

## Research Article

# Assessing Flood Vulnerability in Nigeria: A Model-Based Evaluation

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## Abstract

Several attempts to achieve the Sustainable Development Goals (SDGs) 7 & 13 such as ensuring environmental sustainability, fighting the effects of climate change, have been adopted to address the yearly flood event in different states across the country. Despite these efforts, the threat of flooding is taking on a different dimension yearly. Because of the similarities in the complexity of the flooding factors in different states in the country, this study adopts the integration of Hydrologic Engineering Centre's Geospatial Hydrologic Modelling System (HEC-GeoHMS) for modelling and mapping of flood using Abeokuta and its adjoining hydrological catchments as a case study. The catchments were delineated into 24 sub basins (to make it easier to identify areas of the landscape that are most sensitive or susceptible to flood) and their properties were extracted from a 10 m Digital Elevation Model of the area. Rainfall from January 2020 to December 2023 and discharge data from Ogun-Osun River basin Development Authority (OORBDA) were entered to develop the meteorological model. The resulting model was then calibrated by optimizing the model parameters and thereafter validated. Three statistical evaluation criteria used for the validation of the model showed that there is a good simulation between the observed and estimated values ( $RE_p = -0.24\%$ ,  $RE_v = 0.02\%$ ,  $NSE = 88.16\%$ , and  $R^2 = 0.732$ ). Python regression analysis corroborated the outcome of the modelled hydrological characteristics of the area, thus, demonstrating that the different hydrological properties of the catchments' diverse landscape, coverage area, and climatic conditions are contributors of flood disasters.

## Keywords

Flood, GIS, Hydrology, Model, Rainfall-runoff, Simulation

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## 1. Introduction

Flood undermines the ability of countries to actualize the Sustainable Development Goals (SDGs) in a lot of ways [1]. For instance, communities ravaged by flood disproportionately suffer livelihood disruptions that have implications on the attainment of SDGs1 and 2, which seek to eradicate poverty and hunger [2]. Aside the psychological trauma related to being trapped in contaminated flood water, there is the concomitant transmission of waterborne infectious diseases such as dysentery, hepatitis A, typhoid, diarrhea, cholera, and polio, which impact on good health and wellbeing, and consequently hinder the achievement of SDG 3 (good health and wellbeing). Further, as advanced by [2] flooding also hampers the attainment of the SDG 4 (quality education), as school children are unable to attend schools during flood disasters. Hence, for developing economies like Nigeria, flood mitigation and adaptation plan is not an end in itself, but rather one of the means that can be synergistically deployed with other measures to actualizing the SDG and leapfrogging vulnerable communities from the backwaters.

As a matter of fact, a complex relationship exists among the flood factors such as topography, rainfall, discharge, runoff, and land use [3]. When rain falls, there is an interaction between different components that make up a watershed such as vegetation, land surface, streams, rivers, lakes etc. The interaction begins with falling of the rain on the watershed and ends with the discharge of the water from the watersheds. This discharge maybe infiltrated through the soil and stored underground depending on the type of soil, land use in the watershed, interflow and base flow processes in the watershed while unfiltered water runs through the land surface (runoff) and finally deposits into stream channels. This process is a complex environmental phenomenon that requires complex mathematical model equations which cannot be solved with pencil and paper or calculator but are translated into computer codes and processed with algorithms [4], hence the need for hydrological models. As flood continues to remain a devastating natural menace to mankind, and in a bid to fast-track the attainment of the SDGs, it is very important to understand its hydrological responses in watersheds in order to safeguard and protect the lives and properties of citizens in flood prone communities. Therefore, an understanding of the amount of rainwater runoff within a given catchment is important for sustainable water resources project planning and management [5, 6].

Aside anthropological factors such as poor urban planning practices and environmental infrastructural deficiencies, flooding in Nigeria is also triggered by changes in climate, topography, land cover, river system, dam structures and rainfall, which are also among the critical variables in flood management. Just as the frequency of the flood become extreme, changes in the stream channel cross section of the hydrologic system also become rapid.

This study is essentially leveraging its findings on available

data such as rainfall, land use land cover, discharges and topography to model flood vulnerability in Abeokuta local government area of Ogun State in south western Nigeria. Abeokuta, has experienced its fair share of flood disasters in recent years which are majorly influenced by hydrological responses and processes [7-11]. Hydrological responses and processes, as shown in in different regions and in previous studies, are strongly influenced by variations in data such soil characteristics, slope and vegetation.

The major contributing factors to the runoff process in flood areas apart from rainfall are the physical characteristics of the area such as land use land cover, soil characteristics and topography etc. [12-15]. These responses and processes in previous hydrologic application packages have limitations in compatibilities with the computer hardware, software, data availability and support.

The breakthrough of rainfall simulation experiments in studying how water runs off or infiltrated into the ground surface as well as the movement of soil water under different conditions has given insight into understanding the runoff generation process in catchment areas [16]. The rainfall-runoff simulations are often used for modelling of flood events, water levels measurements or flood predictions [17-19].

Hydrological Engineering Center Geospatial Hydrological Modelling Systems (HEC-GeoHMS) is a Geographic Information system (GIS) extension of Hydrological Engineering Center Hydrological Modelling Systems (HEC-HMS) that is being used at global scale to develop rainfall-runoff models and assess runoff potentials of catchments. It has equally been used to calibrate and validate models and fix corresponding calibrated values for future hydrological investigations within basins using the Nash-Sutcliffe efficiency coefficient, and correlation [20, 21] used the HEC-HMS and HEC-RAS software to calculate discharge volume, peak flow, flood depth, and velocity in order to assess and forecast the risk of flash floods. The Soil Conservation Service method has been widely used to carry out hydrological modelling in different parts of the world [22-24]. However, these hydrological modeling techniques have not been applied in the context of Abeokuta's catchments.

Apart from machine learning, existing studies in Nigeria have not utilized HEC-HMS and GIS with regression analysis to analyze flood models. According to [25], a combination of statistical method, hydrodynamic model and remote sensing enhances flood hazard assessment especially where data is limited. [26] built FloodCast, a geometry-adaptive flood modelling and forecasting framework comprising of multi-satellite observation and hydrodynamic modeling, enabling large scale flood modelling and real-time flood hazard forecasting [27].

This study justifies the need to integrate Remote Sensing data such as Land Use Land Cover maps, and climate data into

hydrological computer programs, such as HEC-HMS and GIS to model the flood hydrological characteristics of Abeokuta, Ogun State of Nigeria and corroborating the finding with regression analysis of python. Remote sensing technology has played major economic roles in supplying multispectral and temporal data that have assisted in identifying subtle land use land cover changes in areas prone to natural disasters. The adoption of remote sensing data as a reliable and economic data sources to flood issues have been on the rise as evidenced in [28-32]. Nigeria as a whole is plagued with yearly flood issues. The choice of Abeokuta as a case study area is because of its shared related hydrological characteristics with major states in Nigeria [33-35].

## 2. Methodology

### 2.1. Study Area

The locational coordinates of Abeokuta is between 7.39 N,

3.01 E and 7.14 N, 3.41 E at average elevation of 64 meters above sea level as seen in the descriptive map of the study area (Figure 1) within a region characterized by bimodal rainfall pattern which commences in March and reach its peaks in July and September, with a short dry spell in August (Figure 3). It has a population of 593,100 making it the biggest city in Ogun.

According to Ogun Osun river Basin Development Authority, there exists strong climatic changes in Abeokuta and its environs and the irregularities in rainfall distribution pattern is between 804 mm and 1400 mm with mean annual temperature of 30 ° [36]. According to [37], there is a contrast between the hummocky land scape and the crystalline rock which is reflected in the topography of the area. The area is also characterized by its compact drainage pattern and the undulating hills that are thickly forested and sedimented swampy lowlands. River Ogun is the major river in the area among other smaller tributaries such as Sasa, Ona, Ibu, Ofiki, Oni etc.

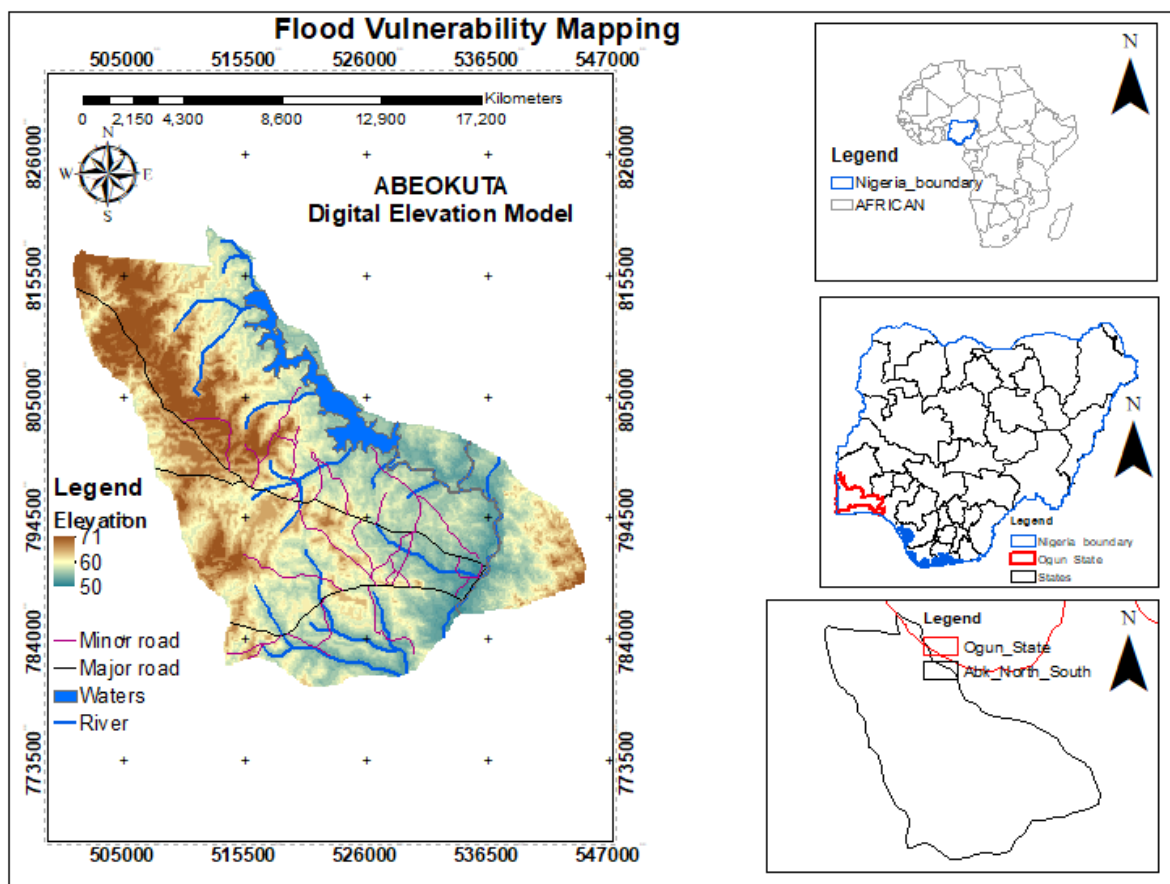


Figure 1. GIS mapping of the Study area.

### 2.2. Data Collection

According to information existing in public records, the

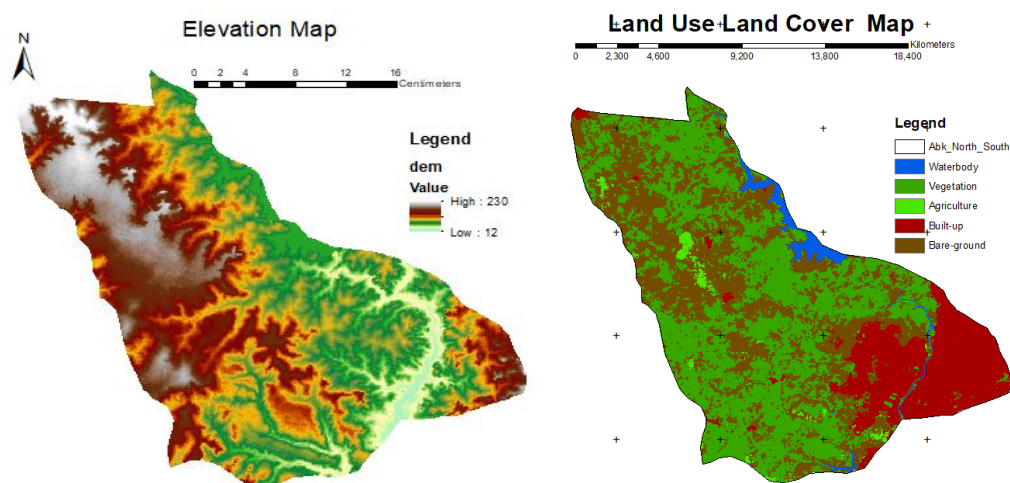
areas more susceptible to flood in Abeokuta are Arakanga, Oke lantoro, Olorunsogo, Ijaiye, Ilawo, Adedotun, Itoko, Kobiti, Enugada, Lafenwa, Ita-Eko, Ago Ijesha, Ijeun-Titun, Oke-Mosan, kuto, Oke-Ilewo, Amolaso, Isale-Igbehin,

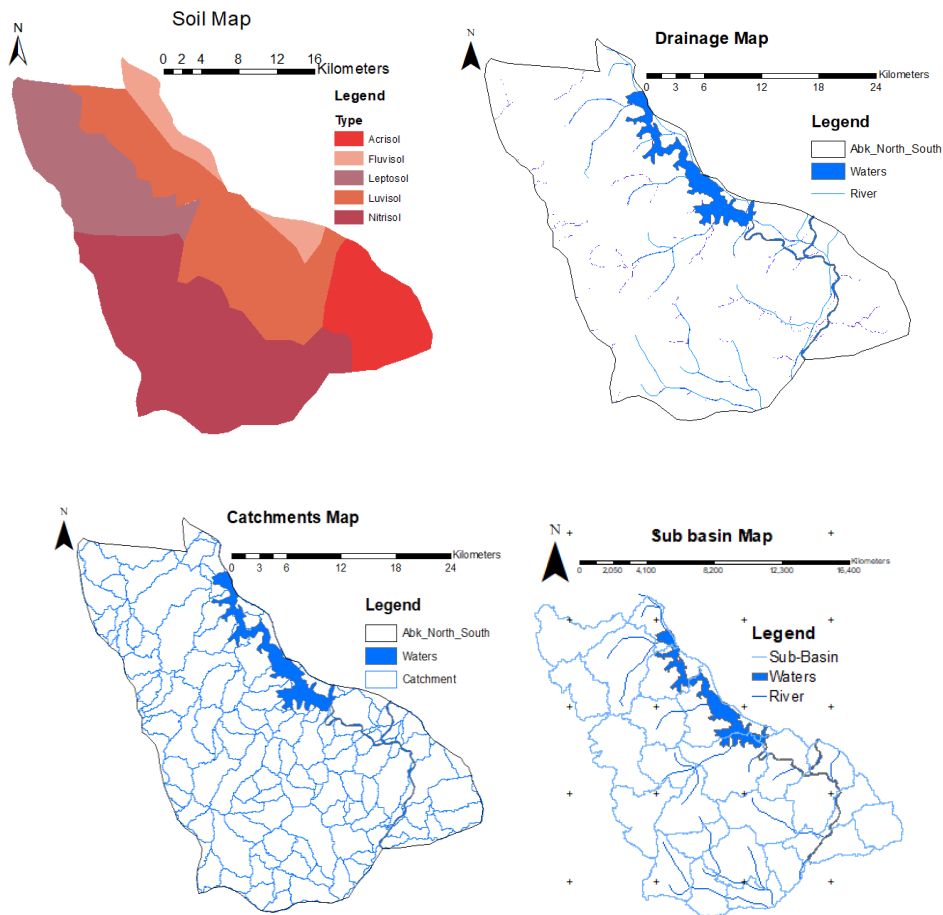
Oke-sokori, Ijeja, and Akin-Olugbade [38-42, 35, 11, 8]. Previous studies have used data mainly from online sources. However, this present study is adopting both online data repository and physically measured hydrological data (Table 1). The data collection phase took two months. Sensitization programs on flooding were conducted in the town halls of the flood communities in the study area on the government's intention with this study to support the communities to reduce the flood effect. Social survey was also conducted to complement hydrological information. River discharge data obtained from government agencies were validated with actual field measurements. Point data of visited location of the flood areas were collected with Tarsus Differential Global Positioning System (DGPS) equipment. Other data such as LULC were obtained from both online sources and relevant gov-

ernment agencies. Sentinel 2 data which was downloaded from the USGS Earth Explorer website (<https://earthexplorer.usgs.gov/>) was used to prepare the LULC map. This was preprocessed in Arcmap 10.6.1 version and then resampled to bring all datasets georeferenced to the same coordinate systems after which the image was reclassified to the different land use land cover types in the study area. This reclassification was also supported by expert judgments of the authors as they are familiar with the study area. The final output of the LULC was validated by carrying out ground truthing, thus engaging in physical visitation to the sites to ascertain the land use land cover types in the communities. The ground truthing activities showed that LULC map is in tandem with ground realities.

*Table 1. Data used.*

SN	Data Type	Purpose	Source
1	DEM	Data support prior to Hydrologic computations & modelling	NASA
2	LULC	To estimate manning's Curve number	Sentinel-2 10 m Land Use/Land Cover Time series Downloader
3	Drainage Network details	Hydrographic data	Office of Surveyor General of the Federation (OSGOF)
4	Soil data	To determine the erodibility of river sedimentary	(Harmonized World Soil Database v 1.2)
5	Discharge-flow	Hydraulic computations	Ogun-Osun River basin Development Authority (O-ORBDA)
6	Satellite Photos	Used as base maps and preparation of vector shapefiles of buildings covering the study areas	OSGOF
7	Monthly rainfall	For Hydrologic modelling	O-ORBDA
8	Historical flood Events	For Model Validation	O-ORBDA





**Figure 2.** Elevation, Land Use Land Cover, Soil, Drainage, Catchment and Sub- basin maps of the study area.

### 2.3. Hydrological Model Selection and Data Input

The hydrological model used in this study is physically based because of the availability of data that spatially describes the catchment process and also follows certain systematic procedures of selection and verification. These datasets are similar across major states in the country, hence they likely exhibit similar hydrological characters.

Abeokuta catchment was divided into 24 sub-basins (Table 5) with Hydrological Response Units (HRU) which were categorized into different classes based on LULC, Soil and slope (Figure 2) so that the model can run easily and give detailed findings [43]. Based on geopolitical distributions, some locations comprise of two or more sub basins, such as Ikereku, Kobiti. These sub basins were recombined. Likewise, some sub basins are large, comprising of more than one location in the study area, such as sub-basin 12 comprising of Enugada, Isale-Igbehin, Ijeja and sub basin 15 comprising of Kuto, Amolaso, Lafenwa.

The basin model and meteorological models were created in ArcGIS 10.6.1 extension of HEC-HMS (HEC-GeoHMS)

which was also used for the control specifications prior to running the model. The resulting files from the model were exported into HEC-HMS 4.11. Hydrological parameters that serve as inputs to HMS are soil, slope, antecedent moisture condition, and land use land covers. They were assigned using the sub-basin parameters option in HEC-HMS. Soil Conservation Service (SCS) for loss method was selected to get excess rainfall from total rainfall. The SCS Curve Number loss method earlier employed by [44-48] was used to estimate direct runoff. SCS unit hydrograph converts excess rain to direct run off. The amount of water that is intercepted, infiltrated, stored, evaporated, or transpired are deducted from the rainfall for computation of the loss model in HEC-HMS.

The hydrological characteristics were modelled using rainfall data between 1st January 2020 and 31st December 2023 (as seen in Figure 3) as well as discharge data from Ogun-Osun River basin Development Authority (O-ORBDA) as seen in (Figure 4). This characteristic is similar to other states in Nigeria under the catchments of O-ORBDA which spans one-third of the River basins in the entire country. Nitrisol and Luvisol are the domineering soil class while major land use in the area is intensive farming, a major land use hit by the floods thereby leading to shortage of food supply.

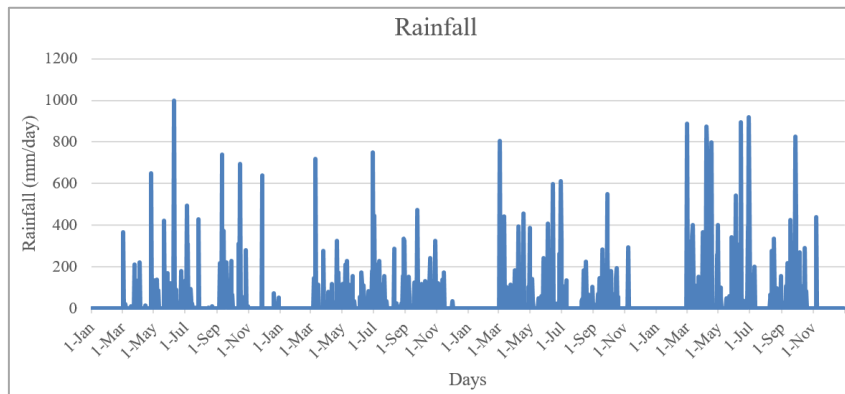


Figure 3. Rainfall (Authors, 2024).

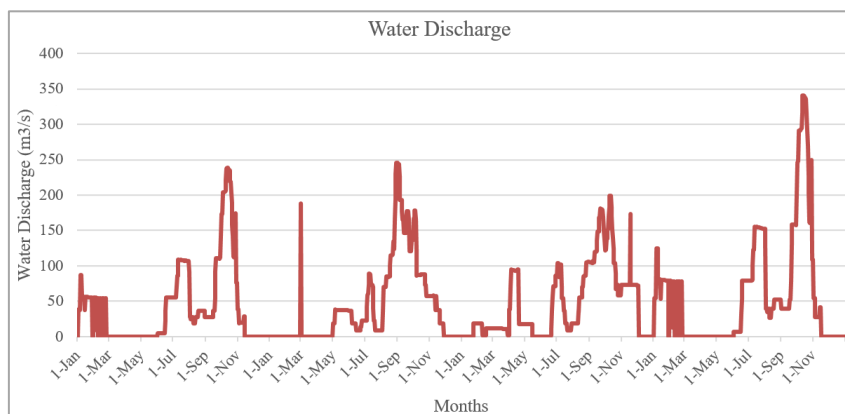


Figure 4. Discharge (Authors, 2024).

## 2.4. Loss Method (SCS Curve Number)

The runoff volume was modelled by calculating how rainfall in the study area is being converted into catchment runoff based on CN values of the sub-basin. The CN values were extracted from the LULC map. The Curve Number (CN) model uses equation 1 to estimate excess rainfall as a function of cumulative rainfall, antecedent moisture, land uses and soil cover. Runoff simulations were carried out by developing curve numbers based on local catchments land use land cover characteristics. This is found in the works of [49, 50].

$$S = \frac{25400 - 254 \text{ CN}}{\text{CN}} \quad (1)$$

Where

S= potential maximum retention, a measure of the ability of a watershed to abstract and retain storm rainfall

## 2.5. Transform Method (SCS Unit Hydrograph, UH)

The discrete convolution equation for a linear system is solved for in HEC-HMS to compute the direct runoff hydro-

graph [51, 52]. The losses were determined from Observed storm runoff hydrograph and precipitation and the subtracted from the precipitation. The base-flow has very minimal contribution to the watershed. The total volume of the direct runoff was determined and converted to its equivalent uniform depth over the entire area covering watershed.

## 2.6. Flood Channel Routing

The Muskingum flood routing model was used to calculate the discharge within a channel reach given the inflow hydrograph at the upstream end. Previous works on long rivers with large drainage areas such as [53, 54] have adopted this method as it has been reported to work well for their routings.

## 3. Results and Discussion

### 3.1. Model Calibration

For the purpose of calibration, four extreme events (Table 2) within the 4 years rainfall that are different from the rainfall events that were used for validation data were inputted.

**Table 2.** Rainfall events selected for Calibration & Validation.

Events	Start date	Start time	End date	End time	Selection
Event 1	July 11th 2020	0:00	July 31st 2020	0:00	Calibration
Event 2	Sept 21 2020	0:00	Oct 28 2020	0:00	Calibration
Event 3	Aug 19th 2021	0:00	Oct 7th 2021	0:00	Calibration
Event 4	July 2nd 2022	0:00	July 9th 2022	0:00	Calibration
Event 5	Aug 26th 2022	0:00	Oct 20th 2022	0:00	Validation
Event 6	July 9th 2023	0:00	Aug 2nd 2023	0:00	Validation
Event 7	Sept 21st 2023	0:00	Nov 1st 2023	0:00	Validation

The outcome of the model before and after calibration is shown in [Figures 5 & 6](#).

The calibrated model ([Figure 6](#)) was tested using Nash-Sutcliffe Efficiency (NSE) as seen in equation 2 to show how well the hydrograph plot of observed values matches with the simulated values [55]. A coefficient of 0.857 obtained indicate that the model and its parameters are reliable.

$$NSE = 1 - \frac{\sum_{t=1}^T (Q_o^t - Q_m^t)^2}{\sum_{t=1}^T (Q_o^t - \bar{Q}_o)^2} \quad (2)$$

Where;

$\bar{Q}_o$  = mean of observed discharges ( $m^3/s$ ), and

$Q_m$  = modeled discharge ( $m^3/s$ ), and

$Q_o^t$  = observed discharge ( $m^3/s$ ) at time t.

According to Nash-Sutcliffe, model efficiency ranges from infinity to 1.

$E = 1$  implies that there is a perfect match between modeled discharge and the observed data.

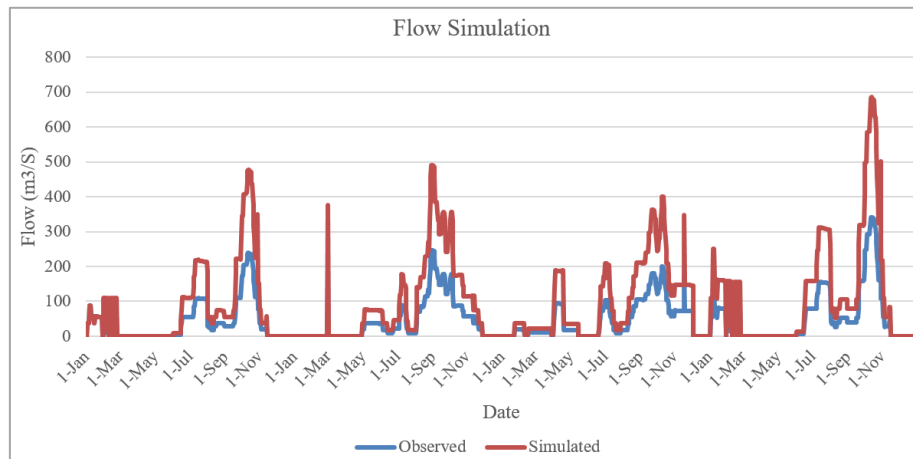
$E = 0$  implies that that the predictions of model are as accurate as the mean of the observed data,  $E < 0$  implies that the observed mean is a better predictor than the model

The modelled peak discharge and its relative errors as well as the total volume and its relative errors with respect to observed data, NSE and Coefficient of determination ( $R^2$ ) are displayed in [Table 3](#) below.

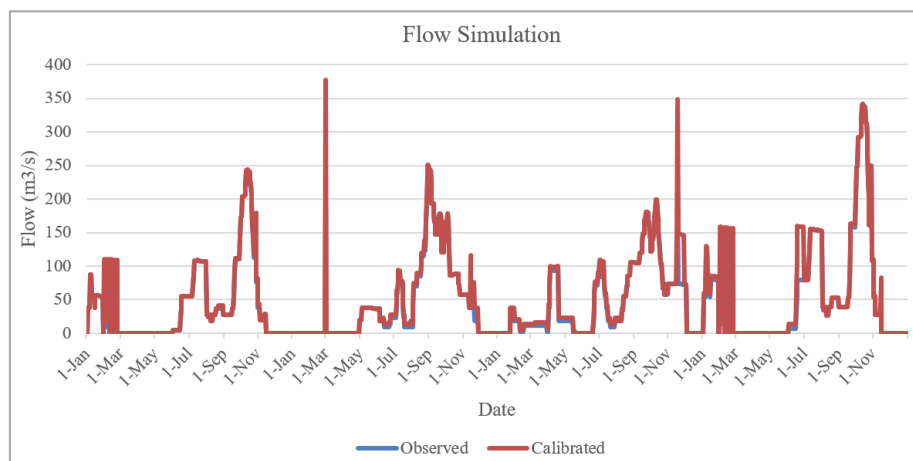
**Table 3.** Observed and simulated values before and after optimization.

Events	Peak Discharge ( $m^3/s$ )				Total Volume (mm)				NSE	$R^2$
	Observed	Simulated			Observed	Simulated				
		Bopt	Aopt	REp		Bopt	Aopt	REv		
Event 1	4.69	7.02	4.68	0.213	93.8	140.4	91.94	1.983	0.978	0.999
Event 2	111.06	125.64	110.98	0.072	332.26	2638.44	328.56	1.114	0.822	0.995
Event 3	114.68	131.21	114.89	-0.183	522.96	2886.62	525.78	-0.539	0.867	0.965
Event 4	104.28	122.61	103.84	0.422	398.44	2820.03	394.53	0.981	0.762	0.844
Mean	83.678	96.62	83.598	0.131	336.87	2121.37	335.20	0.885	0.857	0.9

Bopt = Before optimization, Aopt=After optimization, Rep = Relative Error of Peak Discharge, REv = Relative Error of Total volumes



**Figure 5.** Simulation before Model Calibration (Authors, 2024).



**Figure 6.** Simulation after Model Calibration (Authors, 2024).

### 3.2. Model Validation

It is very important to ascertain that there exists disparity between the calibrated model result and the actual field/terrain conditions. The validity of the model is dependent on the closeness of the error function to unity i.e. the smaller the error function the better is the model (Table 4).

For the purpose of validation, three extreme events (Table 2) within the 4 years rainfall data are used. These rainfall data are different from the rainfall events used for calibration.

The simulated results of the peak discharge, total volume and their relative errors with respect to the observed data as well as the NSE and Coefficient of determination ( $R^2$ ) were validated using events 5, 6 and 7 (Table 4 & Figure 6). This showed that for all the events there is close semblance between the simulated and observed values (Table 4). The average relative percentage error between observed and simulated peak flow values is -0.235% while average relative percentage error between observed and simulated total volume is 0.018%.

During validation, the Coefficient of determination ( $R^2 = 0.732$ ) also shows that there is a close agreement between the

observed and simulated peak flow values. We obtained better results between the observed and simulated values with a mean NSE value of 88.2%, using the NSE evaluation criteria. The three statistical evaluation criteria used in this study showed that there is a good simulation between the observed and estimated values ( $REp = -0.24\%$ ,  $REv = 0.02\%$ ,  $NSE = 88.16\%$ , and  $R^2 = 0.732$ ). This is in conformity with findings of [56-58], which has given credence to the overall model performance in simulating run off. [59] also obtained similar results when they adopted the SCS transform method to ascertain HEC-HMS model performance for continuous runoff simulation of Gilgel Gibe watershed, South West Ethiopia, likewise, [60], during the Calibration and validation of hydrological model using HEC-HMS for Kuantan River Basin, Malaysia.

A comparison of the model result with historical flood events data from O-ORBDA showed that all the historical sites are susceptible to flooding at varying degrees, thus implying that the model is valid. This is corroborated by the topography, soil, land use and hydrological characteristics of the study area. The little disparity between model and actual flood event in Abeokuta showed that the model is a good

reflection of ground reality as observed in [61-63]. Despite that flood studies have been conducted in other areas within the region, none has combined the cutting-edge tool of

HEC-HMS and GIS with statistical evaluation methods to validate the model results, a unique approach that has not been explored in previous studies carried out within the region.

**Table 4.** Observed and simulated values before and after optimization.

Events	Observed	Peak Discharge (m <sup>3</sup> /s)			Observed	Total Volume (mm)			NSE	R <sup>2</sup>
		Bopt	Aopt	REp		Bopt	Aopt	REv		
Event 5	105.17	125.65	105.12	0.048	524.08	3015.6	520.88	0.611	0.794	0.997
Event 6	101.17	120.01	101.17	0.003	529.31	3000.25	530.02	-0.134	0.992	0.999
Event 7	132.33	158.95	133.33	-0.754	440.64	4132.7	442.5	-0.423	0.859	0.198
Mean	112.89	134.87	113.21	-0.235	498.010	3382.8	5 497.8	0.018	0.882	0.732

Bopt= Before optimization, Aopt=After optimization, REp= Relative Error of Peak Discharge, REv = Relative Error of Total volumes

The model showed that Ikereku, Olorunda and Idiya are the most susceptible to flood (Tables 5 & 6). Most of the dwellers have fled leaving the remains of the buildings in dilapidated forms.

Areas more susceptible to flood following Ikereku, Olorunda and Idiya are Arakanga, Oke lantoro, Olorunsogo, Ijaiye, Ilawo, Adedotun, Itoko, Kobiti, Enugada, Lafenwa,

Ita-Eko, Ago Ijesha, Ijeun-Ttitun, Oke-Mosan, kuto, Oke-Ilewo, Amolaso, Isale-Igbehin, Oke-sokori, Ijeja, Iberekodo, Oba, Akin-Olugbade, Arikola, and Iboru-Akute. These communities are at close proximity to the state capital which is the most urbanized in the state. This is majorly attributable to the high rate of urban land use activities, topography and climate.

**Table 5.** Hydrologic Characteristics of Sub Basins.

Hydrologic Elements (Sub-basin)	Area (km <sup>2</sup> )	Peak Discharge	Loss Volume	Excess Volume	Direct Runoff	Communities
		m <sup>3</sup> /s	mm	mm	mm	
4, 9, 24	27.763	132.332	255.29	800.65	529.31	Ikereku, Kobiti
2, 3, 8, 10, 17, 19, 21, 23	12.186	111.06	342.038	713.9025	524.08	Olorunda, Itoko, Adedotun
7, 13, 16	9.9321	104.28	414.703	584.91	522.96	Idiya, Ijaye
11	19.023	114.68	456.56	599.38	440.64	Ago-ijesha, Lantoro
12	14.185	101.173	456.56	599.38	440.64	Enugada, Isale-Igbehin, Ijeja
14	16.599	105.17	456.56	599.38	440.64	Akin Olugbade, Ita-Eko
15	9.7917	58.34	456.56	599.38	398.44	Kuto, Amolaso, Lafenwa
20	10.142	56.432	456.56	599.38	398.44	Oke Sokori, Olorunsogo
22	10.873	80.21	456.56	599.38	398.44	Iberekodo, Oke Ilewo
5	9.7885	31.67	456.56	599.38	398.44	Oba, Arakanga
1 & 6	10.408	29.89	494.41	561.53	332.26	Arikola, Iboru-Akute, Ilawo
18	5.4503	4.69	517.79	538.15	93.80	Totoro, Ijeun titun

Findings show that the basin sub-division enhanced the model performance. This is consistent with outcomes observed in previous related works [64].

As evident in Table 5, flood vulnerability of the study area is generally high, as their runoffs fall between 332.26 mm and 529.312 mm. Communities within this threshold are Ikereku, Kobiti, Olorunda, Itoko, Adedotun, Idiya, Ijaye, Ago-ijesha, Lantoro, Enugada, Isale-Igbehin, Ijeja, Akin Olugbade, Ita-Eko, Enugada, Isale-Igbehin, Ijeja, Akin Olugbade, Ita-Eko, Kuto, Amolaso, Lafenwa, Oke Sokori, Olorunsogo, Iberekodo, Oke Ilewo, Oba, and Arakanga. Only two communities, Totoro and Ijeun titun fall under very low susceptibility with 93.8 mm runoff volume while none of the communities fall under medium or low flood susceptibility (Table 6).

The LULC map in figure 2 showed that Abeokuta North is predominantly grassland, used for intensive farming which contributes to the economic importance of the area. However,

Abeokuta South is majorly urban. Since Abeokuta has similar hydrologic properties, topography, landforms, and geomorphology with many other states as well as same influence, on the country's development, as observed in the works of [65] and [66], digital elevation model, land use land cover, soil and meteorological data were considered. The slope of the catchment which was prepared from the digital elevation model was categorized into five classes, viz 0°-2° (Very Gentle), 2°-4° (Gentle), 4°-6° (Moderate), 6°-11° (Steep) and 11°-31° (Very Steep). The study reveals that 60% of the area have gentle slope, 30% are steep, while 10% are very steep. It is noteworthy of mentioning that the intensity of steepness increases southwardly within the study area. Owing to the combination of spatially matched elevation and water data, these steeply sloped areas give precise modeling of the Earth's surface, thus making the data helpful for any analysis or modeling involving the Earth's surface, including runoff water and erosion studies [67].

**Table 6.** Flood Susceptibility Threshold.

	Runoff Class Threshold	Susceptibility	Communities
1	500 & 530	Extremely High	Ikereku, Kobiti, Olorunda, Itoko, Adedotun
2	400 - 499	Very High	Idiya, Ijaye, Ago-ijesha, Lantoro, Enugada, Isale- Igbehin, Ijeja, Akin Olugbade, Ita-Eko
3	300 -399	High	Kuto, Amolaso, Lafenwa, Oke Sokori, Olorunsogo, Iberekodo, Oke Ilewo, Oba, Arakanga, Arikola, Iboro- Akute, Ilawo
4	200 - 299	Medium	Nil
5	100 - 199	Low	Nil
6	00 - 99	Very Low	Totoro, Ijeun titun

The flood susceptibility of the study area is grouped into 6 run off classes (Table 6) based on HEC-HMS model; extremely high, very high, high, medium, low and very low. The run offs at Ikereku and Kobiti is 529.31 mm, while Olorunda, Itoko, and Adedotun is 524.08 mm thus making them the most susceptible to flood. Of these four communities, Ikereku and Kobiti have the largest coverage area of 27.763 km<sup>2</sup> and the largest peak discharge of 529.31 m<sup>3</sup>/s.

This is followed by Ago-Ijesha and Lantoro with coverage area of 19.023 km<sup>2</sup> and discharge of 440.64 m<sup>3</sup>/s while Totoro and ijeun-titun have the least coverage area of 5.4503 km<sup>2</sup> with discharge of 93.8 m<sup>3</sup>/s. This shows that generally the larger the basins the larger the discharges with some exception based on steepness of the slope, geological composition and climatic variabilities. This is shown in Idiya and Ijaiye having coverage area of 9.932 km<sup>2</sup> with 522.96 m<sup>3</sup>/s run off volume compared to Ago-Ijesha and lantoro with larger coverage area but smaller run off volume of 440.64 m<sup>3</sup>/s as evidenced in [68-70].

Totoro and Ijeun titun are classed under very low run off class between 0 – 99 mm. The flood susceptibility of Totoro and Ijeun titun is the least because of its small coverage area with relatively gentle slope and local conditions such as land use, vegetative cover and soil characteristics that obstructs flood flows are higher than other sub basins in the study area. This means that the infiltration capacity of the soil is very low, thus paving way for the soil to quickly get saturated with rainwater to its full capacity. The implication of this is the soil's inability to retain excess water, thus causing the excess water to run off on the surface of the land.

The flood susceptibility of Kuto, Amolaso, Lafenwa, Oke Sokori, Olorunsogo, Iberekodo, Oke Ilewo, Oba, Arakanga, Arikola, Iboro - Akute, Ilawo, is classified high in the threshold, between 300 and 399 mm runoff volumes (Table 6).

Flood susceptibility of Idiya, Ijaye, Ago-Ijesha, Lantoro, Enugada, Isale-Igbehin, Ijeja, Akin Olugbade, ita-Eko is classified as very high between 400 and 499.

Findings in this study have demonstrated that basin to-

pography, soil type, land use and other catchment characteristics impacts flood in the study area, as justified by the works of [5, 57, 71].

Analysis of the Hydrologic Characteristics of Sub Basins

The Ordinary Least Square (OLS) regression in python was adopted to further corroborate the analysis of the Hydrologic Characteristics of Sub Basins.

**Table 7.** OLS Regression Results.

Dep. Variable:	Direct Runoff Volume (m <sup>3</sup> )	R-squared:	1.000			
Model:	OLS	Adj. R-squared:	1.000			
Method:	Least Squares	F-statistic:	8.943e+11			
Date:	Fri, 06 Sep 2024	Prob (F-statistic):	4.72e-41			
Time:	11:37:16	Log-Likelihood:	94.151			
No. Observations:	12	AIC:	-178.3			
Df Residuals:	7	BIC:	-175.9			
Df Model:	4					
Covariance Type:	nonrobust					
	coef	std err	t	P> t	[0.025	0.975
const	1055.9383	0.003	4.1e+05	0.000	1055.932	1055.944
Area (km <sup>2</sup> )	-5.731e-06	7.68e-05	-0.075	0.943	-0.000	0.000
Peak Discharge (m <sup>3</sup> /s)	-9.759e-05	0.000	-0.217	0.834	-0.001	0.001
Loss Volume (mm)	-1.0000	3.16e-06	-3.17e+05	0.000	-1.000	-1.000
Excess Volume (mm)	3.125e-06	2.5e-06	1.250	0.251	-2.79e-06	9.04e-06

The regression analysis in Table 7 showed that area, peak discharge and the loss volumes are inversely proportional to the direct runoff. A unit increase in the area will cause  $5.731 \times 10^{-6}$  decrease in direct runoff volume. This is attributable to the fact that the coefficient is very close to zero with a very high P-value of 0.943. This suggests that the area have a statistically significant impact on the runoff volume.

Similarly, a unit increase in the peak discharge and excess volume will cause  $9.759 \times 10^{-5}$  and  $3.125 \times 10^{-6}$  decreases respectively in direct runoff volume. This increase is traceable to the closeness of their coefficients to zero with a very high P-value of 0.834 and 0.251 respectively. This suggests also that peak discharge and excess volume have statistically significant impacts on the runoff volume.

## 4. Conclusion and Recommendations

GIS and HEC-HMS was used to model and simulate the relationship between rainfall and surface runoff in the drainage basin of the study area because it is physically based and conceptually semi-distributed, thus producing significant outputs such as groundwater discharge, water movement in streams, excess and loss volumes and direct runoff. The model is designed to simulate rainfall-runoff processes in a

wide range of geographic areas; from large river basin water supplies and flood hydrology to small urban and natural watershed runoffs.

To analyze the flood characteristics of the study area, the influence of topographic details as well as soil and climatic data is essential.

Because hydrological data are complex in nature, they were modelled to be able to holistically include all data involved. The output of the model produced (Tables 3 & 4) shows the resulting relationship among the various factors considered and how each contributes to or affects another. The model was calibrated and indicated a 0.78 coefficient and validated using CN 30, lag time of 60 minutes and initial abstraction of 6.214. The model outputs showed that the flood vulnerability of the study area is mostly described by the hydrological characteristics of the study area. The model is a vital hydrological data for planning mitigation measures against flood in Nigeria.

Since the management and organization of water resources by OORBDA necessitate temporal and spatial data, the results of this research will serve as a guide for the planned water management efforts in the basin. At the local levels, run off simulation with standardized curve numbers has limitations. It is encouraged to develop curve numbers based on state or local levels for catchment areas order to increase the model

performances. Some researchers have suggested this in their recommendations.

This Flood vulnerability assessment from hydrological modelling perspective is using Abeokuta as a case study because of its similar hydrological characteristics with many other states in the country. The outcome of this assessment has lent a good footing for achieving the SDG 13 to combat climate change and its effects as well as SDG 7 to ensure environmental sustainability in the country. Besides, this study is an eye-opener for the Nigerian government and the states in sister African countries sharing the same hydrologic characteristic.

## Abbreviations

SDGs	Sustainable Development Goals
HEC-HMS	Hydrologic Engineering Centre Hydrologic Model Systems
HEC-GeoHMS	Hydrologic Engineering Centre's Geospatial Hydrologic Modelling System
GIS	Geographic Information System
LULC	Land Use Land Cover
OORBDA	Ogun-Osun River Basin Development Authority
NASA	National Aeronautics and Space Administration
ESRI	Environmental System Research Institute
OSGOF	Office of Surveyor General of the Federation
DEM	Digital Elevation Model

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## Declarations

### Ethical Approval

The research is in conformity with the ethical soundness of project execution.

### Consent to Participate

Authors declare that there is agreement among the research

teams to be participative in the project.

## Consent to Publish

Express permission is hereby given to Journal of Environmental Modelling and Software by all authors to publish the manuscript.

## Author Contributions

**Monsur Adewara:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing- original draft, Writing-review & editing

**Olasunkanmi Olapeju:** Data curation, Investigation, Supervision, Writing-review & editing

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## Data Availability Statement

Research data and materials for the project are available on request.

## Conflicts of Interest

The authors declare no conflicts of interest.

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