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Determination of Peak Discharge for Selected Drainage Facilities in Ilorin Metropolis for the Purpose of Storm Water Management

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ABSTRACT

The research work was aimed at determining the peak discharge of flow (maximum storm runoff) into some selected drainage systems in Ilorin metropolis for the purpose of stormwater management. The Ilorin municipality has been observed to have drainage system inadequate in capacities to convey storm runoff as a result of solid waste disposal into drainage systems which leads to drain blockage and the excess runoff result in flood. To obtain the value of excess runoff that leads to flood in the drainage systems under study, the required drainage area (m^2) for the adequate conveyance of the determined peak flow was compared with the existing drainage area (m^2) the difference in both areas results in the excess runoff which leads to flood. The Rational method was used to compute peak discharge for the study areas while the Manning's equation was adopted to compute the expected drainage channel area required for the adequate conveyance of the peak discharge. The result showed that the existing drainage area in most of the selected drainage systems is less than the required area needed to convey the peak stormwater discharge into the drainage system. The average peak discharge obtained for all the drainage channels in the study areas was 266.68 m^3/s while the average area expected to convey the discharge was 8.85 m^2. However, the average area of the existing drainage systems was 0.349 m^2 which is relatively to as compared with 8.85 m^2 which represent the excess discharge that leads to the flooding.

1. INTRODUCTION

Drainage systems are usually constructed to ensure that waste water and sewage is transported neatly to points of disposal, hence, keeping the environment well drained. However, Achalu and Achalu (2004) established the fact that indiscriminate dumping of refuse into the drainage systems hinders the free of erosion and floods when it rains causing blockage of drainages, diversion of floods to various places like living houses, farm lands leading to over-flooding, which results in destruction of life and properties.

Obot (2015) established that the magnitudes of peak flows that have to be received depend on the intensity of rainfall, topography, soil type and land use of the catchment area. The collection and proper drainage of storm water and surface runoff stabilizes the state of wellbeing of occupants in the area, reduces soil erosion for extensive agricultural productivity, mitigate flood occurrence and therefore enhance quality of life.

There has been an increase in the rate at which flooding is experienced today in most parts of the world. This is attributed to increase in human population especially in the urban areas and modes of waste disposal in urban areas are very poor in most developing countries including Nigeria. Due to Illiteracy, a good percentage of the populace disposes off their refuse in drainages and waterways thereby blocking them or reducing their capacity (Douglas et al., 2008).

The approaches to designing of city drainage facilities are becoming increasingly sophisticated, and an urgent need has therefore arisen in urban hydrology and planning to develop a more rigorous technique in assessing, managing and maintaining the quality of the city drainage facilities in urban areas (Annan, 2001; DFID, 2007; Nnodu, 2008). The aim of this research work is to evaluate some selected drainage facilities for stormwater management purpose in Ilorin metropolis.

2. MATERIALS AND METHODS

2.1. Description of Study Area

Ilorin, the State Capital of Kwara State, Nigeria is located on latitude 8º50’ N and longitude 4º35’ E. The city occupies an area of about 468 km^2 and is situated in the transitional zone within the forest and the guinea savannah regions of Nigeria. The climate of Ilorin is characterized both wet and dry seasons. The rainy season begins towards the end of April and last till October while the dry season begins in November and ends in April. The temperature of Ilorin ranges from 33 ℃ to 35 ℃ from November to January while from February to April; the value ranges between 34 ℃ to 37 ℃. Days are very hot during the dry season. The total annual rainfall in the area ranges from 990.3 mm to 1318 mm. the rainfall in Ilorin city exhibits the double maximal pattern and greater variability both temporarily and spatially. The relative humidity at Ilorin city ranges from 75% to 88% from May to October, while in the dry season it ranges from 35% to 80% (Ajibade and Ojelola, 2004). Geology and Drainage Ilorin consists of Precambrian basement complex rock. The soils of Ilorin are made up of loamy soil with medium and low fertility. Because of the high seasonal rainfall coupled with the high temperature, there is tendency for lateritic soil to constitute the major soil types in Ilorin due to the leaching of minerals nutrients of the soil (Ajibade and Ojelola, 2004). The elevation of the area varies from 273 m to 333 m in the western side with isolated hill (Sobi Hill) of about 394 m above the sea level while on the eastern side it varies from 273 m to 364 m (Ajibade and Ojelola, 2004).

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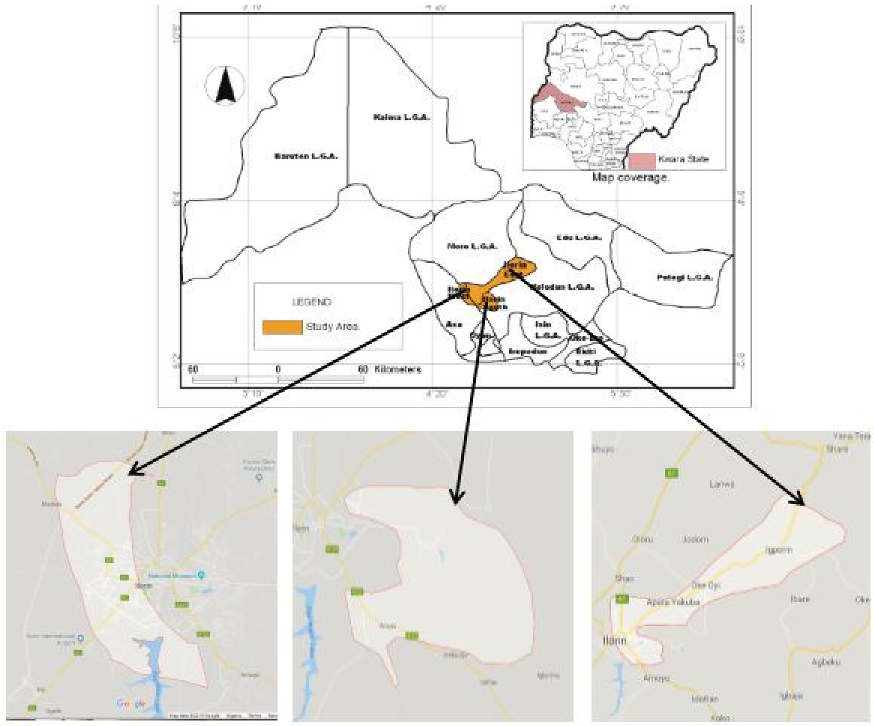

Figure 1: Map of Nigeria showing Ilorin West, South and East LGAs respectively

For this study, information and data collection were acquired from both primary and secondary sources to cover rainfall, watershed parameters and existing drainage in the areas. Google Earth and ArcGis software were used for the catchment delineation and parameters calculation. Forty years (1979-2018) daily rainfall data was obtained from the Nigerian Meteorological Agency (NIMET).

2.2. Development of Intensity Duration Curve (IDF) Curve

Rainfall durations were extracted from the rainfall event data obtained from the data source. The intensity was obtained using Equation 1 (Ganiyu, 2012).

$$I = R/t \tag{1}$$

Where I is the rainfall intensity in mm/hr, R is the amount of rainfall in mm and t is the duration of the rainfall in hours.

The values of maximum intensity were ranked in decreasing order with the highest intensity taking the value of 1 in the rank. The return periods or recurrence intervals were calculated using the Weibull’s formula as shown in Equation 2 (Ganiyu, 2012).

$$T = \frac{N+1}{M} \tag{2}$$

Where T is the recurrence interval in years, N is the highest rank and M is the rank value of each rainfall intensity.

The probability of occurrence was obtained using Equation 3.

$$P = \frac{1}{T} \tag{3}$$

Where P is the probability and T is recurrence interval in years.

K_T which is the frequency factor was computed for corresponding return periods using Gumbel's distribution given in Equation 4.

$$kT = \left[\frac{-\sqrt{6}}{\pi} 0.5772 + \ln\left(\ln \frac{T}{T-1}\right)\right] \tag{4}$$

According to Okonkwo and Mbajiorgu (2010), the return periods of 2, 5, 10, 25, 50- and 100-years intervals are most important and should be calculated using the Gumbel method.

The rainfall intensity was determined as shown in Equation 5.

$$XT = Xav + KTS \tag{5}$$

Where KT is the rainfall intensities for each return period, S is the standard deviation of rainfall intensities and Xav is the mean rainfall intensities

Hence, the graph of rainfall intensities was plotted against duration to obtain corresponding return period. The intensity duration frequency curves were obtained by plotting the rainfall intensity values against corresponding durations for different return periods.

2.3. Determination of Catchment Areas

The watershed areas were obtained with aid of ArcGIS application. Figures 2 to 4 show the images from the ArcGIS software interface for the delineated catchment areas.

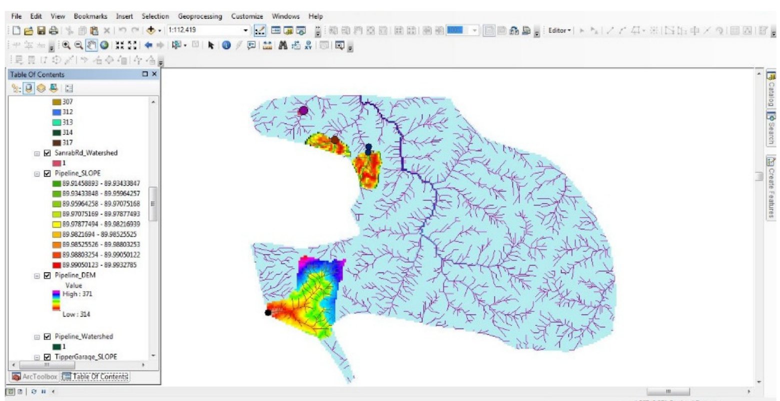

Figure 2: ArcGIS interface for Ilorin South study area delineation

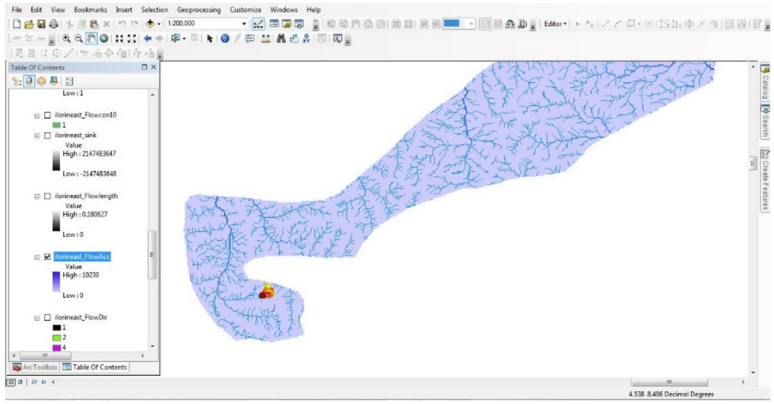

Figure 3: ArcGIS interface for Ilorin East study area delineation

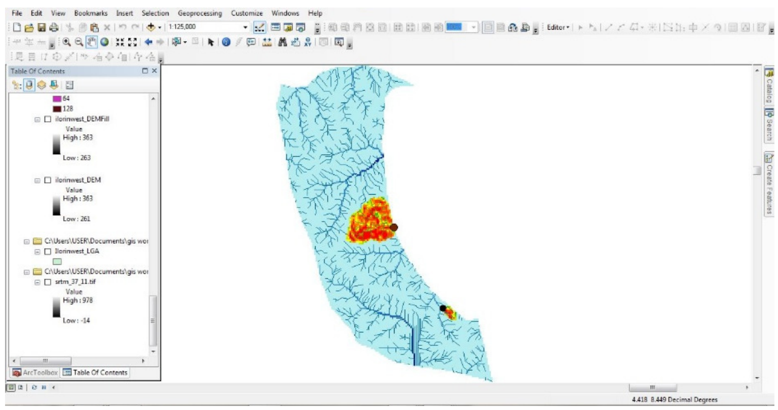

Figure 4: ArcGIS interface for Ilorin West study area delineation

2.4. Determination of Runoff Coefficient (C)

Runoff coefficients were selected based on the computed values for different land uses and drainage areas as recommended by the Natural Resources Conservation Service (NRCS) adopted from Ganiyu (2012). Values were selected for the land use within the study area. The study areas are all developed settlement areas with gravel roadways and shoulders, therefore the average of 0.4 and 0.6 which is 0.5 according to Taiwo (2014) was adopted for the runoff coefficient for all study areas.

2.5. Determination of the Time of Concentration (Tc)

Time of concentration (T_c) is generally defined as the longest runoff travel time for contributing flow to reach the outlet or design point, or other point of interest. It is frequently calculated along the longest flow path physically. The Kirpich formula for calculating Tc is given as (Kirpich, 1940):

$$T_c = 0.019621 \frac{L^{0.77}}{S^{0.385}} \quad (6)$$

Where T_c = time of entry in minutes, L = maximum length of channel reach in meter and S = average ground slope

On the intensity duration frequency chart, the time duration corresponding to the calculated time of concentration in minutes on the horizontal axis was determined. A vertical line from this point is drawn until it reaches the IDF curve labeled as 10-year return period which is mostly used for drainage channel design as recommended by Obot, (2015)

2.6. Determination of Peak Discharge (Q)

The rational method was adopted in this study because it is the oldest method and most widely used method for design of storm drains. Rational method had been used for computing magnitudes of design floods for watershed area less than 30 km^2 (Needhidasan and Nallanathel, 2013). The watershed areas in this project case study are all less than 30 km^2.

$$Q = CIA \tag{7}$$

Where Q = Peak discharge (m^3/hr), C = Runoff coefficient (dimensionless), I = Average intensity of rainfall in m/hr and A = Drainage or catchment area in m^2

2.7. Storm Management

The objective of determining the peak discharge is to evaluate the capacity of the existing drainage facilities in the study areas for the purpose of stormwater management. This is done by the hydraulic analysis of the existing channel to check if the channel can adequately convey the calculated peak discharge. The maximum possible velocities through the openings of the existing structures have been computed assuming structure nearly full flow using Manning's equation (Herget et al., 2014).

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{8}$$

Design discharge:

$$Q = AV \tag{9}$$

Therefore:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{10}$$

Where: Q = Discharge (m^3/s), V = velocity of flow (m/s), n = Manning's roughness coefficient value, S = Hydraulic gradient, or slope, R = hydraulic radius (A/P) (m) and A= cross sectional area (m^2)

The area from the mathematical evaluation is the expected channel area to convey the calculated peak discharge which is then compared with the observed or measured area during site visitation. The expected and measured areas were then compared to check the status and capacity to convey and manage stormwater runoff properly.

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3. RESULTS AND DISCUSSION

3.1. Rainfall Data and IDF Curve

The development of IDF curves requires that a frequency analysis be performed for each set of annual maxima, one each associated with time duration (Ouali and Cannon, 2018). The basic objective of each frequency analysis is to determine the exceedance probability distribution function of rain intensity for each time duration (Deger and Yuce, 2019).

The probability distribution for all time durations in the rainfall data are equal using Equations 2 and 3. Equation 4 and 5 were used to compute the frequency factor and the rainfall intensity for corresponding return periods and duration time. Table 1 shows the return periods and rainfall intensity for each time duration used to plot the IDF curve in Figure 5 for Ilorin metropolis.

Table 1: Frequency factors derived from Gumbel distribution method

T	2	5	10	25	50	100
K_T	-0.164272	0.7194574	1.3045632	2.0438459	2.5922880	3.1366806

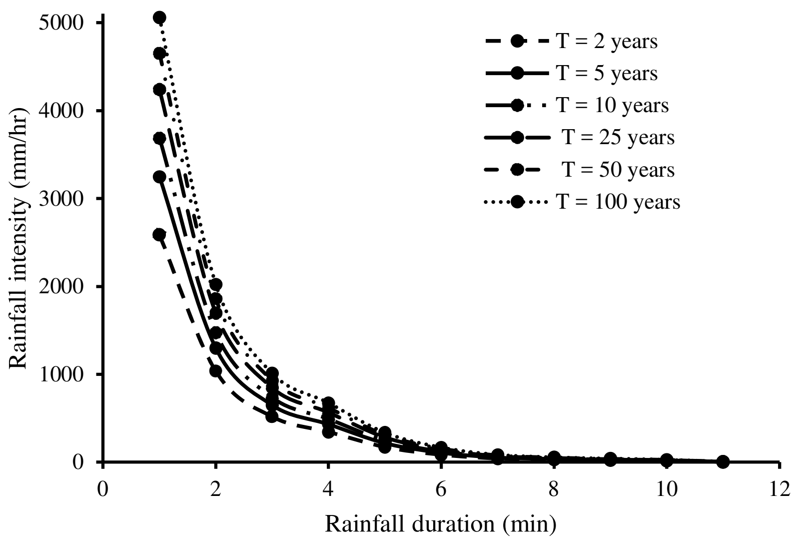

Figure 5: Intensity distribution frequency curve for Ilorin

Figure 5 represents the IDF curve which indicates that as the duration increases, the rainfall intensity (mm/hr) decreases which is common in most design situations. It was found that the rainfall intensity generally increases with increase in return period. The results also indicated a significant percentage of the storm having their peak intensity occurring within the first 12 minutes duration time. Furthermore, the results showed that for shorter durations, the IDF Curves give higher intensities for the return periods while for longer durations, the IDF Curves give lower intensities for the return periods which implies that shorter duration storms are more intense while longer duration storms are less intense.

Table 2 shows the result of watershed areas, slope and drainage length of selected study areas in the Ilorin metropolis obtained with ArcGIS. From the result shown it was observed that amongst the selected study areas, Sanrab Drainage system (Ilorin South) has the least watershed area of 110,163 m^2 given the location of its drainage outlet or pour point and the GRA area has the largest watershed area of 11.950,972 m^2 and highest slope value. This implies that shorter time of concentration is needed for the runoff to get to the catchment outlet. The highest slope value in GRA area makes surface runoff in the catchment area discharge quickly into the outlet which leads directly to a large water course (Ilorin waterside).

Table 2: Watershed area, slope and length of study locations

Study areas	Watershed area (m^2)	Slope	Length (m)
Sanrab road	110162.805	0.0765	831.76
GRA road	11950971.720	6.5558	773.31
Pipeline road	2507262.908	0.0789	1866.29
Tipper Garage road	1744469.349	0.0531	594.81
Asa Dam road	513457.732	0.0442	783.92
Obo road	6512160.279	0.2616	318.51
Basin road	1812030.342	0.0394	1265.75
Fate road	1441656.944	0.0261	860.99

3.2. Time of Concentration

Using the Kirpich equation to compute $T_{c,}$ the corresponding values of intensity for a 10-year return period on the IDF curve was also determined using Excel software (Salimi *et al.*, 2017). Table 3 shows the result of the concentration time and their corresponding rainfall intensity value on the IDF curve for all study areas. The time of concentration used in selecting the design intensity is dependent on both slope and total drainage length. Table 3 shows the that the GRA has the highest slope value which have the shortest concentration time to convey runoff from the farthest point in the watershed to the outlet. The distance covered which is the length is also an important factor which implies that pipeline road having the highest concentration time due to its long channel or flow path.

Table 3: Result of concentration time and intensity

Study area	Slope	Length (m)	Tc (min)	Intensity (mm/hr)
Sanrab road	0.0765	831.76	9.4	784.33
GRA road	6.5558	773.31	1.6	4607.96
Pipeline road	0.0789	1866.29	17.2	428.65
Tipper Garage road	0.0531	594.81	8.3	888.28
Asa Dam road	0.0442	783.92	11.0	670.25
Obo road	0.2616	318.51	2.8	2633.12
Basin road	0.0394	1265.75	16.7	441.48
Fate road	0.0261	860.99	14.5	508.46

3.3. Peak Discharge

From the intensity duration curve (IDF), time of concentration was used to determine design intensity for a 10-year storm return period. With the design intensity, watershed area and runoff coefficients known, the peak discharges were obtained for each study area drainage system. Table 4 shows the results of the peak discharge for all selected drainage channel in the case study areas (Needhidasan and Nallanathel. 2013).

The time of concentration used in selecting the design intensity is dependent on both slope and total drainage length. Table 4 shows that the GRA area has the highest slope value which have the shortest concentration time to convey runoff from the farthest point in the watershed to the outlet.

Table 4: Result of peak discharge channels in the study areas

Study area	Intensity (m/hr)	Runoff coeff.	Watershed Area (m^2)	Discharge (m^3/hr)
Sanrab road	0.7843	0.5	22032.6	8640.43
GRA road	4.6080	0.5	2390194.3	5506956.09
Pipeline road	0.4286	0.5	501452.6	107473.11
Tipper Garage road	0.8883	0.5	348893.9	154957.87
Asa Dam road	0.6702	0.5	102691.5	34414.41
Obo road	2.6331	0.5	1302432.1	1714728.74
Basin road	0.4415	0.5	362406.1	79997.68
Fate road	0.5085	0.5	288331.4	73303.09

The highest peak discharge is recorded from the GRA area due to its high rainfall intensity and watershed area while the lowest peak discharge is recorded from the Sanrab area as a result of its relatively small watershed area when compared to the other catchment areas. Generally, this study reveals that there will be more flood cases or stormwater management problems in the southern part (Sanrab road, GRA road. Pipeline road, Tipper Garage road) of the Ilorin metropolis when compared to the western (Asa Dam road and Obo road) and eastern part (Basin road and Fate road) of the city due to the facts that higher values of peak discharge from this study are attached to areas in the Ilorin south local government.

3.4. Hydraulic Analysis for Stormwater Management

Table 5 shows the values of expected drainage channel area that can convey the calculated peak discharge in each selected drainage channels for the case study.

For the purpose of stormwater management, the area values in Table 6 were then compared with the obtained or measured area during site visitation to ascertain the status of the existing drainage facilities in the case study areas.

Table 5: Result of expected channel area to convey peak discharge

Study area	Discharge	R	N	Slope	V	A
Sanrab road	2.400	0.3	0.015	0.0765	8.260	0.29
GRA road	1529.710	0.3	0.015	6.5558	76.465	20.01
Pipeline road	29.854	0.3	0.015	0.0789	8.389	3.56
Tipper garage road	43.044	0.3	0.015	0.0531	6.882	6.25
Asa Dam road	9.560	0.3	0.015	0.0442	6.279	1.52
Obo road	476.314	0.3	0.015	0.2616	15.275	31.18
Basin road	22.222	0.3	0.015	0.0394	5.928	3.75
Fate road	20.362	0.3	0.015	0.0261	4.825	4.22

The required area of the drainage system is that area of the drainage channel which is supposed to convey the calculated peak discharge. Table 6 shows the required drain size to convey the generated flow compared to the existing drain sizes. It can be deduced that the required area (0.29 sq. meter) in the Sanrab road channel is less than the existing area (0.33 sq meter) which implies that the existing area is capable of conveying the peak discharge thereby mitigating flood.

Table 6: Result of existing and required area of drainage channel

Study area	Depth (m)	Width (m)	Existing area (m^2)	Required area (m^2)
Sanrab road	0.530	0.625	0.331	0.29
GRA road	0.530	0.625	0.331	20.01
Pipeline road	0.610	0.620	0.378	3.56
Tipper Garage road	0.530	0.625	0.331	6.25
Asa Dam road	0.600	0.590	0.354	1.52
Obo road	0.600	0.600	0.360	31.18
Basin road	0.610	0.580	0.354	3.75
Fate road	0.605	0.580	0.351	4.22

The Sanrab area practically is always flooded during heavy downfall despite the above deduction. The flood in this case is as a result of reduction in the original channel hydraulic depth due to siltation or sedimentation, solid waste disposal and poor management practice.

Generally (excluding sanrab area) the measured areas for all drainage channel are too small compared to the expected area. This implies that the existing drainage facilities in the selected areas of this study are all functioning above capacity which makes the channels insufficient to convey the peak discharge and cannot be integrated for the purpose of stormwater management. This result justifies why the areas are always waterlogged and flooded during rainy seasons leading to environmental deterioration.

4. CONCLUSION

This study assessed existing drainage systems, indicated storm event, determined peak discharge, and analyzed drainage channel hydraulic parameters which could be used for storm water management purpose. The assessment of the existing drainage facilities reveals the condition of the drainage channels which entails siltation or sedimentation, blockage with solid waste disposal, poor maintenance, damaged channel walls, low self-cleansing velocity and totally covered up drainage channel. The hydrological analysis entails the development intensity-duration-frequency relationship and is feasible for return periods up to 100 years. It was found that rainfall intensity generally increases with increase in return period and decreases with increase in duration time. The highest peak discharge of 1529.71(m^3/s) was computed for the GRA area due to its high rainfall intensity and watershed area. It was also concluded that the Ilorin metropolis generally generates high runoff discharge values especially in the southern part of the city. The hydraulic analysis carried out based on the peak discharge shows that all drainage channels in the selected study areas are functioning above their capacity and are therefore ineffective for the purpose of stormwater management. This has led to re-occurrence of flooding, loss of lives and properties in the past as well as environmental deterioration. One of the measures that can be taken to reduce excess surface runoff is encouraging site infiltration through permeable pavement like porous concrete and coble stone.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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