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STORMWATER RESOURCES POTENTIAL AND IMPACT OF RAINFALL VARIABILITY: A CASE STUDY OF ILORIN METROPOLITAN CITY, NORTH CENTRAL, NIGERIA

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Abstract: Stormwater refers to rainfall that flows overland and eventually draining into waterways, it can be of benefit resources rather than a nuisance, especially in large cities if it can be harnessed through harvesting. Growing demand for water has led to increase pressure on groundwater through wells and boreholes dug in every city in Nigeria. These challenges motivated the evaluation of the stormwater resources as additional sources of water through harvesting to supplement water supply and reducing flash flood through proper management of river watershed. This study aims to quantify harvestable stormwater from excess rainfall derived from rainfall depth of different probability of exceedance in order to detect the effect of its variability and to identify the potential harvesting sites using GIS model and Soil Conservation Service (SCS) Synthetic unit Hydrograph. The result revealed total harvestable volume of stormwater for rainfall depth of different probability of exceedance of 50%, 20%, 10%, 5%, 2% and 1% corresponding to return periods of 2–yrs, 5–yrs, 10–yrs, 20–yr, 50–yrs and 100–yrs to be 13.67 Mm^3, 53.63 Mm^3, 86.63 Mm^3, 121.04 Mm^3, 168.18 Mm^3 and 204.84 Mm^3 respectively. Three available harvesting sites out of seven depressions were also identified. The implication of rainfall variabilities is that the lower the return period the higher the probability of recurrence of the amount of stormwater to be captured. For example, 13.67 Mm^3 volume of stormwater have return period of 2–yr with 50% probability of recurrence compare to 204.84 Mm^3 volume of stormwater that have return period of 100–yr with 1% probability of recurrence. In planning for harvesting of stormwater, there is need to put the variability of rainfall into consideration. However, for the 13.67 Mm^3 volume of stormwater that is likely to be recurring annually is a good motivator to incorporate stormwater harvesting in overall water resources management in the study area.

Keywords: Stormwater harvesting, Rainfall variability, return period, watersheds, SCS synthetic hydrograph

1. INTRODUCTION

Nigeria is experiencing water poverty due to the inability of the dwellers to access affordable and sustainable potable water at all times and breakdown of water sources which is conditioned according to Feitelson, & Chenoweth, 2002 and Balogun, & Redina, 2019. In Nigeria, water will likely be a source of conflict as in many countries that share rivers fight for access to these resources in less than three decades, especially if the population of Nigeria rises from 140 million in 2006 to over 250 million in 2025 as predicted (FGN (2007). Okeola, & Balogun, (2015) discussed water conflicts issues, therefore Nigeria needs structural and non–structural strategies to improve Nigerian's finite renewable water resources which cannot meet the increasing demand due to rising in population. Stormwater harvesting as a renewable resource for surface and underground water at different scale levels and scope is promising. The chronological implementation of stormwater harvesting is available in (Ali, (2017) and Ketsela, (2009). The challenge of achieving Africa's water security depends on the hydrological variability and its extremes (UN–Water, 2010)). The existing water management in most cities has been challenged by climate change, urbanization, and environmental degradation, hence the need to find a more sustainable solution. There is evidence that Nigeria is tending towards into water crises considering the shrinking lakes, disappearing of rivers, environmental pollution is becoming obvious (Gusikit, & Lar, 2014).

The purpose of urban stormwater management in the 1980s was to dispose of stormwater quickly into receiving water bodies (Akram, et al., 2014 and Dayaratne, 2001) due to catastrophic flooding. Many studies have revealed the use of stormwater harvesting as an effective structural approach to supplement renewable water resources or to reduce the vulnerability of urban flash floods as part of holistic water resources management (Shanableh, et al., 2018 and Freni, & Liuzzo, 2019). In order to supplement potable water demand and alleviate capacity challenges, stormwater harvesting may become valuable water resource to solve problem of inadequate water supply in the cities (Flectcher, et al., 2008 and Inamdar, et al., 2013). The integration of the management of stormwater has received strong consideration in many countries. For example, in France 15% of the populations have a stormwater harvesting system due to factors such as the 2008 law on stormwater harvesting, incentive mechanisms to foster the practice, and the increasingly "green" sensitivities of various stakeholders (Belmeziti, et al., 2014). There is the American Rainwater Catchment Systems Association (ARCSA) that caters to over 3,000 members who either owned, installed, or have observed stormwater harvesting in the field (Thomas, et al., 2014).

The UN's Food and Agriculture Organization (FAO) (Ammar, et al., 2016) gave guidelines to select stormwater harvesting potential sites that are very comprehensive, it incorporates wider ranges parameters and various socioeconomic criteria that are associated with local farmers. The challenge of water security tied to climate change problem, urbanization, increase in population, and environmental pollution, these are precursor to the increased studies in stormwater harvesting as a sustainable approach to address water scarcity.

In identification of suitable locations for stormwater harvesting in Iraq's Western Desert, Adham, et al., 2018 came up with a model using Model Builder in Arc GIS. The model utilized biophysical factors that included land use, slope, soil texture, stream order slope, and runoff depth to develop a suitability map for stormwater harvesting sites. GIS was confirmed as a tool that integrate a variety of information in identifying suitable sites for stormwater harvesting dams. The authors concluded that Arc GIS was a flexible, time–saving, and cost–effective tool for screening large areas for their suitability for stormwater harvesting intervention. Similar studies were reported in (Tiwari, et al., 2018).

In Iraq's Maysan province, (Alwan, et al., 2020) selected optimum sites for harvesting using FIS–based Multi–Criteria Evaluation. In doing this, the authors selected a Fuzzy membership that was used for standardization of the criteria in a Fuzzy Gamma overlay and then generated a combination of multilayer's in the ArcGIS interface. The authors then generated seven criteria layers (the Normalized Difference Vegetation Index (NDVI), roads, slope, evaporation, precipitation, soil type, and stream order) for identification of stormwater harvesting catchment. They finally developed a potential stormwater harvesting catchment map to aid the water resources management of the region. Other similar studies are (Ranan, & Suryanarayana, (2020)).

Ohiambe et al., (2019) carried out extensive studies on stormwater harvesting in both scale and scope in Nigeria. The water scarcity in Abuja, Nigeria have motivated the authors to investigate the stormwater harvesting potential of the city. The GIS and Multi–Criteria Evaluation (MCE) are the methodological tools of assessment. The significant criteria are prioritized with Analytical Hierarchy Process (ANP) which gave; rainfall 55.9%, LULC 26.3%, slope 12.2%, and soil 5.7% respectively. With GIS, they produced potential sites map for harvesting with grouping into moderate (10.7), good (34.4), and excellent (54.9) respectively. They confirmed from their investigation that Abuja will have at least 5.8 x $10^3 m^3$ of harvestable stormwater per year which is an increment of 14.8% compared to the 2016 estimation. This assertion was supported due to increased rainfall from 1,170 to 1,470 mm in 2016 to 1,230–1,910mm in 2046, impervious surfaces from urbanization, and an increase in population. Ishaku, et al., (2012), and Wahab, & Ojolowo, (2013) also revealed other location where specific studies on stormwater harvesting were carried out in the country.

Salami, et al., (2011) determined stormwater from rainfall of various return period for the watershed of river Asa. Oyun and Moro. Snyder, SCS and Gray synthetic methods were adopted to developed unit hydrographs. The peak flows obtained based on the unit hydrograph ordinate determined by Snyder for 5–yr, 20–yr, 50–yr, 100–yr and 200–yr return period varies from 230.0 rn^3/s and 806.0 m^3/s, while those based on the SCS varies from 260.0 m^3/s and 1053.0 m^3/s and those based on Gray varies from 208.0 m^3/s and 861.0 m^3/s for the three watersheds. The study revealed that Snyder method can best be used to estimate ordinates required for the development of peak runoff hydrograph of different return periods in the watershed under consideration.

Salami, et al., (2013) developed unit and runoff hydrographs for Awun, Ogunpa and Wuruma river watershed. Snyder, SCS and Gray synthetic unit hydrograph were adopted. The SCS curve Number method was used to estimate the cumulative watershed excess rainfall values for rainfall depth of different return periods. The peak runoff determined based on the ordinates derived from Snyder for 5–yr, 20–yr, 50–yr, 100–yr and 200–yr return period varies between 54.8 m^3/s and 746.3 m^3/s, the values of peak runoff based on the SCS varies between 110.8 m^3/s and 651.8 m^3/s and those obtained based on Gray method varies between 87.4m^3/s and 453.1 m^3/s for the three river watersheds respectively.

The statistical analysis and graphical comparison inferred that SCS method is more suitable for the three river watersheds.

Salami, et al., (2017) developed runoff hydrographs for selected rivers in the Ogun–Osun river catchment, south west, Nigeria using Snyder and Soil Conservation Service (SCS) methods of synthetic unit hydrograph to determine the ordinates. The SCS curve Number method was used to estimate the excess rainfall from rainfall depth of different return periods. The runoff hydrographs were determined by convoluting the unit hydrographs ordinates with the excess rainfall and the value of peak flows obtained by both Snyder and SCS methods observed to vary from one river watershed to the other. The study revealed SCS method as more appropriate for the estimation because it utilized additional morphometric parameters such as watershed slope and the curve number (CN) which is a function of the properties of the soil and vegetation cover of the watershed.

The rapid grow in population, shortages of water, and annual flash flood has motivated the current study for stormwater harvesting in Ilorin metropolitan city, Nigeria. Despite abundant water resources, the city still faces the challenge of meeting water demand while several volumes of water are annually wasted through storm runoff. This study aims to quantify harvestable stormwater from excess rainfall derived from rainfall depth of different probability of exceedance in order to detect the effect of its variability and to identify the potential harvesting sites using GIS model and Soil Conservation Service (SCS) Synthetic unit Hydrograph.

2. METHODOLOGY AND MATERIAL

Study area

Ilorin metropolitan city comprises of three merged local government areas (LGAs): Ilorin West, East, and South on latitude 080 241N and 080 361N and 08 360N and longitude 040101E and 040 361E with a total catchment area of 2056.3km2. (Figure 1). The climate has dry season from November to May. The annual rainfall is 1200mm and relative humidity ranges from 75–80% in the wet season, while 65% in dry season is. From November to May, the sun shines between 6.5 and 7.7 h daily. The geology consists of Precambrian basement complex rock. River Asa, which flows in a south–north direction, drained the catchment.

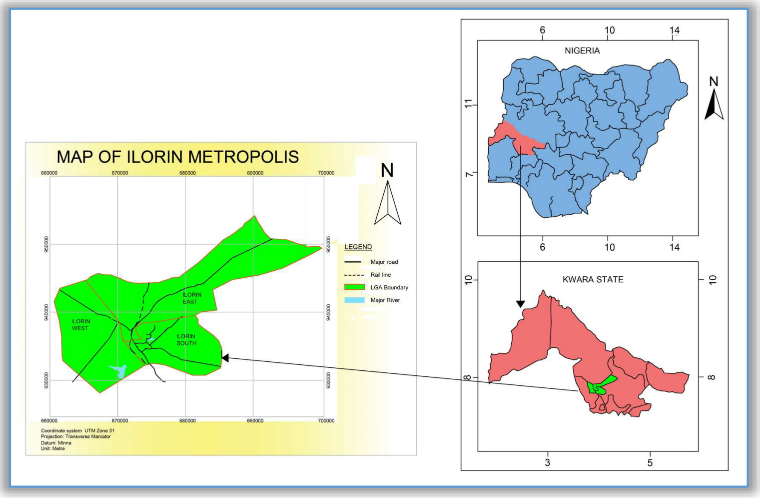

Figure 1: Map of Nigeria showing kwara state and the study area

Data Collection

The data collection involves desk and field works. The desk work includes study of surface water hydrology. The fieldwork entails a reconnaissance survey, identifying the drainage outlet potential storm water capturing sites. The data sourced from administrative map and rainfall data. Forty (40) years of rainfall data ranging from 1982 to 2022 were obtained from Nigeria Meteorological agency

3. DATA ANALYSIS

GIS Analysis

The major analytical tools include Google Earth, ArcGIS, and Global Positioning System (GPS). The ArcGIS desktop 9.3 was utilized for the spatial analysis from which watershed characteristic was determined. The Digital Elevation Model (DEM) used in this study was obtained from the archive of Shuttle Radar Topographical Mission (SRTM) and the assessment of hydrologically based indices from digital terrain analysis is done with DEM, while the drainage outlet's location on the ground surface was achieved with GPS using coordinates generated with ArcGIS. The DEM cell–wise elevation information was adopted in the determination of the drainage structure of the catchment and it involves the filling of depressions, flow direction, and flow accumulation datasets. The D8 (eight flow direction matrix) is the approach commonly used in deriving drainage networks from raster DEM data. The D8 model was adopted to identify flow direction. That is the streamflow to a neighboring cell in a straight or diagonally steeper cell.

The flow direction of a cell is the direction water will flow out of the cell. The peak flow discharge was computed using SCS synthetic unit hydrograph and storm water hydrograph generated through convolution methods.

Hydrological Analysis

— Unit hydrograph

It refers to as an approach commonly adopted to develop stormwater hydrographs from actual watershed rainfall. The method is based on assumptions that the same unit hydrograph shape applies to all catchments but only differs in scale (Natakusumah, et al., (2012). In predicting the basin's response to design storm events, unit hydrographs are produced for gauged watersheds from historical records. In this study, there was no available streamflow data to develop hydrographs. Hence, a synthetic unit hydrograph for ten sub–watersheds was developed using SCS method with the following parameters: The peak discharge, the time to peak and the lag time can be determined in accordance to SCS (Salami, et al., (2011), Natakusumah, et al., (2012), Salami, et al., (2013) and Salami, et al., (2017)). The peak discharge and other parameters can be obtained through the equation (1) to (6).

$$Q_p = \frac{2.08A}{t_p} \quad (1)$$

Time to peak and lag time

$$t_p = \frac{t_r}{2} + t_L \quad (2)$$

or

$$t_p = \frac{t_c + 0.133t_c}{1.7} \quad (3)$$

$$t_c = 0.06628\left\{\frac{L^{0.77}}{S^{0.385}}\right\} \quad (4)$$

$$t_L = 0.6t_c \quad (5)$$

$$t_r = \frac{t_L}{5.5} \quad (6)$$

where; qp= peak discharge (m3/s/cm); A = watershed area (km2) and tp= time to peak(hr); tc= time of concentration (hr); tr= storm duration (hr); tL = lag time (hr) tc = time of concentration (hr); L = length of channel (stream) in km; S = Slope of channel and tL= Lag time (hr)

— Estimation of rainfall of a particular return period using Gumbel's Extreme value type I

The event RT of the return period T year is defined as in equation (7) and the probability of occurrence of a magnitude being equal to or greater than any value RT is expressed in equation (8), other parameters as given in equations (9 and 10). (Salami, et al., (2011), Natakusumah, et al., (2012), Salami, et al., (2013), and Salami, et al., (2017)).

$$R_T = R_{av} + \sigma(0.78y - 0.45) \quad (7)$$

$$P = \frac{1}{T} \quad (8)$$

$$P = 1 - e^{-e^{-y}} \quad (9)$$

$$y = -\text{In}\left[-\text{In}(1 - \frac{1}{T})\right] \quad (10)$$

where: RT= Peak annual daily rainfall with magnitude with return period T; Rav=average value of peak annual daily rainfall; N= number of years of records, σ= standard deviation; e= base of Napierian logarithm and y= reduced variate

— Estimation of Rainfall Excess using runoff curve number

In the USDA–SCS–CN method of estimating the excess rain volume (Qd), it required the volume of precipitation, P, and the volume of the total storage S, which includes both the initial abstraction, Ia,= 0.2*S and the total infiltration. The relation between rainfall excess and total rainfall (on 24–hrs basis), the equations required are 11, 12 and 13 (Adornado, & Yoshida, (2010), Pandey et al., (2003), Waler, et al., (2001), Silva, & Oliveira, (1999), Salami, et al., (2011), Natakusumah, et al., (2012), Salami, et al., (2013), and Salami, et al., (2017)).

$$Q_d = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (11)$$

$$P = \frac{P^*}{24} * P_T \quad (12)$$

$$S = \frac{25400}{CN} - 254 \quad (13)$$

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where: P= accumulated rainfall (mm), PT = rainfall recurrence interval of the sub–basin (mm); P*= precipitation ratio, S= volume of total storage (mm); CN is runoff curve number and is dimensionless (0<CN<100). Value of 75 was adopted for the study area based on the soil type and land use of the study area.

— Estimation of stormwater hydrograph

The estimated values for both the peak discharge q_p and time to peak t_p are applied to the dimensionless hydrograph ratios to obtain points for the unit hydrograph. The Design storm hydrographs for average annual rainfall data were obtained using convolution method. Convolution is the process of determining storm hydrograph from a multi period of rainfall excess ((Bedient, & Huban, (2002), Salami, et al., (2011), Salami, et al., (2013), and Salami, et al., (2017)) and mathematically expressed as presented in equation (14).

$$Q_n = R_1 U_n + R_2 U_{n-1} + R_3 U_{n-2} \quad (14)$$

where: R=incremental rainfall excess (cm); U= unit hydrograph ordinate ($m^3/s/cm$)

Equation (14) is for the computation of discrete convolution of direct runoff Qn. The summation of the areas under storm hydrograph curve is the runoff volume determined by segmenting the graph into several trapezoidal shapes using equation (15).

$$Q = \sum \frac{(Q_1 + Q_2) * t}{2} \quad (15)$$

where Q_1 = first discharge m^3/s, Q_2 = second discharge m^3/s and t=time (sec).

4. RESULTS AND DISCUSSION

This study utilized GIS to determine watershed characterization, boundary, area coverage, and volumetric capacity of runoff. SCS synthetic hydrograph (equations 1 to 6) were analysed to obtained the watershed characteristics for ten sites presented in Table 1.

Table 1: Watershed characteristics for the identified ten sites (catchments) based on SCS methods

Sites (Catchments)	Catchment area, A (km^2)	River length, L (km)	River length near centroid to outlet, L_c (km)	Catchment slope, Sc (%)	Time of concentration, t_c (hr)	Lag time, t_L (hr)	Rainfall duration, D (hr)	Time to peak, t_p (hr)	Peak discharge, Q_p (m^3/s)
1	36.20	7.30	4.60	0.0234	7.66	4.60	0.84	5.02	15.01
2	26.60	5.00	3.10	0.0207	6.01	3.60	0.66	3.93	14.07
3	196.80	15.00	11.00	0.0287	12.34	7.40	1.35	8.07	50.69
4	445.30	26.20	11.80	0.0536	14.90	8.94	1.65	9.75	94.96
5	575.30	41.80	21.00	0.0606	20.37	12.22	2.22	13.33	89.76
6	210.00	13.00	22.00	0.0141	14.55	8.73	1.59	9.52	45.88
7	28.30	5.10	2.50	0.0245	5.71	3.43	0.62	3.74	15.74
8	59.68	9.80	5.30	0.0302	8.72	5.23	0.95	5.71	21.76
9	60.20	9.90	4.60	0.0341	8.38	5.03	0.91	5.49	22.82
10	95.95	16.70	7.50	0.0441	11.36	6.81	1.24	7.43	26.85

The study also utilized forty years of peak average annual rainfall depth (1982 to 2022) to forecast rainfall of 2–yrs, 5–yrs, 10–yrs, 20–yr, 50–yrs and 100–yrs return periods corresponding to 50%, 20%, 10%, 5%, 2% and 1% probability of exceedance (reliabilities) from which excess rainfall used in computing stormwater hydrograph through convolution were obtained. The outcome was utilized for the estimation of stormwater harvestable for the study area. The watershed excess rainfall estimated based on forecasted rainfall of various return periods are presented in Table 2.

Table 2: Estimated rainfall excess from daily rainfall depth of different return periods

Parameters	Values					
Return periods (years)	2	5	10	20	50	100
Probability of exceedance (%)	50	20	10	5	2	1
Rainfall depth (mm)	47.00	85.85	111.58	136.25	168.19	192.13
Excess rainfall (mm)	7.88	30.92	49.95	69.78	96.96	118.10
Percentage of rainfall contributed to excess rainfall (%)	16.77	36.02	44.77	51.21	57.65	61.47

Catchment characteristics

The watershed with its stream network is presented in Figure 2 with its highest elevation above mean sea level of 550m and the lowest elevation of 147m is depicted in Figure 3. The flow direction tool in the ArchHydro tool extension in ArcMap 9.3 was used to determine the flow direction and accumulation. A running iterative process of the cell was carried out to determine flow direction based on the D8 model.

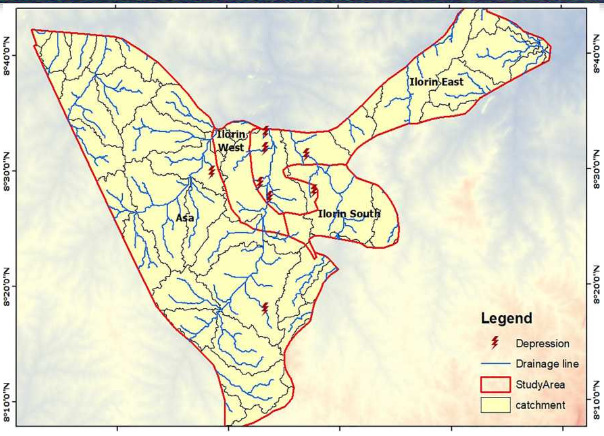

Figure 2. The merged LGAs' watershed and streams

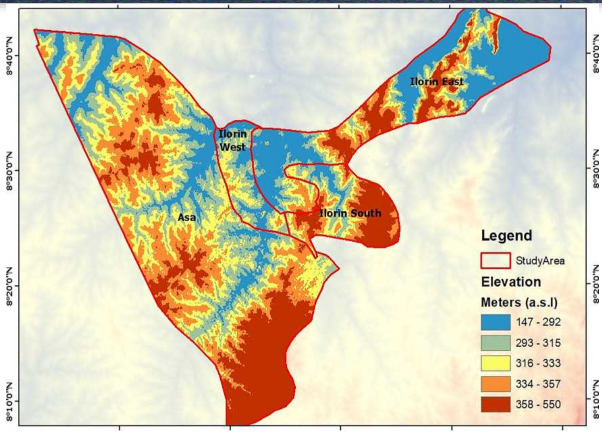

Figure 3. The study area DEM layer

Rainfall depths of various return periods using Gumbel model distribution

Equations (7) to (10) were adopted to estimate rainfall depths of 2, 5, 10, 20, 50 and 100 return periods. The statistical analysis of rainfall yielded an average and standard deviation value of 54.21mm and 43.95mm respectively. The rainfall depths of 2–yrs, 5–yrs, 10–yrs, 20–yr, 50–yrs and 100–yrs return periods were determined as 47mm, 85.85mm, 111.58mm, 136.25mm, 168.19mm and 192.13mm respectively, while the total rainfall excesses were obtained from the forecasted rainfall depth for each return periods as 7.88mm, 30.92, 49.95mm, 69.79mm, 96.97mm and 118.11mm respectively using Equation (11 to 15) as presented in Tables 2.

Storm hydrograph development

The study area was delineated into ten watersheds. Each watershed's characteristics such as catchment area, streams length, and catchment slope were determined with ArcGIS and SCS are convoluted with excess rainfall by adopting equations (14 – 15) for the computation of storm runoff for the ten–watersheds using Microsoft Excel.

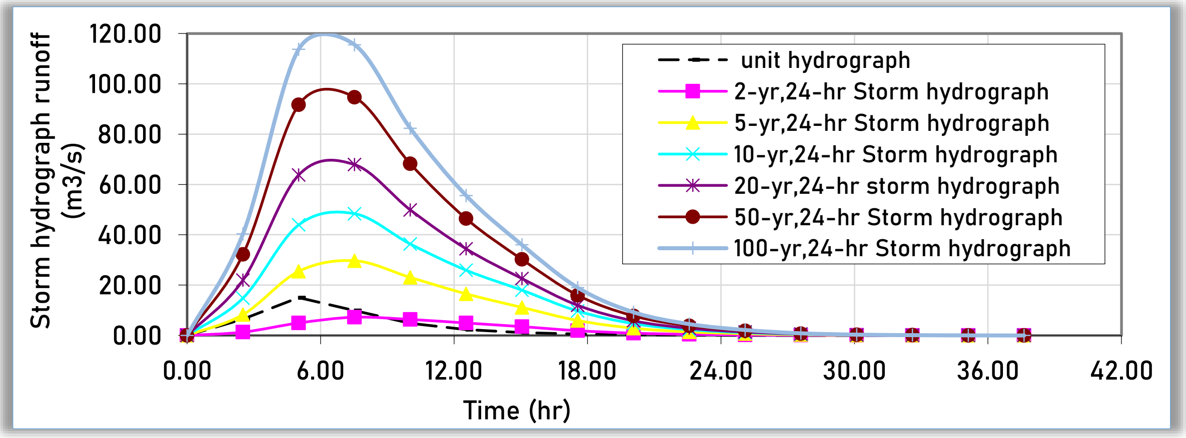

Figure 4a. Comparison of unit and storm hydrographs of different return periods for site 1

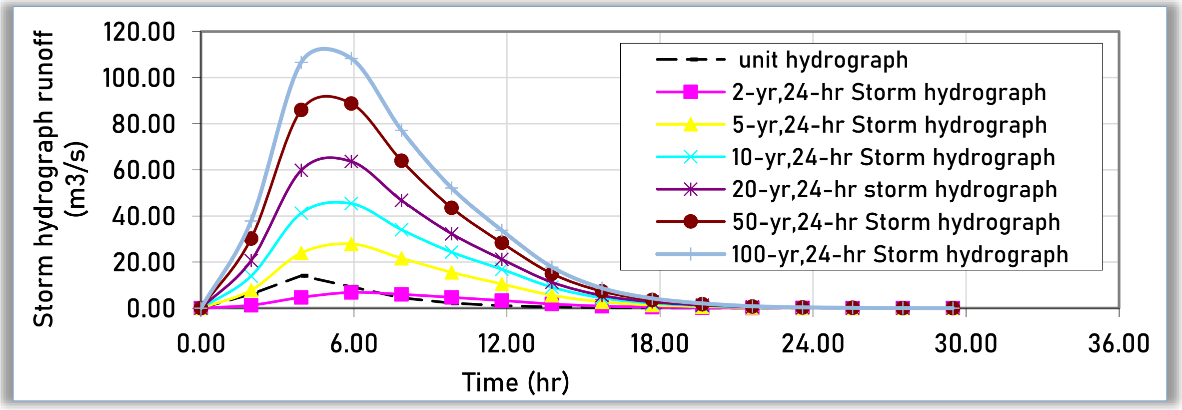

Figure 4b. Comparison of unit and storm hydrographs of different return periods for site 2

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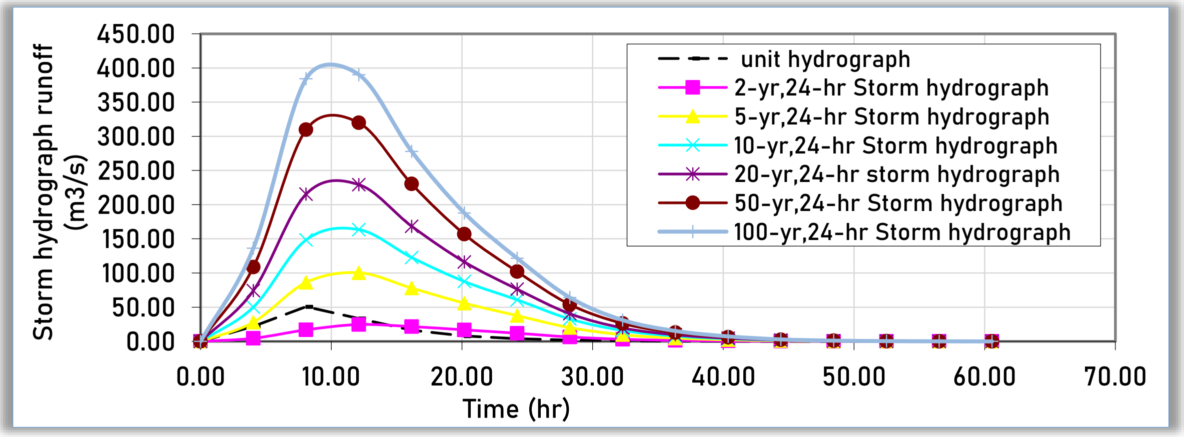

Figure 4c. Comparison of unit and storm hydrographs of different return periods for site 3

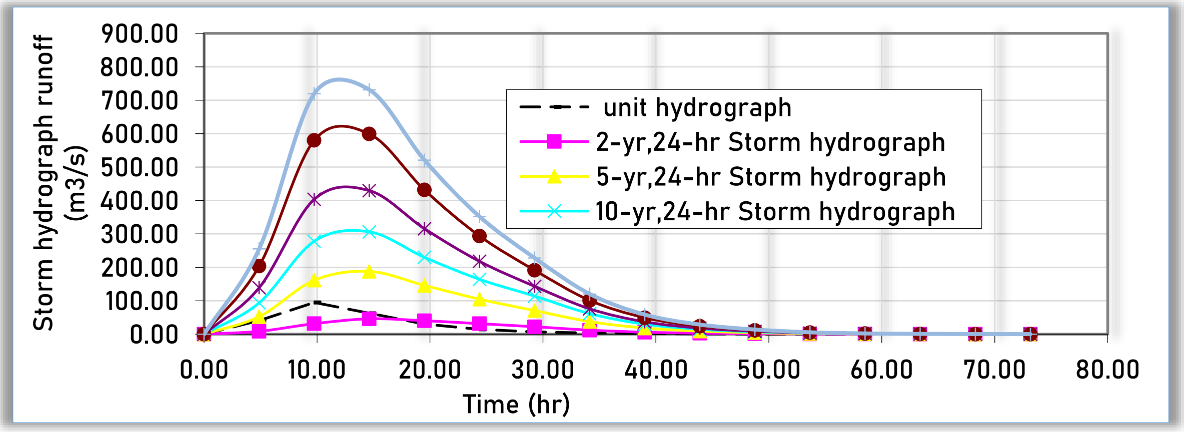

Figure 4d. Comparison of unit and storm hydrographs of different return periods for site 4

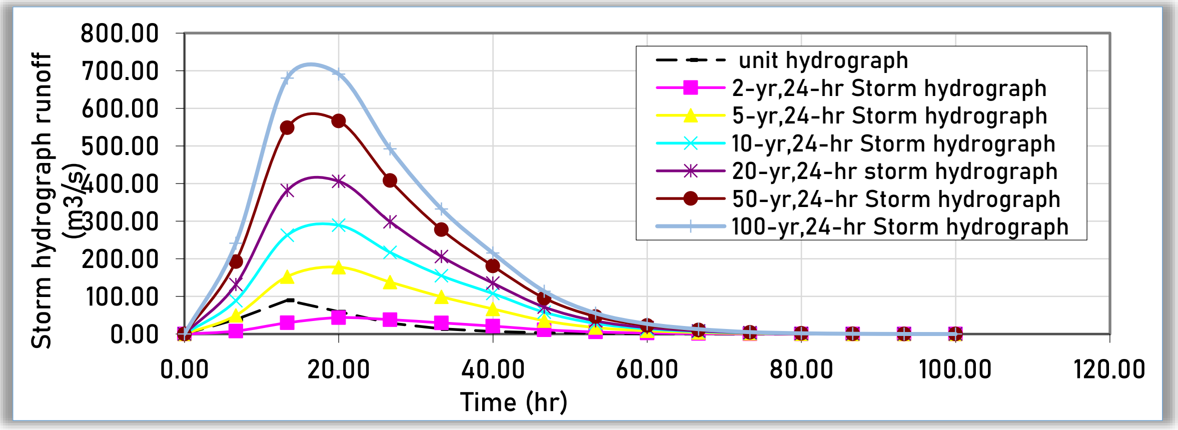

Figure 4e. Comparison of unit and storm hydrographs of different return periods for site 5

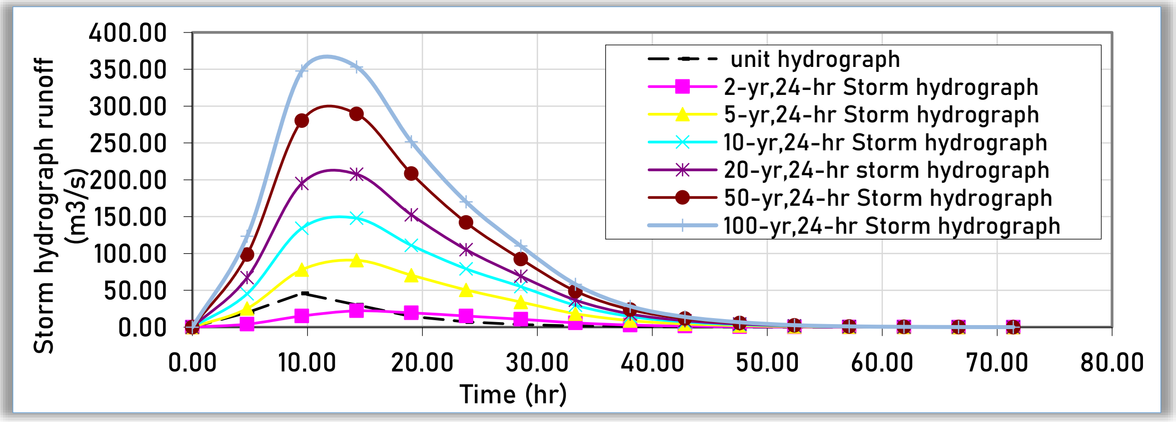

Figure 4f. Comparison of unit and storm hydrographs of different return periods for site 6

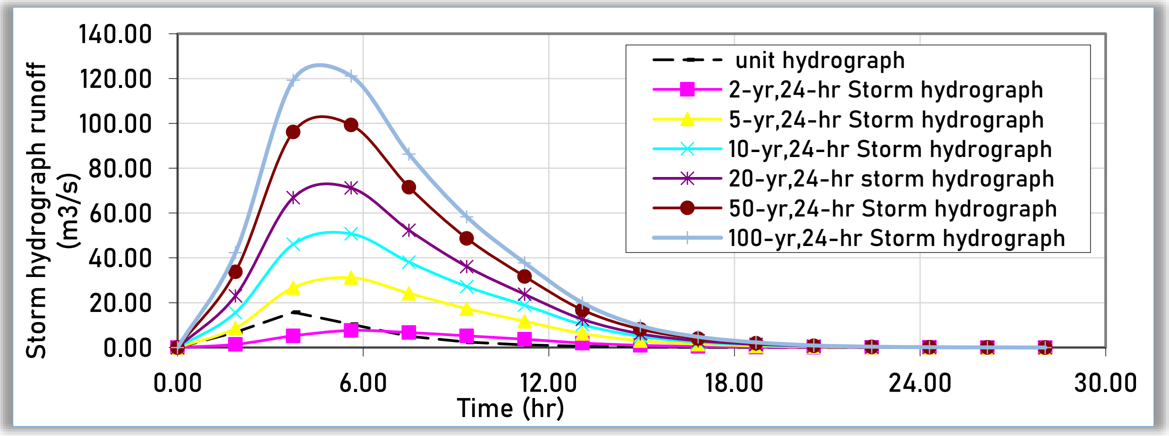

Figure 4g. Comparison of unit and storm hydrographs of different return periods for site 7

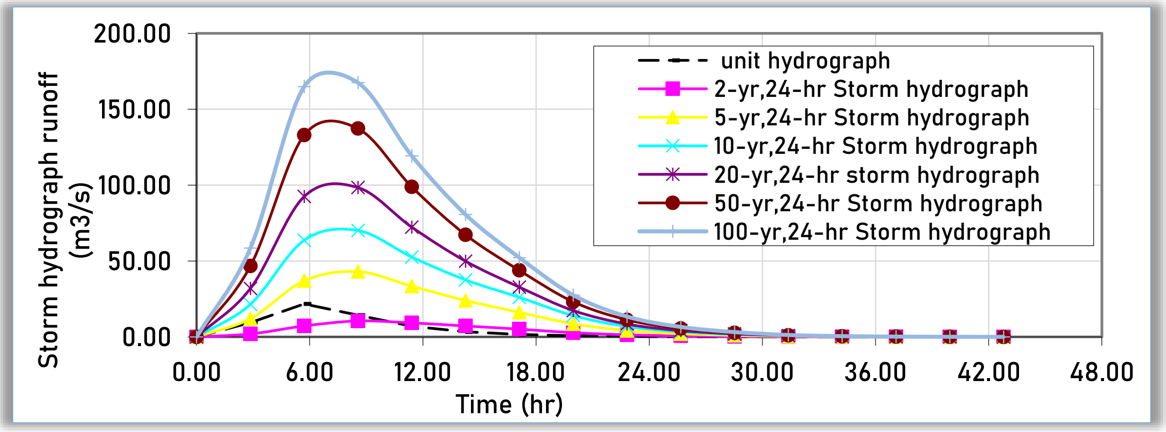

Figure 4h. Comparison of unit and storm hydrographs of different return periods for site 8

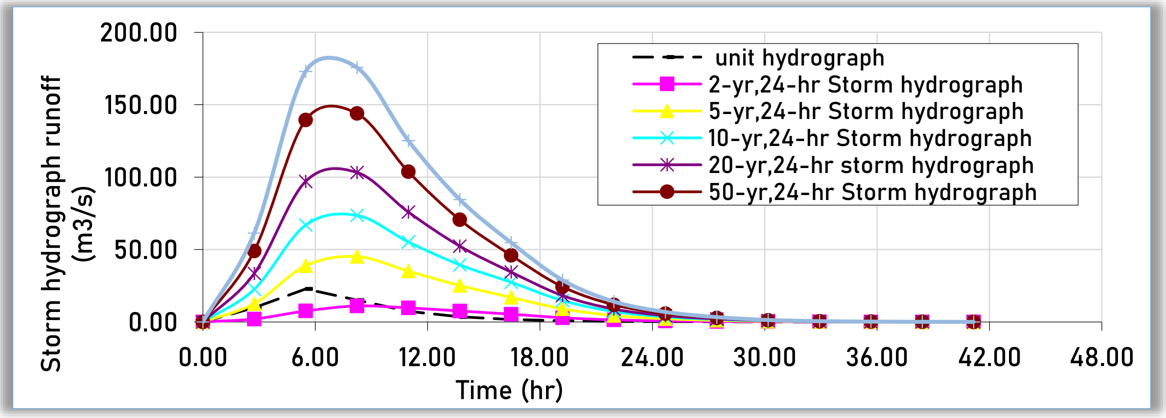

Figure 4i. Comparison of unit and storm hydrographs of different return periods for site 9

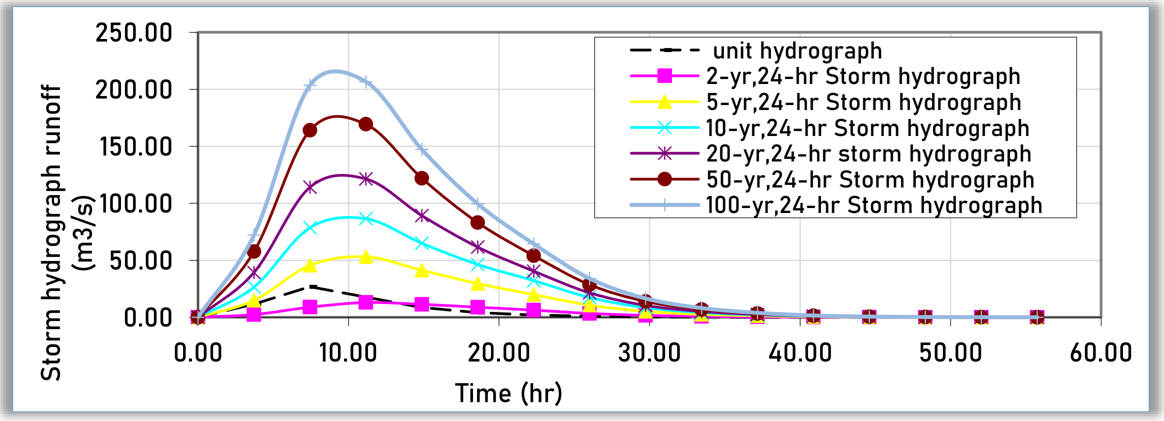

Figure 4j. Comparison of unit and storm hydrographs of different return periods for site 10

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The unit hydrograph and storm hydrograph were established for the sites based on excess rainfall estimated for different return period and revealed in Figure 4. Figures 4a – 4j for sites 1 – 10 respectively. The results showed that storm hydrograph peak runoffs were obtained as 7.26 m^3/s, 29.70 m^3/s, 48.38 m^3/s, 67.89 m^3/s, 94.68 m^3/s and 115.52 m^3/s for return period of 2–yrs, 5–yrs, 10–yrs, 20–yr, 50–yrs and 100–yrs respectively.

Stormwater volume and harvesting site locations

The harvestable stormwater was estimated as the product of excess rainfall and the watershed area of each site. The value obtained based on the excess rainfall derived from rainfall depth of various return periods were presented in Table 3.

Table 3 Stormwater harvestable for the ten (10) sites or catchment for different return periods

Return periods, T (Yrs)	Storm water harvestable based on each site (watershed areas) $x10^6m^3$ (Mm^3). Sites (Catchments)										Total Mm^3
	1	2	3	4	5	6	7	8	9	10	
2	0.29	0.21	1.55	3.51	4.53	1.66	0.22	0.47	0.48	0.76	13.67
5	1.12	0.82	6.09	13.77	17.79	6.49	0.88	1.85	1.86	2.97	53.63
10	1.81	1.33	9.83	22.24	28.74	10.49	1.41	2.98	3.01	4.79	86.63
20	2.53	1.86	13.74	31.08	40.15	14.66	1.98	4.17	4.20	6.70	121.04
50	3.51	2.58	19.08	43.18	55.79	20.36	2.75	5.79	5.84	9.31	168.18
100	4.28	3.14	23.24	52.59	67.95	24.80	3.34	7.05	7.11	11.33	204.84

The slopes established from the DEM were used to determine seven outlets through which runoff escapes from Ilorin metropolitan city (Figure 5). The contours established from the DEM were employed in identifying the seven retention ponds shown in Figure 6, which are the depressions that could serve as the potential stormwater harvesting sites. The coordinates of each identified depression were generated from ArcGIS as presented in Table 4. The coordinates were used in locating the depressions on the earth's surface on GE imageries. The derived potential runoff volume and topography were considered in the location of appropriate sites for stormwater harvesting. Out of the seven obtained potential retention ponds, depressions 2, 3, 4 and 5 were developed residential areas confirmed with the GPS. However, depressions 1, 6, and 7 ae available and suitable as harvesting locations. Depression 6 may not be suitable because it was found along the exiting river channel. The large amount of stormwater estimated with the three available depressions makes stormwater harvesting feasible.

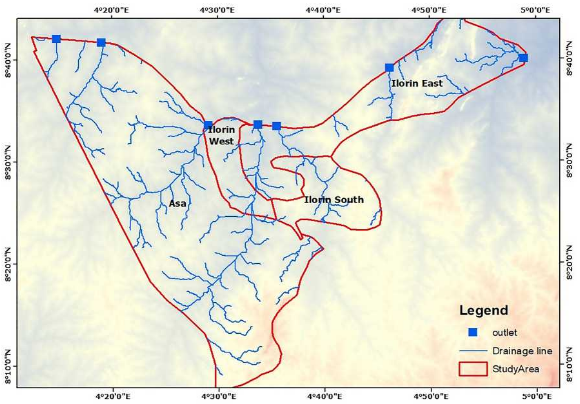

Figure 5. Outlets through which stormwater escapes from Ilorin

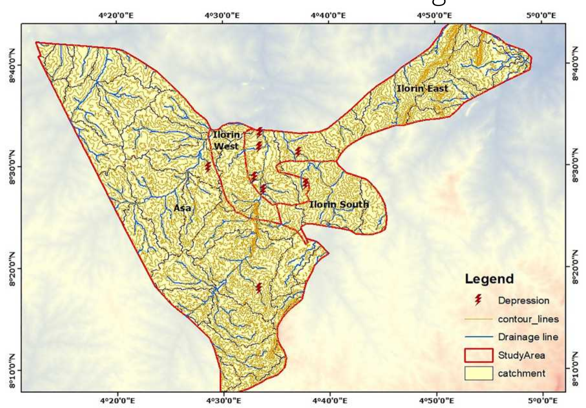

Figure 6. Contour, depressions, and watersheds of the study area

Table 4: Descriptions of depressions for potential stormwater harvesting locations

Depression	Coordinates		Locations	Remarks
	Longitude (°E)	Latitude (°N)		
1	4.467	8.503	Afon	Available
2	4.567	8.476	Onikanga	Built–up
3	4.610	8.530	Sango	Built–up
4	4.623	8.485	Tanke	Built–up
5	4.550	8.490	Edun	Built–up
6	4.570	8.550	Shao	Available
7	4.530	8.320	Asa	Available

5. CONCLUSIONS

The excess rainfall derived from daily rainfall depth in Ilorin metropolitan city with different return periods of 2–yrs, 5–yrs, 10–yrs, 20–yr, 50–yrs and 100–yrs revealed the corresponding harvestable volume of storm water of 13.67 Mm^3, 53.63 Mm^3, 86.63 Mm^3,121.04 Mm^3, 168.18 Mm^3 and 204.84 Mm^3 respectively. This volume of water has been wasted through runoff, but if harvested it will offer a potential alternative source of water for potable and non–potable purposes and also serve as a means of mitigating flooding and pollution in natural waterways.

The implication of variabilities of rainfall is that the lower the return period the higher the chances of recurrence of the amount of stormwater to be captured. For example, 13.67 Mm^3 volume of stormwater have return period of 2–yr with 50% probability of exceedance compare to 204.84 Mm^3 volume of stormwater that have return period of 100–yr with 1% probability of exceedance. In planning for capturing of stormwater, there is need to put the variability of rainfall into consideration. However, for the 13.67 Mm^3 volume of stormwater that is likely to be always available is a good motivator to incorporate stormwater harvesting in overall water resources management in the study area. The locations and sizes of the identified three available harvesting sites of seven depressions are advantageous to stormwater harvesting in Ilorin metropolitan city in terms of supporting topography, high soil water holding capacity, and less vulnerability to flooding.

The urban runoff water harvesting system, though a new phenomenon at a large scale in Nigeria, can serve all the non–potable water demands. It can be integrated into the city planning to reduce the frequent flooding thereby improving the street landscape, greener environment, and reducing water shortage by providing an alternative water source. This study has identified three depressions for locating appropriate sites for stormwater harvesting and storage. The large quantity of stormwater volume determined with the three available depressions will make stormwater harvesting practices in the Ilorin metropolis feasible.

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