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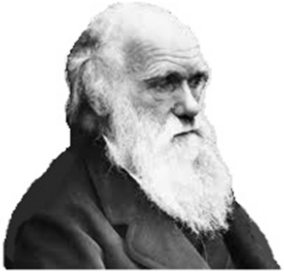

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A model for Flood Prediction in Ibadan, Nigeria

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ABSTRACT

Flooding in Ibadan has led to loss of life, property damage, uninhabitable dwellings, infrastructure destruction, crop loss, traffic congestion, and transportation disruption. This project focused on studying flooding in Ibadan by analysing flood events spanning 1981 to 2021, examining rainfall data, and developing a prediction model for estimating the return periods of peak monthly rainfalls in the city. In this project, rainfall data was obtained from NASA's website and analysed using Microsoft Excel for Exploratory Data Analysis. Three probability positions (Hazen, California, and Weibull) were utilized to estimate return periods of peak monthly rainfalls in Ibadan. Various linear regression models were generated at different scales and evaluated using the Coefficient of Determination. The best model was selected to predict the return period of peak monthly rainfall. Hourly discharges were also compared. In the Exploratory Data Analysis, the maximum annual rainfall and wettest month in Ibadan were identified. The prediction model for peak rainfall return period yielded a satisfactory coefficient of determination of 0.9389, making it suitable for predictions. The graph comparing Hourly Discharges over two days revealed that the discharge during the 2011 flood in Ibadan was three times higher than four days prior. The study shows that to manage the effect of future flood, a prediction model such as the one generated in this project is needed to allow for maximum preparation. Furthermore, the drainage channels need to be widened and deepened to allow them to carry any sudden increase in discharge from the Ogunpa river.

Keywords: Flood, return period, flood prediction, coefficient of determination

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1. INTRODUCTION

Flooding is defined as the overflowing of a body of water over dry ground (Hutapea, 2020). The word "flood" comes from the Old English language and is a word that is used frequently in Germanic languages (compare German "Flut" and Dutch "vloed," which all derive from the same root as "flow" and "float," as well as Latin "fluctus" and "flumen"). It was first used in 1663. In the past ten years, the humanitarian impacts of floods in sub-Saharan African have surpassed that of drought (Turay(2022), Nwigwe and Emberga (2014), Aderogba (2012)).

Every year, floods are a serious tragedy that afflict many nations of the world, particularly in many flood plain areas (Agbede and Aiyelokun, 2016). In Nigeria, from 1985 to 2014, flooding has impacted the lives of more than 11 million people (Nkwunonwo, 2016). Floods not only cause property destruction and put human and animal lives in danger, but they also have additional unintended consequences including the spread of illnesses like cholera and malaria (Louw et al., 2019).

The fact that the 2012 flood disaster in Nigeria was unparalleled in the previous 40 years is what makes it significant. Excessive rainfall, terrain and type of soil were established to be the natural causes of flood in Mfon et al. (2022).

This research aims to study flooding events in Ibadan from 1981-2021, with a focus on building a predictive model to estimate the return period of peak monthly rainfalls in the city. Furthermore, an exploratory data analysis of the rainfall data during the study period will be conducted to visualise and characterize the rainfall patterns.

In Nigeria, flooding is a yearly occurrence (Emeka (2012), Umar, N. and Gray, A., (2023)). It often happens from July until September/October, when there are particularly severe rainstorms. Floods are a problem throughout Nigeria, from the Niger Delta to the Niger-Benue basins to the Sokoto Rima basin. Large river basins and sheds around the nation make many locations vulnerable to flooding (Echendu, 2020). The Ogunpa flood in Ibadan in 1980, which took many lives and significantly damaged property, was one of the notable flood years. Other years include 1987, 1991, 1994, and the terrible 2012 floods, which are reportedly the worst in forty years.

There was major flooding in the Rima basin in 2010 that impacted many rural towns, inundated highways, forced thousands of people to leave their homes, and devastated food crops. The Usman Danfodio University was completely shut off from the rest of the town when the bridge that connected it to it was washed away, therefore the university had to be closed. Even the city of Sokoto experienced the pain of the floods. The area had to be classified as a national catastrophe, and the federal government had to offer aid to the local governments and state governments.

In other regions of the nation, the tale is comparable. 2011 saw unprecedented devastation and hardship to coastal areas because of catastrophic flooding. In other regions of the nation, the tale is comparable. Massive floods in 2011 devastated coastal towns in Lagos and inland regions of Ibadan, causing incalculable harm and hardship. The renowned University of Ibadan in Ibadan was submerged by floodwaters and a deluge that destroyed a number of academic buildings, the museum, the botanical gardens, etc. The yearly tradition of flooding throughout the rainy season from Kano to Jos, from Makurdi to Benin, and from Lagos to Port Harcourt does not spare many cities.

Ibadan has experienced flooding to varied degrees. For instance, flooding occurred in the Ogunpa and Kudeti streams' basins (one of Ibadan's two main streams) in 1955, 1960, 1961, 1963, 1969, 1978, and 1980. The 1969 flood was exceptional since it was brought on by just 25.4 mm of rain.

It is challenging to gain an exact evaluation of the damage inflicted by floods in Ibadan over the years. Nevertheless, numerous official projections have been made at various times. The highest loss recorded in the city was during the 2011 flood (Agbola et al., 2012). The University of Ibadan lost properties estimated at 10 billion naira. Six flooding events in Ibadan are listed in Table 1 along with their timeline.

On August 26, 2011, a record-breaking 187.5mm of rain fell at the IITA, starting at 16:40 and lasting until 20:00, with sporadic drizzle continuing until 23:00 and winds gusting as high as 65 km/h. According to IITA, the heaviest rain came between 18.10 and 19.20 hours, when 75% or 140.63 mm of rain fell. Rainfall intensity is currently averaging 127.84/hr (Alayande et al., 2012). Tella and Balogun (2020) found the rainfall, runoff, and distance to stream to be the major factors contributing to flood in Ibadan.

Table 1. Major Flood occurrences in Ogunpa River (1960-1980)

Year	Properties damaged in Naira	Lives lost
1960	Multiple	Not recorded
1963	Multiple	Two or less
1969	Multiple	Two or less
1973	Above N100,000	Three
1978	Multiple	Two or less
1980	Above N300,000	Over 500 lives lost with 50,000 displaced

Flood prediction is the process of using various tools and techniques to forecast the likelihood, timing, and magnitude of future flood events. Return period is one of the key factors that can be used to make flood predictions. By understanding the average frequency with which flood events of a certain magnitude are expected to occur, decision makers can make informed decisions about how to prepare for and respond to potential flooding (Tramblay et al., 2021, Lawal et al, 2021).

A return period, which is sometimes referred to as a repeat interval or recurrence interval, is the average or estimated average time between occurrences of certain phenomena, such as earthquakes, floods, landslides, and river discharge flows. It is a statistical measurement that is frequently based on historical data collected over a long period of time and is typically used for risk assessments.

Linear regression is one of the common methods to find the relationship between a dependent variable and a number of independent variables. After getting the return period data, linear regression tools in Microsoft Excel were used in this project to plot the expected annual rainfall against the number of years they'll occur.

2. MATERIALS AND METHODS

2. 1. Study Area

Ibadan is chosen as the study area for this project. It is the capital of Oyo State and is located in the rainforest region of the country. Four rivers, including the Ona River in the north and west, the Ogbere River to the east, the Ogunpa River that runs through the city, and the Kudeti River in the middle of the metropolis, naturally drain the city. Ogunpa river is the focus of this project for discharge modelling.

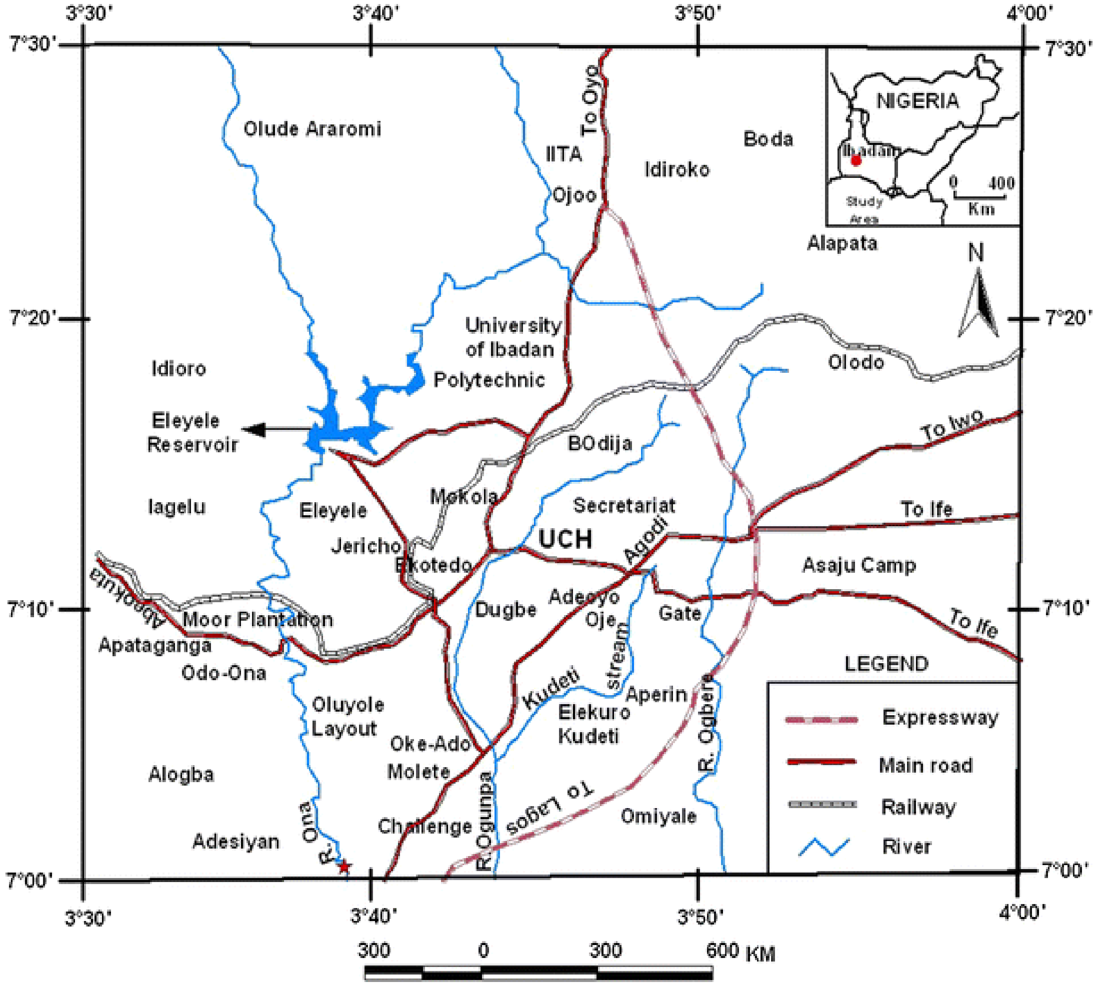

Figure 1. Map showing different parts in Ibadan and its major rivers
Source: Ganiyu et al., 2016

2. 2. Data Collection

The data used in this project was collected from the National Aeronautics and Space Administration (NASA) website. The monthly rainfall data in Ibadan from 1981 -2021 was collected. Hourly rainfall data for the 22nd and 26th of August 2011 was also collected to compare discharges from the Ogunpa river basin.

2. 3. Exploratory Data Analysis

Exploratory Data Analysis (EDA) was done on the data to visualize the trends in the amount of rainfall recorded in Ibadan from the years 1981 to 2021. The monthly rainfall distribution over the years was also analysed.

2. 3. 1. Annual Rainfall Trend

This will show the trend in annual rainfall during the period. Microsoft Excel will be used to calculate total rainfall in each year during the period.

2. 3. 2. Monthly Rainfall Distribution

The mean rainfall across the different months across the years was also calculated to see the wettest months across the years in Ibadan.

2. 3. 3. Data Visualization

Visualization in the form of charts such as bar chart, line chart. A bar and line chart were used in this project to visualize the total annual rainfall and mean monthly rainfall respectively.

2. 4. Probability Plotting Positions

Probability plotting position (PPP) is a statistical method used in hydrology to analyse flood frequency data. The PPP method involves ranking flood events in descending order of magnitude and calculating their corresponding exceedance probabilities (the probability of a flood event being equal to or exceeding a certain magnitude in any given year). This project applied the use of three commonly used plotting position relationships (Table 2) namely the California, Weibull and Hazen methods.

2. 5. Linear Regression Model

Linear regression is one of the common methods to find the relationship between a dependent variable and a number of independent variables. After getting the return period data, linear regression tools in Microsoft Excel were used in this project to plot the expected annual rainfall against the number of years they'll occur. A mathematical model equation was generated which can be used to predict the return period of an expected monthly rainfall.

2. 5. 1. Coefficient of Determination

The linear regression model was used to predict the peak rainfall for the calculated return periods. The R squared value (coefficient of determination) was used in the evaluation of the models built in this project (Table 2).

2. 6. Peak Maximum Discharge

The rational method is used mostly to calculate the maximum discharge. It is widely used to estimate the peak surface runoff for design of a wide variety of drainage structures, such as the length of a storm sewer, storm water inlet. The equation is given by:

$$Q = 0.0028\,CiA \quad \text{….. equation 1}$$

where:
A = The area of the watershed (drainage area) that drains to the point (ha for S.I. units)
C = runoff coefficient for drainage area A. A physical interpretation is the faction of rainfall landing on the drainage area that becomes storm water runoff
i = the intensity of the design storm for peak runoff calculation (mm/hr for S.I. units)
Q = the peak storm water runoff rate from the drainage area, A, due to the design storm of intensity, i (m^3/s for S.I. units).

Table 2. Return period.

Plotting Positions	**Source**	**Formula $P(Q \geq Q_T)$**
California	California (1923)	N/m
Hazen	Hazen (1930)	$^{N}/_{m} - 0.5)$
Weibull	Weibull (1939)	$N + \frac{1}{m}$

2. 6. 1. Drainage Area, A

The Area of the Ogunpa Drainage basin is 7330 hectares (Akin-Oriola, 2003), which was used in this project.

2. 6. 2 Runoff Coefficient, C

The runoff coefficient represents the fraction of the rainfall that will eventually become surface runoff.

2. 6. 3. Rainfall Intensity, I

Two days were chosen: 26th August 2011 (The day of the 2011 flood in Ibadan) and the 22nd of the same month (no flood), to compare the discharges at both dates and draw inferences.

3. RESULTS AND DISCUSSION

3. 1. Exploratory Data Analysis

The results of the exploratory data analysis are shown in this section. From the annual to the monthly analysis.

3. 1. 1. Annual Rainfall during the period

Fig 2 shows a clear picture where 2021 was the wettest year during this period, with a total rainfall of 2832.92 mm. 1983 was the driest year, with a total rainfall of just 1017.77 mm.

There is an observed upward trend in the total annual rainfall over the years. The increase in rainfall totals suggests the impact of climate change on precipitation patterns.

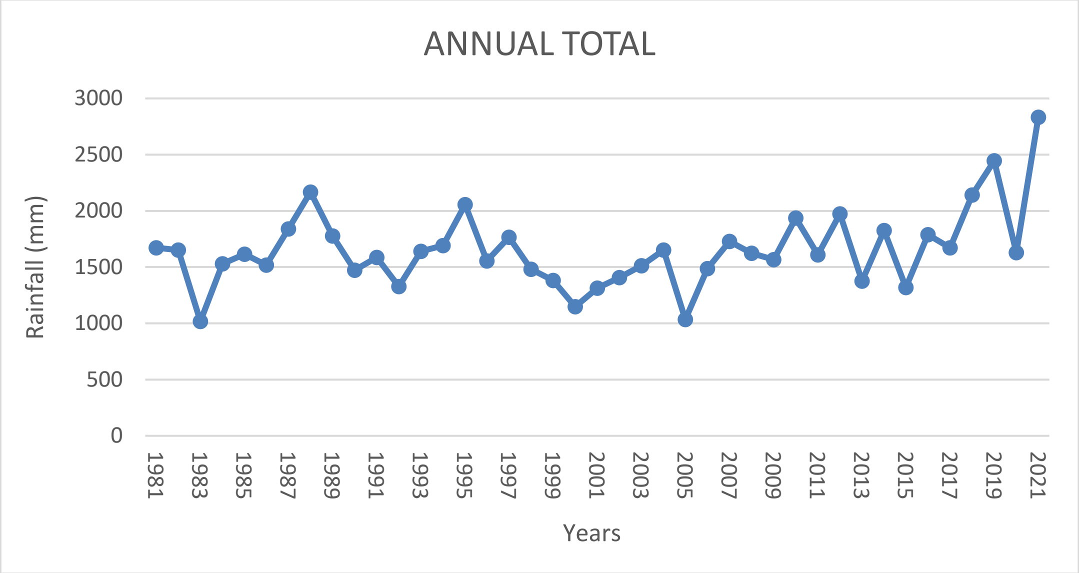

Figure 2. Annual rainfall trends in Ibadan (1981-2021)

3. 1. 2. Monthly Rainfall distributions

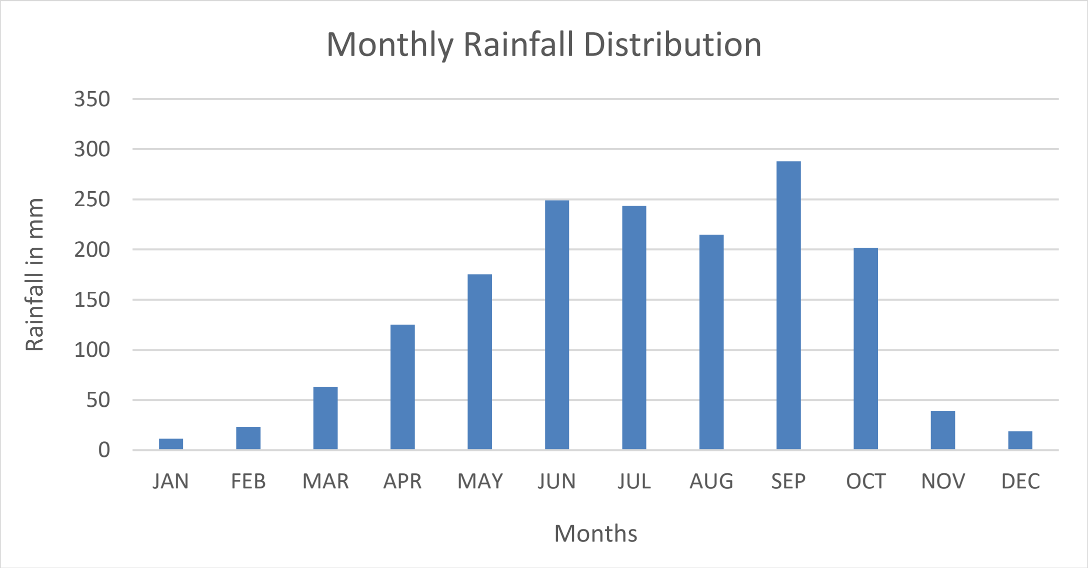

Figure 3. Mean monthly rainfall distributions in Ibadan

Figure 3 shows the mean monthly rainfall distributions over the period. January has the lowest rainfall of 11.44 mm, while September has the most rainfall of 287.8 mm with August (the month when most of the floods occur) having a rainfall of 214.7 mm. June to October appear to be the rainiest periods in Ibadan. The figure shows a clear seasonal trend with a steady increase in rainfall from March and peaking in September before a sharp decline towards the dry season in November and December.

3. 2. Return Period

The probabilities of recurrence were calculated using the California, Hazen, and Weibull methods. For each of the methods, the return period was calculated as the inverse of the probabilities of recurrence.

3. 2. 1. Linear Regression

Linear regression models were generated using excel with the data from each of the three Probability Plotting position methods (Weibull, Hazen, and California). The models were generated on a linear, exponential, and logarithmic scales. The R2 value using the Weibull plotting position was calculated first, which generated low values of 0.5412 and 0.4482 for the linear and exponential scales respectively. Only the logarithmic scale generated a high R2 value of 0.9382. The rain intensity in mm was also plotted against the return periods on a linear scale as seen in Figure 4 for the Weibull plotting position.

Table 3. Regression equations and R^2 – Weibull plotting positions

Scale	Equations	R^2
Linear	$y = 8.6283x + 318.27$	0.5412
Logarithm	$y = 95.462\ln(x) + 263.67$	0.9389
Exponential	$y = 315.5e^{0.0214x}$	0.4482

Table 4. Regression equations and R^2 – Hazen plotting positions

Scale	Equations	R^2
Linear	$y = 4.0103x + 333.89$	0.3934
Logarithm	$y = 84.952\ln(x) + 270.93$	0.9124
Exponential	$y = 328.33e^{0.0098x}$	0.3143

The Hazen plotting position equations were generated next as seen in Table 4. Similar to the Weibull position, the Logarithmic scale produced the highest R2 value of 0.9124. The corresponding equation is shown in Table 4. Additionally, Figure 5 shows the plot of rainfall intensity (mm/month) against return periods (years) on a linear scale.

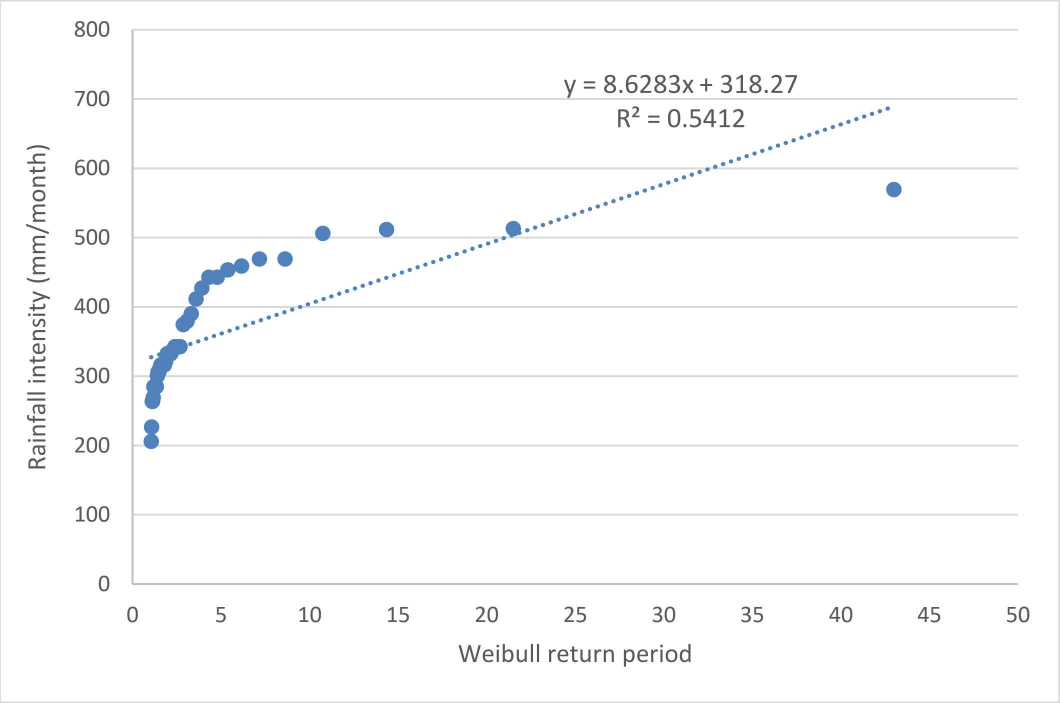

Figure 4. Weibull return period

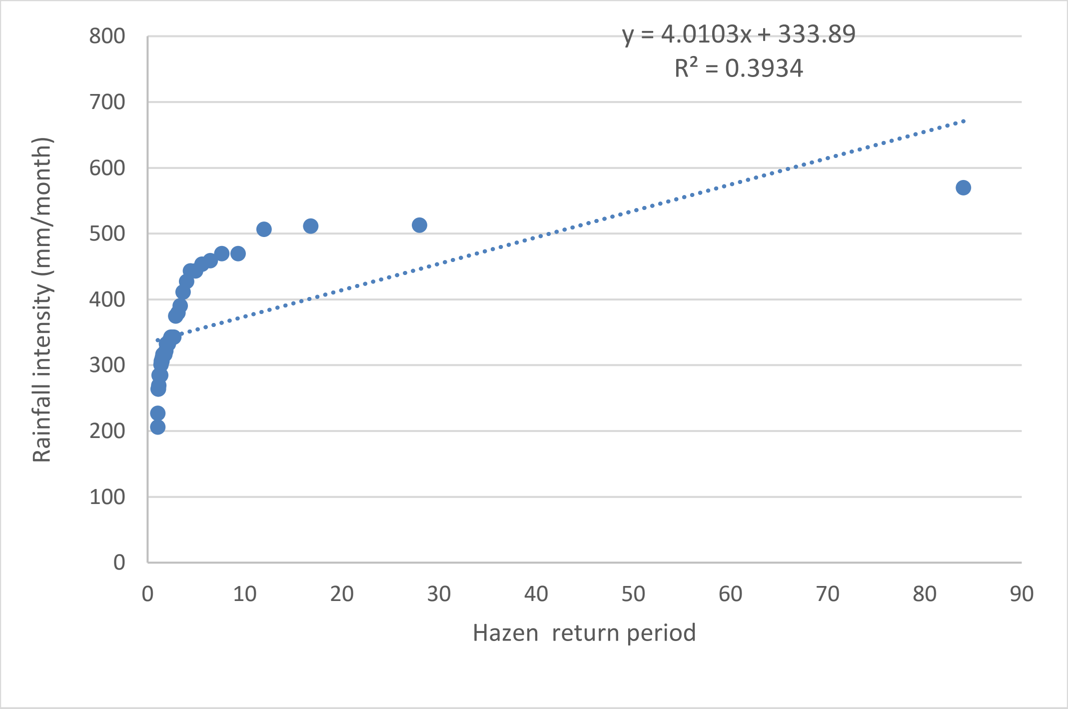

Figure 5. Hazen return period

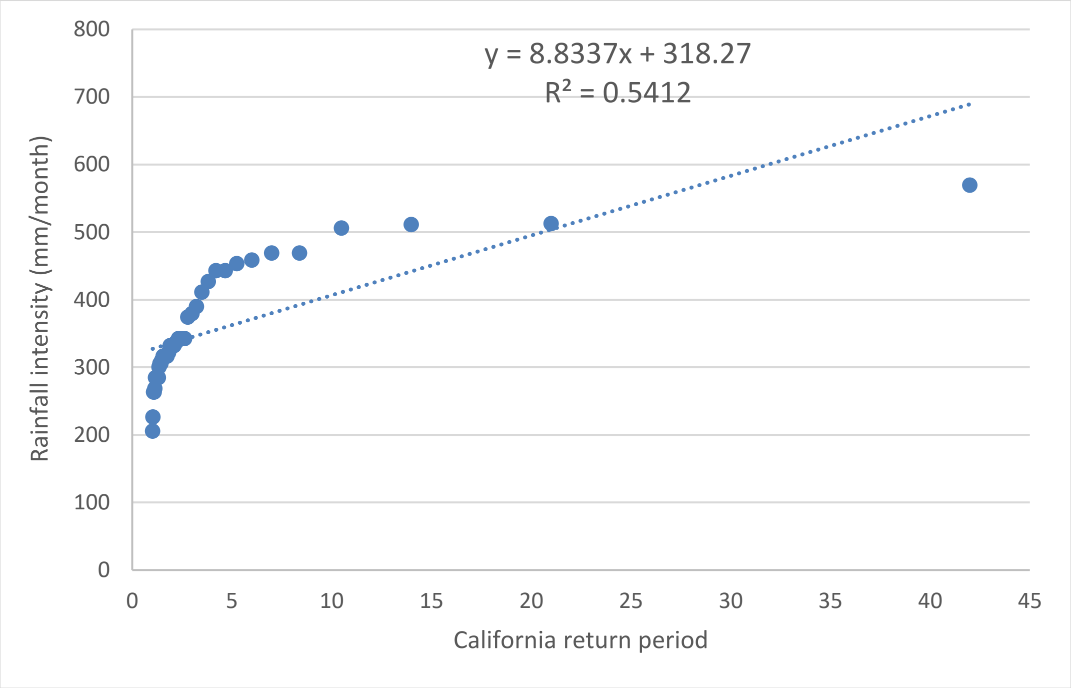

Figure 6. California return period

The California plotting position shows similar results to the Weibull, with the linear, logarithmic and exponential scales producing the same R2 values as seen in Table 5. Figure 6 depicts the relationship between the rainfall intensity in mm/month and return period in years on a linear scale.

Table 5. Regression equations and R^2 – California plotting positions

Scale	Equations	R^2
Linear	$y = 8.8337x + 318.27$	0.5412
Logarithm	$y = 95.462\ln(x) + 265.92$	0.9389
Exponential	$y = 315.5e^{0.022x}$	0.4482

From Tables 3, 4, 5, both the Weibull and California logarithmic scales generated the highest coefficients of Determination (R^2) of 0.9389.

$$Y = 95.462 \ln x + 263.67 \qquad \text{equation 2}$$

where: $y\ is\ the\ return\ period\ of\ the\ peak\ monthly\ rainfall$
$X\ is\ the\ peak\ monthly\ rainfall$

Equation 2 was selected from the Weibull plotting position and has a coefficient of 0.9389.

3. 3. Peak maximum discharge

To obtain this, the Rational method equation, equation 1 was used. The parameters are: Runoff coefficient: Ogunpa area in Ibadan can be classified as a neighbourhood area and the runoff coefficient for neighbourhood areas is shown in Table 6 to be 0.30-0.70. 0.37 was used in this project. The rainfall intensities can be seen in Table 7 and 8. The Drainage Area was taken to be 7330hectares (Akin-Oriola, 2003)

Table 6. Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units. detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks. cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25

Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, > 5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.70
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Table 7. Rainfall intensity: 22nd August, 2011.

HR	**Rainfall Intensity (mm/hr)**	**$Q = CIA/Z$ (m^3/s)**
0	0.37	2.787436
1	0.38	2.862772
2	0.4	3.013444
3	0.44	3.314789
4	0.48	3.616133
5	0.51	3.842142

6	0.5	3.766806
7	0.41	3.088781
8	0.33	2.486092
9	0.29	2.184747
10	0.31	2.335419
11	0.31	2.335419
12	0.26	1.958739
13	0.18	1.35605
14	0.15	1.130042
15	0.11	0.828697
16	0.09	0.678025
17	0.08	0.602689
18	0.09	0.678025
19	0.09	0.678025
20	0.1	0.753361
21	0.11	0.828697
22	0.12	0.904033
23	0.15	1.130042

Table 8. 26th Rainfall Intensity: August, 2011

HR	**Rainfall Intensity (mm/hr)**	**Q = CIA/Z (m^3/s)**
0	1.46	10.99907222
1	1.52	11.45108889
2	1.5	11.30041667
3	1.35	10.170375
4	1.02	7.684283333
5	0.72	5.4242
6	0.49	3.691469444
7	0.35	2.636763889

8	0.37	2.787436111
9	0.54	4.06815
10	0.79	5.951552778
11	1	7.533611111
12	1.2	9.040333333
13	1.24	9.341677778
14	1.24	9.341677778
15	1.07	8.060963889
16	0.96	7.232266667
17	0.95	7.156930556
18	0.9	6.78025
19	0.84	6.328233333
20	0.83	6.252897222
21	0.87	6.554241667
22	0.82	6.177561111
23	0.68	5.122855556

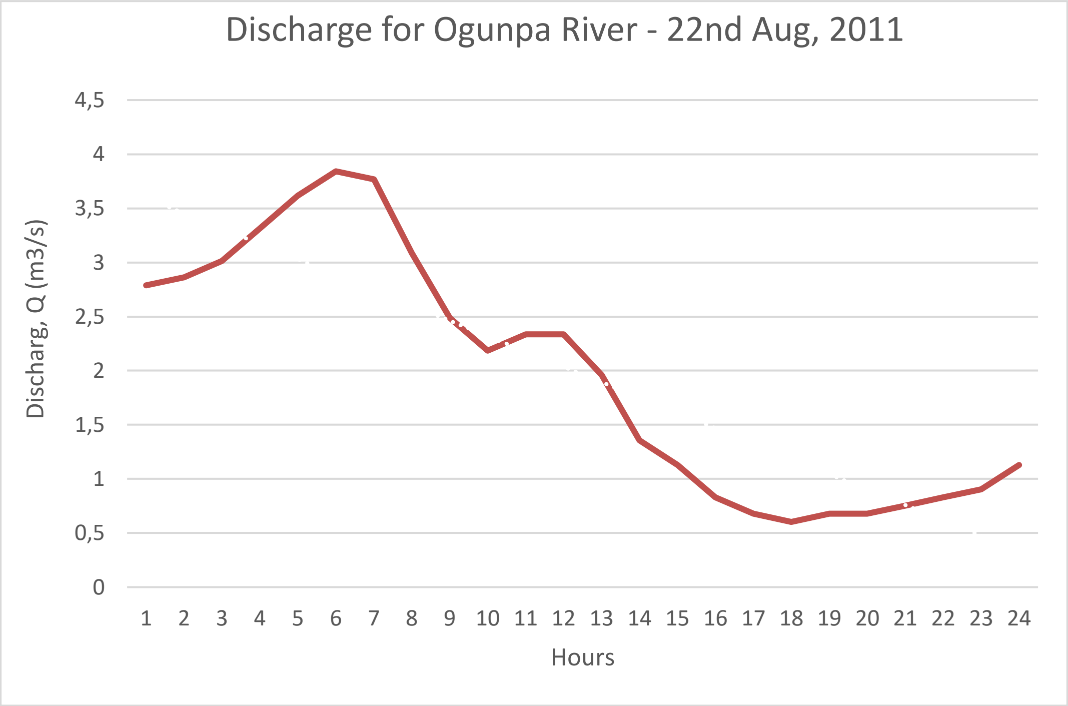

Figure 7. Hourly discharge four days prior to the 2011 flood

In Figure 7, the discharge graph for the 22nd of August, 2011, a day where there was no flood in Ibadan, shows that the highest discharge from the Ogunpa river was 3.842m^3/s.

In Figure 8, the day of the 2011 flood, the first three hours of the day had a discharge of 11.3 m^3/s, which is over a 200% increase from that of the 22nd.

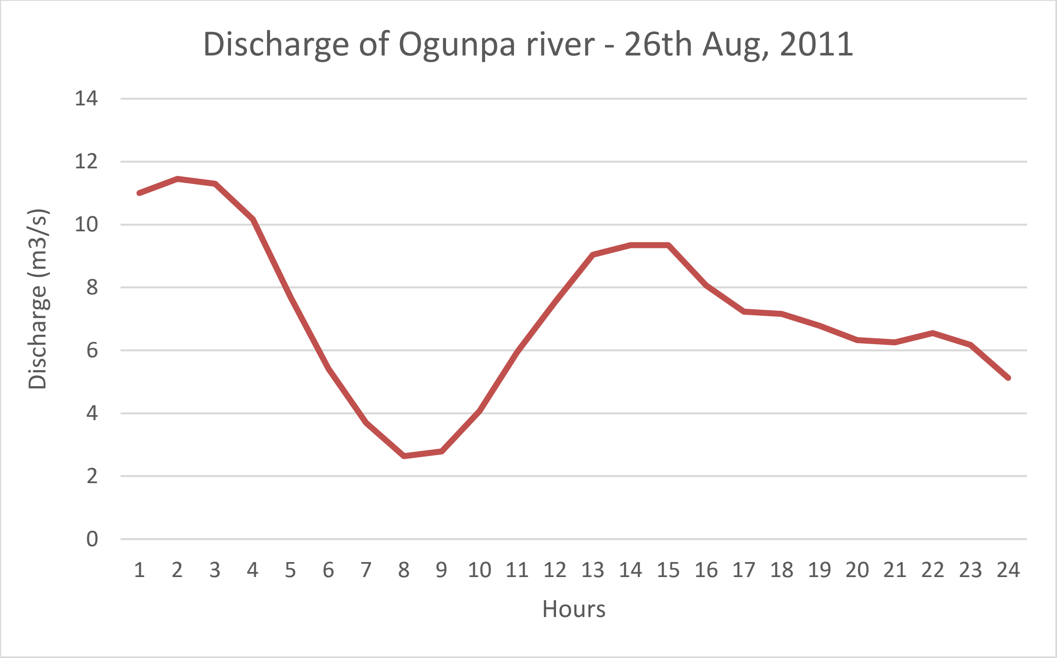

Figure 8. Hourly discharge on the day of the 2011 flood

The severe change in the discharge from the river within just four days as seen in Figures 7 and 8 shows how rapidly rainfall intensity can change in Ibadan. The cause of the flood on the 26th could be seen as the drainage channels not being able to control or cater for the massive increase in run off from the Ogunpa river. The rainfall intensity on the day of the flood was higher than the average rainfall intensity, which led to higher runoff. The drainage channels must be wide enough to cater for this rapid increase in runoff from the drainage basins.

The significant rise in discharge within hours shows the direct impact of high rainfall intensity of runoff. It indicates limited infiltration capacity due to urbanization or soil saturation. This emphasizes the importance of early warning systems and prediction mechanisms.

Akinyemi (2020) concluded that many of the hydraulic structures in the University of Ibadan did not have sufficient capacity to convey all the stormwater runoff. This project shows this further by comparing the discharges on the 26th and 22nd as shown in Fig 7 and 8, where the discharge tripled in a four-day period. This project generalizes Akinyemi's conclusion to the whole of Ibadan.

Tella and Balogun (2020) used the Analytic Hierarchy Process (AHP) and the Fuzzy Analytic Hierarchy Process (FAHP) to evaluate ten factors contributing to flood in Ibadan. The major factors were discovered to be rainfall, runoff, and distance to stream. As seen in Figures 7 and 8, the heavy rainfall and increase in runoff was responsible for the flood which proves their finding. In Ogbuene et al., (2024), machine learning algorithms were used to predict flooding with the Naïve Baise algorithm generating a higher accuracy than the others (78%) in terms of the root mean squared error and confusion matrix. The predictive ability of the model was limited due to data unavailability and domain knowledge. This research recorded a higher performance of 93.89%.

In Ondo, Nigeria, a city close to Ibadan, respondents believed human factors were also responsible for the consistent floods in the area, with 14% of respondents stating a poor drainage system while 18.5% mentioning the blockage of drainages by human waste (Olorunlana, 2021). Omolara et al (2023) demonstrates this further by studying flooding in Ogun state, another neighbouring city; the causes of the floodings were found to be heavy rainfall and blocking of waterways. These findings are consistent with this research on the causes of the floods to be the inability of the drainage systems to carry the increased discharge.

4. CONCLUSION

Data with a much longer time horizon (like 100 years) and spatial data will be required to provide more precise pattern on the causes of the flooding events in Ibadan. However, obtaining this from the relevant weather monitoring organizations was challenging. Using the 41-year period data, it was observed that most of the flooding events were due to the sudden increase in discharge from the Ogunpa river, which ultimately led to the drainages not being adequate enough to handle the surge, as seen in the 2011 flood in Ibadan (Figs 7 and 8), where the peak daily discharge nearly tripled in four days, leading to the flood. The highest rainfall occurrence in a month in the 41-year period was 569.53 mm/month in 2019. The highest annual rainfall occurred in 2021 (2832.92 mm), with September been the wettest month across the years.

Three probability plotting positions were used to calculate the return periods. The prediction model in equation 2 can be used to predict the return periods of the peak monthly rainfalls in Ibadan, which will allow for adequate preparation in cases where the peak monthly rainfall will exceed the design rainfall intensity of the drainage. The model was evaluated using the Coefficient of Determination and a value of 93.89% was gotten, which is reasonable.

To reduce the occurrence of flood in Ibadan, drainages should be built using reinforced concrete, which is more suited to transport storm runoff than mass concrete. It is important to perform routine maintenance on exposed drainage channels, which includes routine removal of solid waste, clearing vegetation from earthen channels, and installing drainage screens to prevent solid waste from flowing with runoff.

There will always be better flood predicting techniques; thus, it is important to keep researching flood risk assessment for storm drainage schemes.

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