

Assessment of Storm Drain for 33KV Switches Yard at Sagamu Substation, Ogun State, Nigeria

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ABSTRACT

Storm drain serves a lot of purposes most especially for a substation and if not properly channeled and constructed might cause a lot of harm to the environment in the form of pollution and electrocution in the substation since the area will be waterlogged. This paper focused on assessment of the existing drainage system of 33KV Switches Yard at Sagamu Substation, Ogun State, Nigeria with the view of re-designing storm drain that can accommodate excess flow. After the preliminary locations of the inlets, connecting pipes and outfalls with tailwater were determined. Subsequently, the rate of discharge carried by the storm drain as well as the size and gradient of pipe required to convey this discharge in the substation were computed. The inlet location and the spacing were determined. The storm drain which was designed to drain a major sag point was sized to accommodate the runoff from a 25 year frequency rainfall. Landsat 7 and 8 imagery of the area for 2018 from Google Earth Survey were used to generate Land use map and cover. Peak discharge was computed using a rational method. The estimated time of concentration (t_c) using Morgali and Linsley, Kirpich and Kerby-Hatheway methods were 26.2, 0.67 and 3.8 minutes, respectively. The land use map of the area is majorly characterized by built up area and vegetal cover. The unbuilt parts of the catchment were riverine and has vegetal cover. The estimated composite co-efficient of the total drainage area was 0.5653 m^2 which reflect the land use pattern of the study area. The peak discharge using rational method has a mathematical relationship of $y=125.6x + 5E-11$ with coefficient of regression of unity.

1. INTRODUCTION

A storm drain or drain system is designed to drain excess rain and groundwater from impervious surfaces such as paved streets, car parks, parking lots, footpaths, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems. They are fed by street gutters on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns which experience regular storms. Many storm drainage systems are designed to drain the storm water into rivers or streams. Some storm drains lead to mixing of storm water with sewage, either intentionally in the case of combined sewers or unintentionally (Martins, 2002; Dieter, 2013; Sobinho, 2009).

A substation is part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions. Between the generating station and consumer, electric power may flow through several substations at different voltage levels. Substations may be owned and operated by an electrical utility, or may be owned by a large industrial or commercial customer. Generally substations are unattended, relying on Supervisory Control and Data Acquisition (SCADA) for remote supervision and control. A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two different transmission voltages. The word substation comes from the days before the distribution system became a grid. As central generation stations become larger, plants generating smaller energy were converted to distribution stations, receiving their energy supply from a larger plant instead of using their own generators. The first substations were connected to only one power station, where the generators were housed, and were subsidiaries of that power station (Donald and Wayne, 1998).

Sagamu is the third largest settlement in Ogun State after Abeokuta and Ijebu-Ode with a land area of 68.03 km² which lies within latitude 6°50' - 7°00' N and longitude 2°45' - 4°00' E. Storm drains is an important part of stormwater management system in the substation which is designed to control the quantity, quality, timing and distribution of storm runoff through its network of structures, channels and underground pipes that carry stormwater (rain water) to ponds, lakes, streams and rivers. The main function of the substations is to improve the availability of quality power supply to Sagamu and neighbouring environment. This research assess the existing drainage system with the view of re-designing storm drain that can accommodate for excess flow.

2. METHODOLOGY

Storm Drains

After the preliminary locations of the inlets, connecting pipes, and outfalls with tailwater were determined, the rate of discharge by the storm drain was computed and the size and gradient of pipe required to convey this discharge in the substation were determined. This was carried out by starting at the upstream reach, calculating the discharge and sizing the pipes, then proceeding downstream reach to the point the storm drain connects with other drains or the outfall. At manholes where the pipe size was increased, it is recommended that pipe be inverted in the manhole to be lowered to match crowns or at least 80% of the difference in pipe sizes.

The release at any point in the storm drain is not the sum of the design inlets above the storm drain section. It is generally less than its total. The rainfall intensity used in the design grows smaller while the time of concentration is mostly influenced when it grows larger. In some cases, where a relatively large drainage area with a short time of concentration is added to the system, the peak flow maybe larger using the shorter time even though the entire drainage area is not contributing. For ordinary conditions, storm drains was sized on the assumption that they flow full or practically full under the design discharge but not flow under pressure head. Manning's Formula is recommended for capacity calculations. The exceptions are depressed sections and underpasses where ponded water can be removed only through the storm drain system. In this design, a-25 year return period of discharge was adopted to design the storm drain at the Sagamu substation in Ogun State.

Design Procedures

The design of storm drainage was generally divided into different operations. The inlet location and the spacing were determined. The data used for preparation of layout plan of the storm drainage system were location of the storm drains, direction of flow and location of existing utilities such as water, gas or underground cables in the switch yard. Intensity-Duration-Frequency (IDF) curve (Figure 1) obtained from Awofadeju *et al.* (2018) was used to determine the drainage areas, runoff coefficients and a time of

concentration to the first inlet. The rainfall intensity and the discharge was determined by multiplying $A \times C \times I$; where A – is the area (km^2), C – is the runoff coefficient, and I – is the rainfall intensity (mm/hr). The size of the pipe that will convey the discharges by varying the slope and pipe sizes were necessary and the storm drain systems were normally designed for full gravity flow conditions using the design frequency discharge. Travel time in the pipe to the next inlet or manhole was calculated by dividing the pipe length by velocity. At the next entry point, the new time of concentration and rainfall intensity was derived with the addition of travel time and time of concentration.

The new area (A) multiplied by the runoff coefficient (C) was added to the previous (CA) multiplied by the new rainfall intensity to determine the new discharge. Size of the pipes and slopes were determined to convey the discharge. The above process was repeated for the storm drain outlet. Equation and monograph were utilized to accomplish this design effort. This design was checked by calculating the hydraulic grade line (HGL). The design procedures include storm drain design computation and design sheets clearly identified (Wong, 2005).

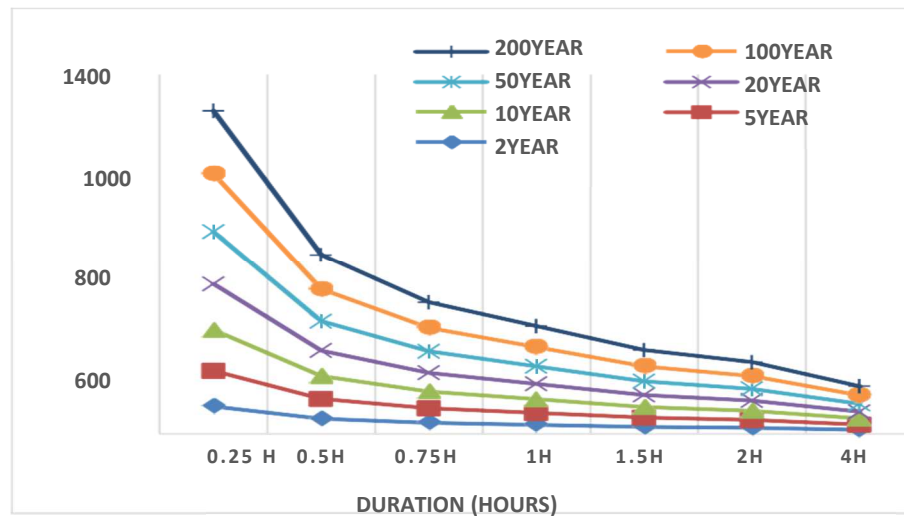


Figure 1: IDF Curve for Abeokuta
Source: (Awofadeju *et al.*, 2018)

25 Years Return Period of Discharge

The storm drain for a major sag point was sized to accommodate the runoff from a 25 year frequency rainfall. This was done by computing the runoff occurring at each inlet during a 25 year rainfall and accumulating it at the sag point. The inlet at the sag point as well as all storm drain pipes leading from the sag point to the outlet were sized to accommodate the additional runoff within the established criteria. Another method which is approximate is the assumption that during the 25 years rainstorm, the on-grade inlets intercept the 10 year flow and the runoff consist of the difference between the 25 years and 10 years runoff (Brater, 2006; Sherindan *et al.*, 2002; Martins, 2006). The approximate method follows a step-by-step procedure as follows:

- i CA contributing to the sag point was calculated.
- ii From the IDF curve (Figure 1), the rainfall intensity for both I_{25} and I_{10} for the concentration computed in the storm drain pipe at the sag point was determined.
- iii Multiplication of the total CA by the difference of $I_{25} - I_{10}$.
- iv This is the 25 year runoff.
- v The 25 year runoff was converted to an equivalent of CA by dividing it by I_{10} in the pipe at the sag point.

- vi Addition of the equivalents of CA to the total CA.
- vii The pipe from the sag point resulting from the CA in (v) multiplied by I_{10} and continuous addition of CA from the additional inlets.

Hydraulic Capacity

Manning's Formula is the most widely used formula for determining the hydraulic capacity of storm drains for both gravity and pressure flows. It is expressed with the following equation:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \quad (1)$$

In terms of discharge, the above equation becomes:

$$Q = VA = \frac{1.486}{n} AR^{2/3} S^{1/2} \quad (2)$$

For storm drains flowing full, the above equations become:

$$V = \frac{0.590}{n} D^{2/3} S^{1/2} \quad (3a)$$

$$Q = \frac{0.463}{n} D^{8/3} S^{1/2} \quad (3b)$$

where:

V = mean velocity of flow (m/s)

S = the slope of the energy grade line

R = hydraulic radius (m) area of flow divided by the wetted perimeter (AP)

n = Manning's roughness coefficient

Q = rate of flow (m³/s)

A = cross sectional area of flow (m²)

D = diameter of pipe (m)

Minimum Grades

The velocities of flow should not be less than 3 f/s at full flow or lower during the design for all storm drains. For very flat grades, the general practice is to design components so that flow velocities increase progressively throughout the length of the pipe system. The storm drainage was checked to ensure there was sufficient velocity in all of the drains to deter setting of particles. Minimum slopes required for velocity of 3fts was calculated by the Manning formula or by using equation (4)

$$S = (nV)^2 / 2.208R^{4/3} \quad (4)$$

where:

S = slope of the energy grade line

n = Manning's roughness coefficient

V = mean velocity of flow (m/s)

R = hydraulic radius (m) area of flow divided by the wetted perimeter (A/P)

Alignment

Curved storm drains are permitted where necessary. Long radius band section was available and the preferable means of changing the direction in 48" and larger. Short radius bend sections was also available and can be utilized if there is no room for the long radius bends. Deflecting the joints to obtain the necessary curvature is not desirable except in very minor curvatures (Wong, 2005).

Hydraulic Grade Line

The hydraulic design of storm drains is established in relation to its important feature using the hydraulic grade line. During the operating system of a flood design frequency, the grade line aids in determining the acceptability of the proposed system by establishing the elevations along the system to which the water will rise. Alternating between pressure and open channel flow conditions from one section to another can also be done by storm drain systems. A special concern with storm drains was designed to operate under pressure flow conditions and possible manhole lid displacement can occur if the hydraulic grade line rises above the ground surface. Evaluation of the potentials for excessive and inadvertent flooding created when a storm

larger than the design storm pressurizes the system was a carefully planned design based on open channels conditions as adopted by Dieter (2003) and Sherindan *et al.* (2002).

Tailwater

The tailwater, either above the crown of the outlet or between the crown and critical depth are used for most designs application. When estimating tailwater depth on the receiving stream, the probability of two events occurring at the same time either joint or coincidental was considered. For the case of this storm drain, its relative independence was qualitatively evaluated by a comparison of its drainage area with that of the receiving stream. A short duration storm which causes peak discharges on a small basin is not be critical for a larger basin which will safely be assumed that if the same storm causes peak discharges on both basins, the peak was out of phase (Dieter, 2003; Sherindan *et al.*, 2002).

Estimation of Time of Concentration

Morgali and Linsley

Morgali and Linsley (1965) equation in ODOT 2014 is as shown in equation (5) is

$$t_c = \frac{0.94(nL)^{0.6}}{i^{0.4}S^{0.3}} \quad (5)$$

where:

t_c = time of concentration (min),

i = design rainfall intensity (in/hr),

n = Manning surface roughness (dimensionless),

L = length of flow (ft), and

S = slope of flow (dimensionless)

Kirpich Method

The Kirpich equation is shown in equation (6)

$$t_c = 0.0078 \left(L^3 / h \right)^{0.385} \quad (6)$$

where:

t_c = time of concentration (min),

L = length of main channel (ft), and

h = relief along main channel (ft).

Kerby-Hatheway Method

The Kerby-Hatheway equation is presented in equation

$$t_c = \left[\frac{0.67NL}{\sqrt{S}} \right]^{0.467} \quad (7)$$

where:

t_c = time of concentration (min),

N = Kerby roughness parameter (dimensionless), and

S = overland flow slope (dimensionless).

Estimation of Composite Coefficient

A composite coefficient for the total drainage area is computed by dividing the summation of the products of the sub-areas and their coefficients by the total area where a drainage area is composed of subareas with different runoff coefficients as shown in equation (8)

$$C(\text{Composite}) = \frac{\sum (C_{\text{individual area}} A_{\text{individual area}})}{A_{\text{Total area}}} \quad (8)$$

The available data used in the computation is as shown in Table 1

Table 1: Available Data used for Computation

Parameters	Unit	Values
L	feet	300
h	feet	4
N	-	0.3
S	-	0.05
n	-	0.05
i	mm/hr	155

3. RESULTS AND DISCUSSION

Time of Concentration (t_c)

Table 2 shows the time of concentration obtained using the methods of Morgali and Linsley, Kirpich and Kerby-Hatheway. The time of concentration estimated by Morgali and Linsley was higher than others. The value estimated was 26.2 min. The lowest time of concentration was obtained with Kirpich method and was 0.67min. The assumption made by Kirpich was not appropriate for the study area. Kerby-Hatheway method of computation for time of concentration gave 3.85 min for the study area. For application of the rational method, TxDOT recommends that t_c be less than 300 min (5 hours) and greater than 10 min. Other agencies require that t_c be greater than 5 min. The concept is that estimates of I become unacceptably large for durations less than 5 or 10 min. For long durations (such as longer than 300 min), the assumption of a relatively steady rainfall rate is less valid.

Table 2: Time of Concentration (t_c)

Morgali and Linsley method	26.2 min.
Kirpich method	0.67 min.
Kerby-Hatheway method	3.85 min.

The length of the overland sheet flow segment is the shorter of: the distance between the drainage divide and the upper end of a defined channel, or a distance of 300 feet. The overland sheet flow velocity is usually slower than the velocities further downstream. The kinematic wave equation can be used to estimate the time of concentration associated with overland sheet flow. Both the flow time and the rainfall intensity are unknown and can be calculated using the time of concentration for overland sheet flow which could either be an iterative or trial and error solution.

Land Use Map

The land use pattern of the study area were classified as water bodies, vegetal area built up and paved area using Landsat 7 and 8 Satellite images of the area obtained from google Earth Geological Survey with 30 by 30 m resolution. The satellite images of 2018 was processed ArcGIS 10.4 software. The percentages of the built up environment, paved area, vegetal area and water bodies from ArcGIS software were 84.4, 0.6, 10 and 5%, respectively. The land use pattern showing the hectares covered is shown in Table 3 and the Land use map is shown in Figure 2. The study area is a developed area. Most areas with vegetal cover are riverine area which limit its usage for construction purposes. The paved sections are located after Ikorodu–Sagamu axis where some companies are located.

Composite Coefficient of Total Drainage

The composite Coefficient of Total drainage was computed using Land use map (Figure 2) and equation 8. The land use map, its percentages and values of coefficient are presented in Table 3. The composite coefficient was used in the rational equation to compute Total discharge. It should be noted that using an average value from the Table 3 may not be realistic because of varying land use pattern. It is therefore

important to estimate the composite coefficient to reflect the real nature of land use in the area instead of a general value. The estimated composite coefficient was 0.5653 instead of a general value of 0.5 from the Table 3.

Table 3: Land use Pattern of the Study Area

Land Use	Ha	Percentage	Coefficient
Medium Residential	30	45	0.38
High Residential	25	29	0.75
Industrial/Commercial	35	26	0.68

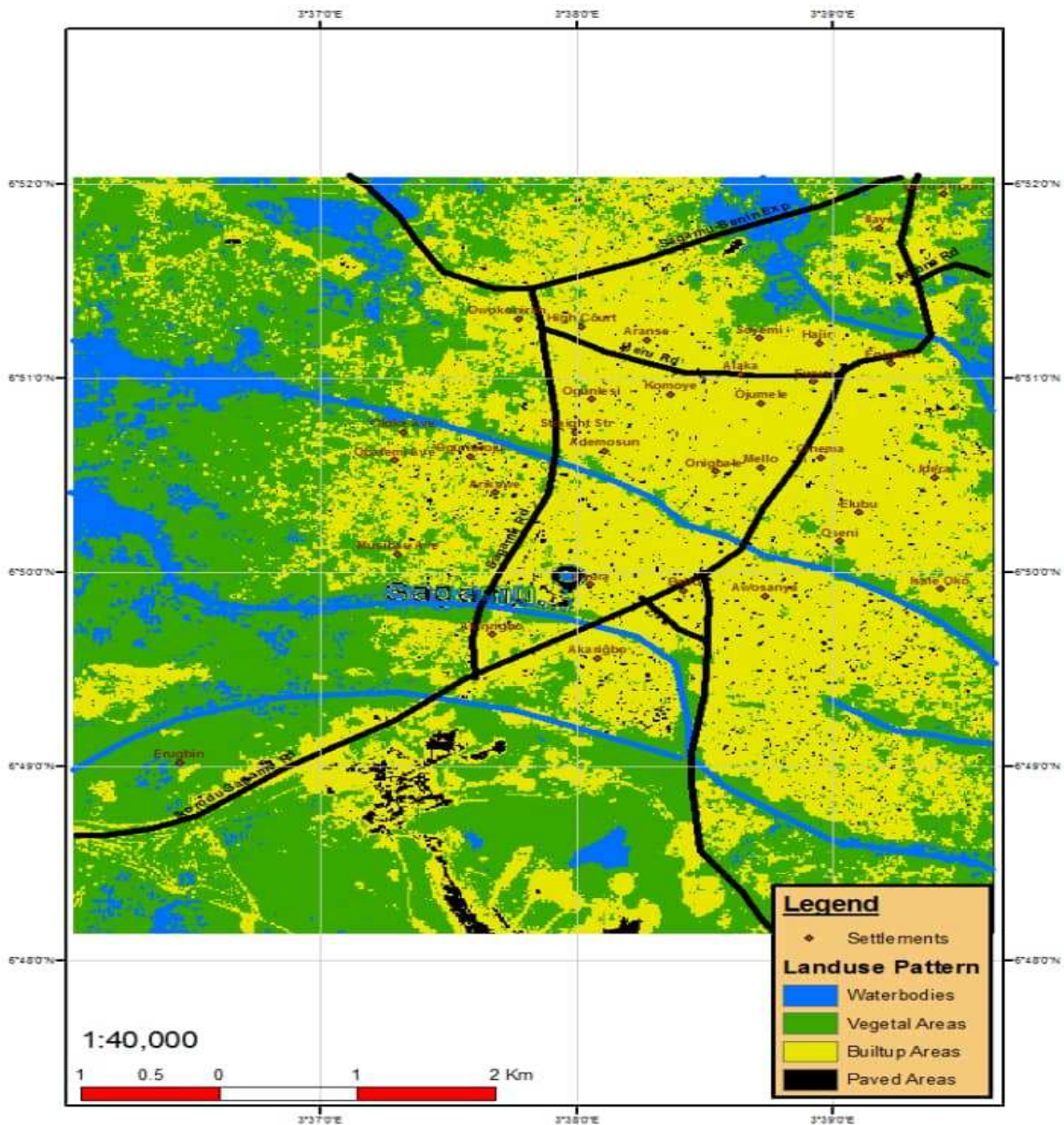


Figure 2: Land Use Map of the Study Area

Peak Discharge Computation

The peak discharge is presented in Figure 3. The highest and lowest discharge values were 20598.4 and 1758.34 CFS in 1980 and 1975, respectively. The discharge is a variable of the rainfall intensity. The variability of discharge data due to varying rainfall intensities was also observed in Figure 3. Figure 4 shows the rainfall-runoff relationship of the study area. The relationships was linear as represented by the mathematical relationship of $y = 125.6x + 9E-11$ with coefficient of regression of 1. Although, climatic data like hydrological data are probabilistic in nature. At the same time, the rainfall runoff relationship could be linear if the water shed is paved. This implies that runoff is a function of the rainfall intensity, higher the rainfall intensity will produce higher discharge. The power and exponential model of the rainfall-runoff relationship of the catchment are shown in equations 9 and 10 with coefficient of regression of 1 and 0.994, respectively. Figures 5 and 6 show the rainfall-runoff relationship using power and exponential functions respectively

Power Model

$$y = 125.6x^1 \quad (9)$$

$$R^2 = 1$$

Exponential Model

$$y = 480.88e^{2E-05x} \quad (10)$$

$$R^2 = 0.994$$

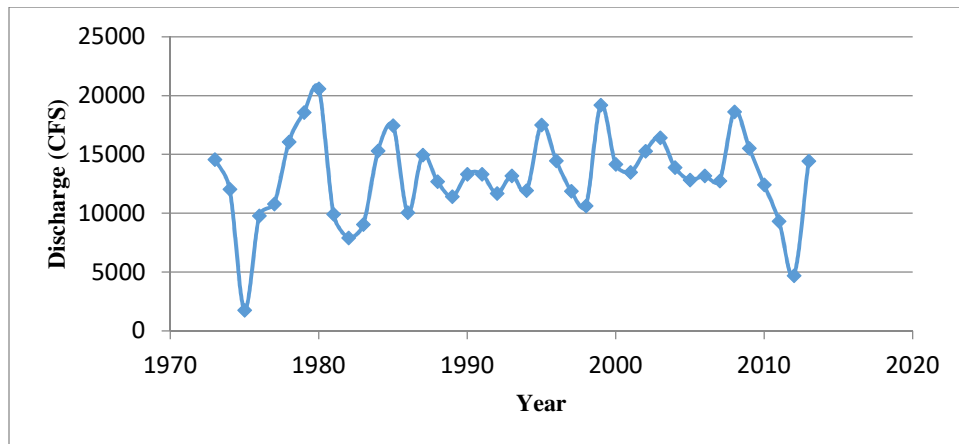


Figure 3: Annual Peak Discharge

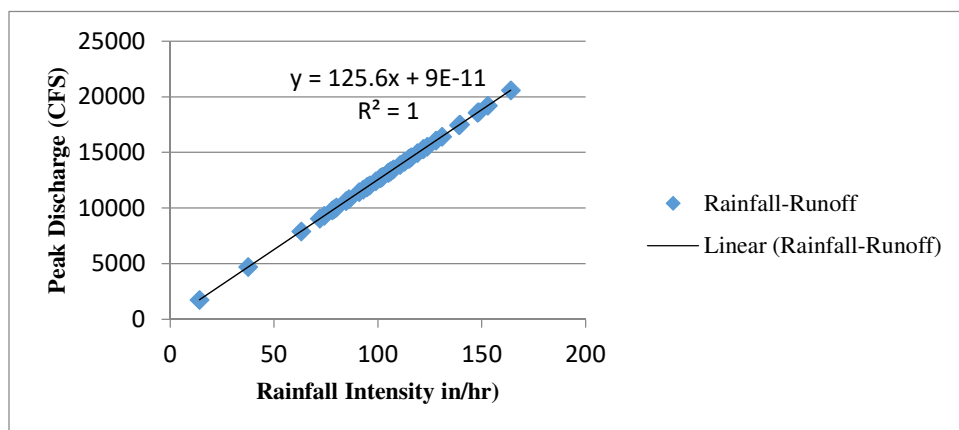


Figure 4: Rainfall-Runoff Model

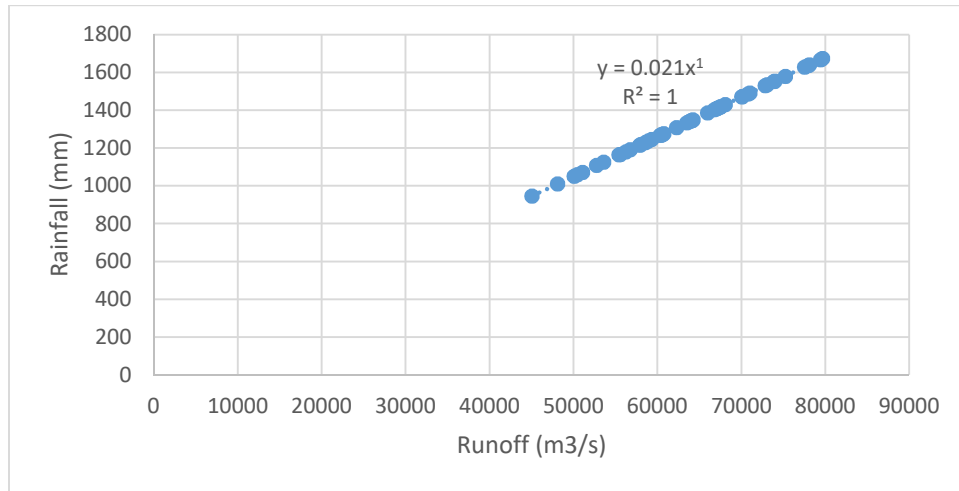


Figure 5: Ranfall- Runoff Relationship Showing Power Relationship

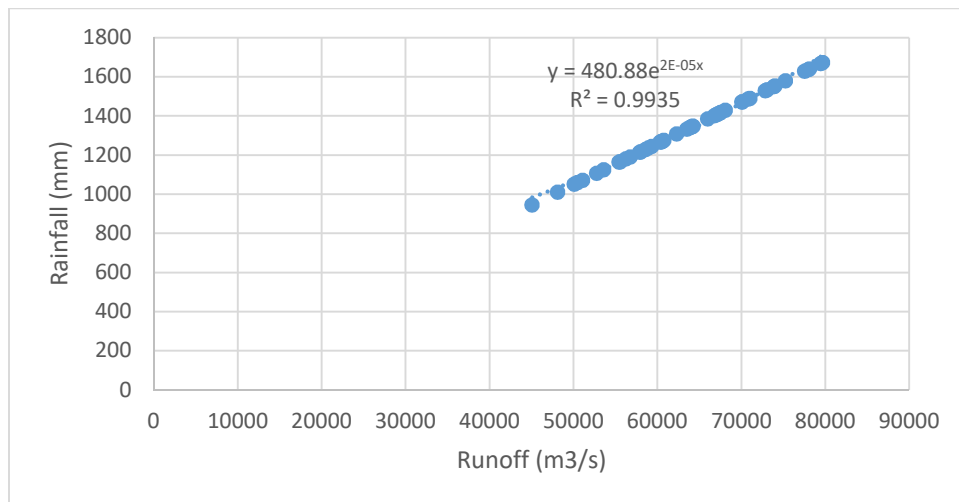


Figure 6: Ranfall- Runoff Relationship Showing Exponential Relationship

4. CONCLUSION

The following conclusions are drawn based on the results of the study.

- The estimated time of concentration t_c using Morgali and Linsley, Kirpich and Kerby-Hatheway method were 26.2, 0.67 and 3.8 minute, respectively.
- The land use map of the area is majorly characterized by built up area and vegetal cover. The unbuilt parts of the catchment were riverine and has vegetal cover.
- The estimated composite co-efficient of the total drainage area was 0.5653 which reflect the land use pattern of study area.
- The peak discharge using rational method has a mathematical relationship of $y = 125.6x + 9E-11$ with coefficient of regression of 1.
- It can be recommended from the study that de-silting of the drains must be done regularly to reduce flooding menace.

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