because most drainage system are designed with two years to five years return period (Needhidasan.S et, al 2013) The Figure 3 shows the IDF curve for 40years, on a two years return period it is observed that there is a steady decline in the rainfall intensity with time of rainfall, as the time increases the rainfall intensity decreases over time and at the shortest period of time the highest rainfall intensity occurs, this is observed in the 2minutes rainfall intensity and the 24hrs rainfall intensity which were at 3686mm/hr and 7.02259 mm/hr. for 24hr

3.3 Computation Of Discharge With Rational Method

The rational formula was used to compute the discharge accumulated from the drainage sub catchment area for the analysis of the drainage channels.

Table 6: Time of Concentration

Location	Length (m)	Slope(m/m)	T_c(min)
Basin Ilorin East	1265.75	0.26	8
Farte Ilorin East	860.99	0.26	6
Obo Road Ilorin West	218.51	0.26	3
G.R.A Ilorin South	773.32	6.55	2
Pipeline Ilorin South	1866.29	0.0789	18
Sanrab Ilorin South	831.76	0.0765	10
Tipper Garrage	594.81	0.0531	8
Asa Dam Ilorin West	783.92	0.0422	11

The rational formula was used because the area of the drainage is not up 200 arches which is the standard for using the rational formula (OBT 2015). From the IDF curve utilizing 2 years return period. From Equation 11 the time of concentration for all the study areas were obtained and displayed in Table 6.

Table 6 gave us the various time of concentration and from it intensities are traced for all the various study areas in Figure 3 (IDF curve). From table 5 all rainfall co efficient are obtained and through satellite imagery areas are obtained. These satisfies all the factors necessary for obtaining discharge in Equation 11 which are intensity, area and coefficient of roughness factor. The peak discharge obtained by the rational formula is hence given in Figure 4.

The figure 4 shows the discharge pattern for all the sub catchment with the study area with G.R.A area in Ilorin South having the highest rainfall discharge of 4315.6582m^3/s while Sanrab had the lowest discharge of 13.70m^3/s, this due to the area obtained by them.

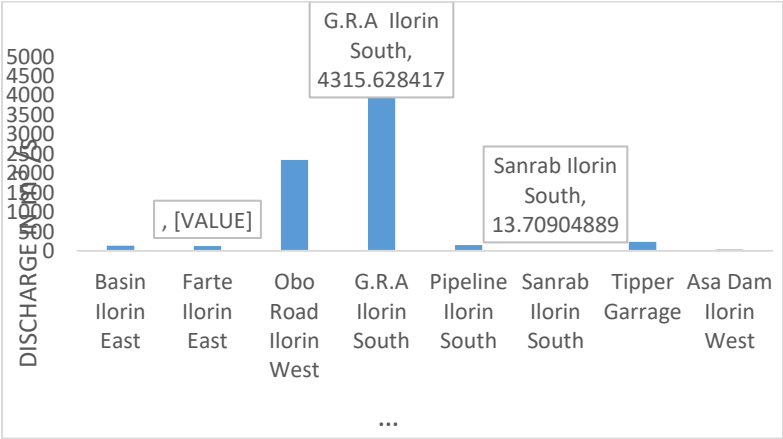


Figure 4: Figure showing the discharge at various areas in Ilorin metropolis

3.4 Evaluation Of Drainage System

The various observed areas obtained due to earlier observation carried out on the various study areas were different from the original designed areas from the ministry of works originally and there were changes in percentage as high

as 10%. Also the Sub catchment areas Expected area gotten from all the sub catchment close to the various area were obtained utilizing the rational formulas and there values were different from the observed area which is the main reason were most drainage channels are flooded because the area is not sufficient to hold and convey the amount of water supplied.

Furthermore, From the values of the sub catchment area gotten via Arc GIS delineation various the values for the discharge was obtained using the rational formula Q= CIA the values for the C the co efficient was obtained from Table 2 while the intensity were gotten from the IDF curve in figure 3 produced the intensity needed through the various time of concentration traced from Table 3 to arrive at the discharge values in Figure 4. With the observed and sub catchment hydraulic parameters known and evaluated, the expected discharge and area were also obtained from manning's equation. From the area gotten from the sub catchment they are substituted into manning's equation to obtain the expected area required

$$Q=\frac{A}{N}R^{\frac{2}{3}}S_2^1 \tag{12}$$

Therefore the expected area A

$$A=\frac{N}{R_3^2}\frac{1}{S_2^1}Q \tag{13}$$

The various discharge values were gotten for areas of the closet watershed to the drainage area and this discharge is substituted into manning's equation in Equation 12 to arrive at the required areas that would be sufficient to carry the area from the watershed. The Figure 4 shows the comparison between the expected and observed area. If the observed area is higher it means it's uneconomical but if lower means its prone to flooding and poor storm water management.

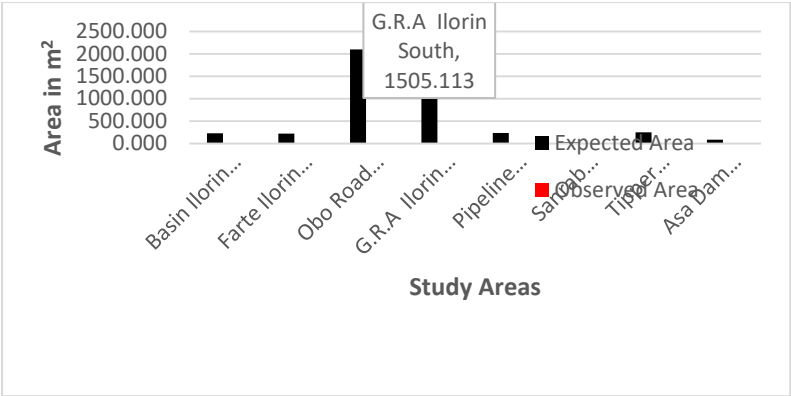


Figure 5: Graphical representation of the expected areas and observed area

From Figure 5 it is clear all the drainage facilities in Ilorin metropolis are prone to flooding. Also due to the relationship between discharge area and velocity in Equation 4 the expected velocities and observed velocities were also compared in Figure 6

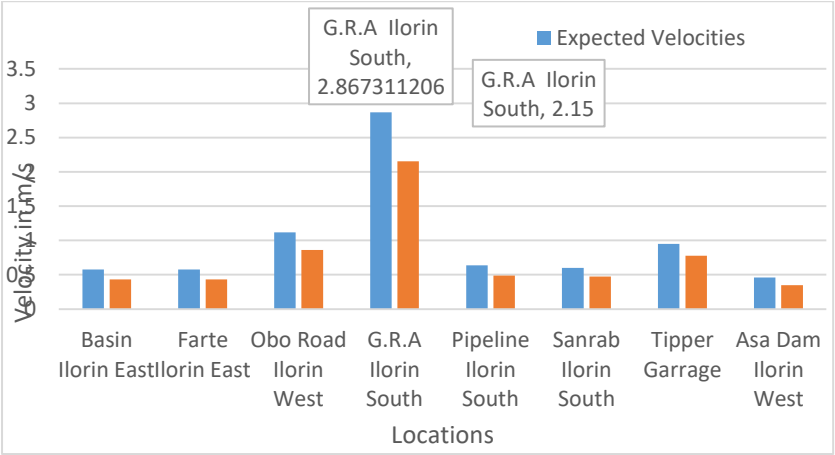


Figure 6: Graphical Representation of the observed and expected velocities

From the Figure 6, it is clear that the observed velocities is lower than the expected velocities required to carry the amount of water released due to this discovery the velocity required to properly move the drainage channel is not achieved this leads to clogging and accumulation of solid waste in the drainage channel.

4. Conclusion

This study has shown that the present drainage channels in Ilorin metropolis are below capacity based on their hydraulic features. The reconnaissance survey carried out showed variation from 1.3% - 8% in the standard drainage dimension and the observed hydraulic properties of the drains, in all the study area. The IDF curve was plotted for all the study area and the resultant rainfall intensity for Ilorin metropolis keeps increasing consistently up to a return period of 41.2 years and the rainfall intensity at 2min return period causes flash flooding at any probability of exceedance.

The discharge computed from the rational formula, the velocity and area obtained from manning's equation, varied greatly from the measured discharge, area and velocity. Therefore, the measured hydraulic properties of the existing drainage facilities in Ilorin metropolis are below the expected hydraulic features in terms of discharge, velocity and area. The discharge, velocity and area of the drainage channels makes them prone to flooding, due to the expected imminent overtopping of the drainage channels and this is in all the study area.

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