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Research Article

Influence of Hydrological Variation Pointers and Incorporated Muskingum Flow Scrutiny on Flooding Frequency in the Upper and Lower Ikpoba Stream, Southern Nigeria

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Keywords

Flood modeller,
Peak discharge,
Rainfall hyetograph, Prediction Curve.

Abstract

Flood frequency curve using River Ikpoba as Case study was estimated for a return period of 100 years, the flood magnitude is 461 m3/s as against the 380m3/s which was observed to be the highest discharge value throughout the simulation period. This value was found to have occurred in September 2012. The flood frequency curve therefore can aid in flood hazard preparedness since it can be employed to forecast the flood magnitude at different recurrent intervals. There is an increase in the number of wetted with corresponding increase in recurrence interval. For example, for 50yrs and 100 years return period, the number of wetted cells was observed to be 26171with a runoff volume of value of 0.14 x 108m3/s. Using the computed volume of runoff and the corresponding number of wetted cells, the spatial extent of flooding for each return period was generated. Similarly, red spots which are seen in areas such as Lucky Igbinedion Way, Temboga, Second Lagos Road, Mission Road, Ewah Road, Federal Road, Ikpoba, Oregbeni and MM Way shows that these areas are flood prone areas and requires adequate attention and effective early warnings systems in order to alleviate the magnitude of destruction that is caused by flood. Likewise, there is an indicate that as the day's progress the flow rate was increasing for consecutive 30 days but at low flow rate, but at 90 days it declines. For maximum value as day progress the values decreases.

1. Introduction

Adequate knowledge on the response of stream flow to climate change and human activities will not only help protect the natural water quality on which lives depend, it will also help to guarantee sustainable watershed management thereby preventing the ravaging effects of flooding and other environmental disaster that has continuously threatens the existence of man on the planet called earth (Ogwueleka and Igibah 2021; Srishti et al. 2020; Darwet et al. 2018). Understanding the impact of climate change and land management practice on stream flow regime and flood extent will help progressive government and other relevant agencies in formulating policies and enacting laws that will help check the activities of man while also protecting the environment from further damage. Information regarding climatic variability (Gupak et al. 2021; Ng 2016). Studies will not only provide better understanding of the impact of climate change on the hydrologic cycle, it will also help to visualize and characterize the water resources situation and create a clearer picture about certain concerns for the area regarding extreme precipitation events such as drought and flooding (Ali et al. 2016; Guan et al. 2015). Despite the large uncertainty in future flood risk; hydrologists still have plenty to offer adaptation planners. More accurate, timely, and clearly articulated flood warnings will continue to improve the safety of vulnerable populations living with unavoidable flooding (Mahmood et al. 2016; Muis et al. 2015). Simulations of flood depths and areas will help planners to zone floodplains and regulate development in hazardous places. Field monitoring and modeling will contribute to improved understanding of the physical processes that generate extreme floods in different environments. Remotely sensed data and seasonal forecasts can inform the operation of infrastructure to optimize benefits across multiple objectives (such as flood control, hydropower production, and water supply).

1.1. Flood frequency analysis under climate change

Flood is an overflowing or irruption of a great body of water over land not usually submerged. It is an extreme weather event naturally caused by rising global temperature which results in heavy downpour, thermal expansion of the ocean and glacier melt, which in turn result in rise in sea level, thereby causing salt water to inundate coastal lands (Remondi et al. 2016; Mishra et al. 2015). Flooding is the most common of all environmental hazards and it regularly claims over 20,000 lives per year and adversely affects around 75 million people world-wide. Across the globe, floods have posed tremendous danger to people's lives and properties (Ablain et al. 2020; Von et al. 2020). Floods cause about one third of all deaths, one third of all injuries and one third of all damage from natural disasters (Lutz et al., 2016). Since 1900, floods have claimed more than 10,000 lives in the United States alone. In China, some of the world's most disastrous floods have been caused by the unstable Huang He (Yellow River). In 1970, 1985 and 1991, hundreds of thousands of people in Bangladesh were killed when the combination of high tides and a tropical cyclone storm surge caused widespread flooding of the low-lying delta of the Ganges and Brahmaputra rivers. In Nigeria, the pattern is similar with the rest of world. Excluding droughts, almost 90% of damages relating to natural disasters are caused directly or indirectly by floods. Record shows that more than two hundred people have lost their lives to flooding while hundreds of thousands have been rendered homeless and properties worth billions of Naira have been destroyed as a result of devastating floods across the country (Ablain et al. 2019; Okonofua et al. 2019). Flooding in various parts of Nigeria have forced thousands of people from their homes, destroyed businesses, polluted water resources and increased the risk of diseases.

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Floods occur in Nigeria in three main forms, viz; coastal flooding, river flooding and urban flooding. Coastal flooding occurs in the low-lying belt of mangrove and fresh water swamps along the coast. River flooding occurs in the flood plains of the larger rivers, while sudden, short-lived flash floods are associated with rivers in the inland areas where sudden heavy rains can change them into destructive torrents within a short period. Urban flooding on the other hand occurs in towns, on flat or low-lying terrain especially where little or no provision has been made for surface drainage, or where existing drainage has been blocked with municipal waste, refuses and eroded soil sediments. Flood scenarios have been reported by many studies. Most of these researches examined extensively the causal factors among which are high river levels, concentrations of overland flow following heavy rainfall, limited capacity of drainage systems and blockage of waterways and drainage channels (Dun et al. 2021; Ilaboya et al. 2014). However, some problems can be isolated to a single cause but more often it is a combination of factors which causes the worst flooding. Studies also reported the associated hazards following the occurrence of flooding and have tried to proffer solutions to the problem of flooding (Ilaboya et al. 2014; Ekhaise and Anyasi 2011). But in spite of the recommendations of the researchers and government efforts at mitigating the menace, urban flooding has become perennial event in most Nigerian cities. This is because the frequency and magnitude of the occurrence have more than double in recent times. This is due to the fact that as urban population keeps on increasing, more and more people are living in flood-prone areas, such as areas along river beds and floodplains, which consequently increase the damage and death toll.

Besides, experts have predicted that climate change will make the problem of urban flooding more serious because of the increased likelihood of more intense and frequent rain storms (ActionAid, 2006). According to the UK Climate Impacts Program, rainfall intensity will increase in the future, perhaps by as much as 20% by the end of the century (Ablain et al. 2020; Okonofua et al. 2019). Since climate change cannot be stopped, a lot can be done to adapt to it by way of early warning arising from frequency analysis and flood risk estimation. Many questions arise with respect to impacts of climate change on floods. In addition to the impact on flood magnitudes and frequencies, the timing of flood events could also change with warming. Flood risk would be affected by land use and land cover changes, and changes in temperature, humidity, soil moisture, and groundwater levels would also affect the risk of large floods. Since current extreme value distributions may not hold under global warming, a statistical flood estimation would not be useful under climate change (Dunn et al. 2021; Von et al. 2020). A more physically based approach is needed, which incorporates meteorological and hydrologic information. Flood modelling under climate change can use analytical methods or Monte Carlo simulation. For example, IDF curves could be used for deriving future flood frequency distributions analytically. Synthetic meteorological series input to a rainfall–runoff model could also be used to derive future streamflow time series to which a suitable extreme value distribution could be fitted. Thus the aim of the study is to evaluate the impact of climate change on flood frequency analysis and assess the alterations of river flow regime at daily and monthly scales by the Indicators of Hydrologic Alterations (IHA).

2. Description of Study Area

Ikpoba River is situated within the rainforest belt of Edo State, southern Nigeria. The River rises from the Ishan Plateau in the northern part and flowing in south westerly direction in a steeply incised valley and through sandy areas before passing through Benin City and joining the Ossiomo River. Edo State lies roughly between longitude 06o 04'E and 06o 43'E and latitude 05o44' N and 07o34' N. Edo State has a tropical climate characterized by two distinct seasons: the wet and dry seasons. The wet season occurs between April and October with a break in August, and an average rainfall ranging from 150 cm in the extreme north of the State to 250 cm in the south. The dry season lasts from November to April with a cold harmattan spell between December and January. The temperature averages about 25 °C (77 °F) in the rainy season and about 28 °C (82 °F) in the dry season. The climate is humid tropical in the southern part and sub-humid in the northern part. Ikpoba River is highly disturbed while passing through Benin City due to the high population density and the dependence on the stream (Okonofua et al. 2019; Ilaboya et al. 2014).

Victor and Dickson (1985) reported that in the upper reaches of the stream, it flows through a dense rainforest where surface run-off and organic matter from the surrounding vegetation contribute to organic input. At the outskirt of the city, riparian settlements are thinly populated, so that disturbance due to human activities is low and localized. The river is particularly important to the people of Benin City.

Figure 1. River Ikpoba and activities around its settlement

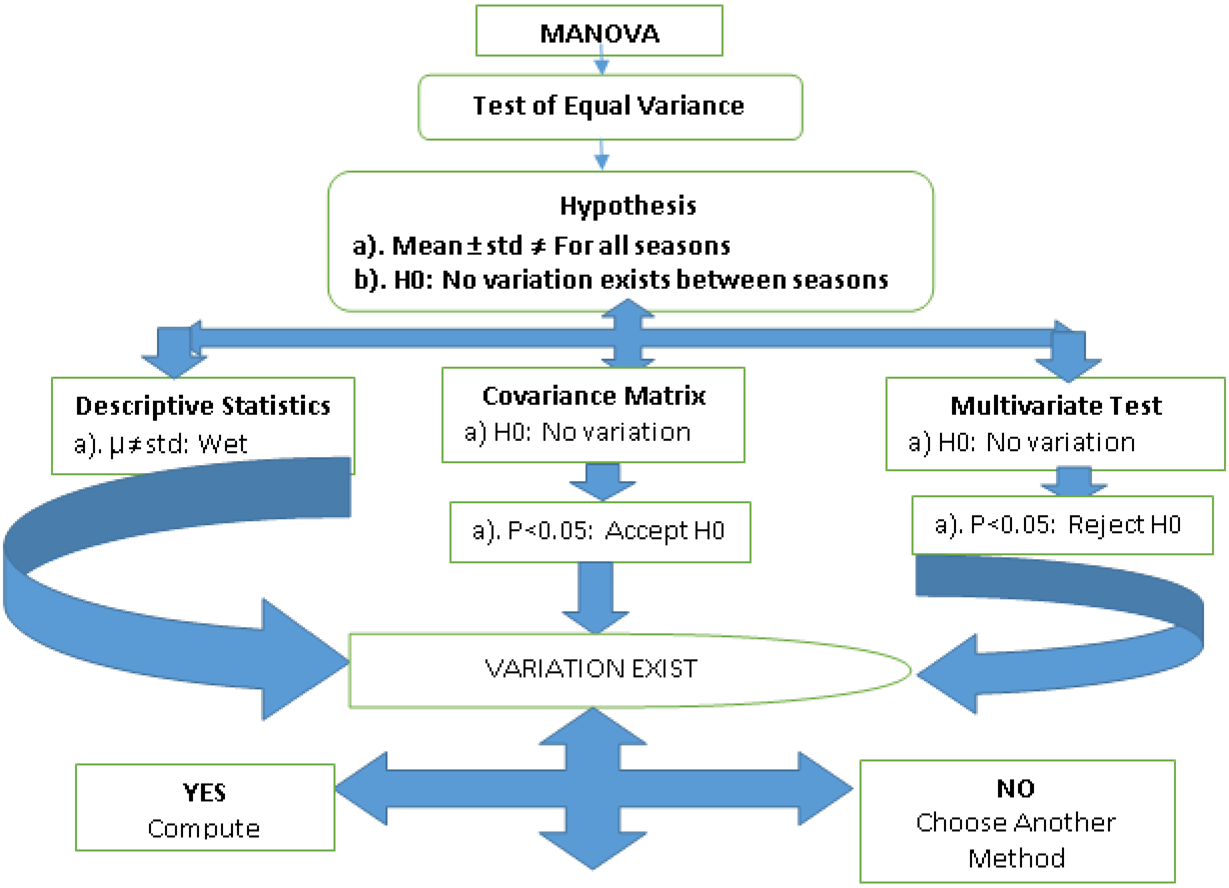


Figure 2. Schematic of multivariate analysis of variance

One of the major dams in the Edo State was constructed across the river in Okhoro Community. The name of the dam is Okhoro Dam. The dam was built mainly for water supply and was used by the then Bendel State Urban Water Board to supply pipe-borne water to some parts of Benin Metropolis. Downstream riparian communities depend on the river for water for various domestic purposes. Car washing companies are also attached to the river in Benin City. Industrial effluence and water from drainage channels are discharged into the river at various points which is displayed in Figure 1.

3. Results and Discussions

3.1. Analysis of seasonal variability occasioned using Magnitude of variation

To study the seasonal variability of the water quality parameters, multivariate analysis of variance (MANOVA) was employed. The schematic of MANOVA is presented in Figure 2. The overall magnitude of variation between the water quality for wet season and that of dry season was calculated by means of multivariate analysis of variance and it was established to be 98.60% variability.

Table 1. Magnitude of variability among the water quality parameters

Water Quality Parameters	Magnitude of Variability between Wet Season and Dry Season (%)
pH	1.400
Nitrate	38.00
EC	23.60
Turbidity	6.100
DO	26.10
TDS	4.400
Sodium	69.00
Lead	7.500
Sulphate	81.20
Zinc	2.800
Copper	7.200
Chloride	9.500
Iron	3.700
Carbonate	33.20
TSS	73.60
Nitrite	0.100
Cadmium	43.30
Nickel	1.400
THC	25.40
Phosphate	8.400
Alkalinity	22.80
Calcium	82.00
Total Coliform Count	32.00
COD	0.900
Manganese	41.00

To determine the variation parameter by parameters, (for example what is the magnitude of variation between pH for wet season and pH for dry season), parameter estimate statistics using the 95% confidence interval was done for all the parameters employed to assess the overall water quality for both wet and dry season and results obtained are presented in Table 1.

Using the result of Table 1, the magnitude of variation between the selected water quality parameters occasioned by season that was determined using the Partial Eta Squared statistics shows the variations that exist among all the independent variables occasioned by seasonal impact. It was also observed that higher magnitude of variation exists between the level of calcium, Sulfate, sodium, total suspended solids, cadmium and manganese.

3.2. Impact of climate change on flood frequency analysis

The flood frequency curve which shows the discharge against the reoccurrence interval is presented in Figure 3.

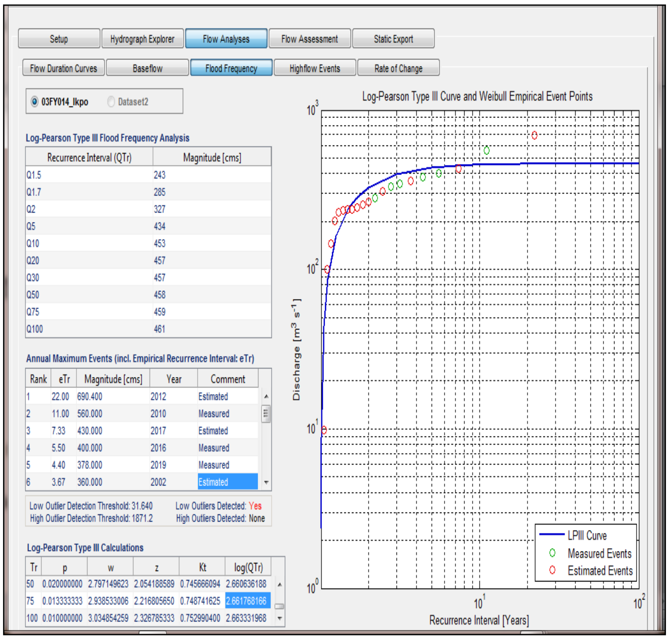


Figure 3. Flood frequency curve

The flood frequency curve which is a prediction curve can be employed to estimate the magnitude of discharge from the stream at selected recurrence interval or return period. From the frequency curve of Figure 3, it was estimated that for a return period of 100 years, the flood magnitude is 461m3/s as against the 380m3/s which was observed to be the highest discharge value throughout the simulation period. This value was found to have occurred in September 2012. The flood frequency curve therefore can aid in flood hazard preparedness since it can be employed to forecast the flood magnitude at different recurrent intervals (Gumindoga et al. 2016; Mishra et al. 2015).

3.3. Flood Event Modelling

The mathematical relationship between the calculated rainfall intensities (I) and the selected durations (d) was determined using the curve fitting tool in MATLAB and result is presented in Table 3. and results of regression model from Observed versus predicted rainfall intensity for Benin.in Figure 4. 40 years daily rainfall data for the period 1980 to 2020, the annual maximum daily series (AMDS) were determined using Microsoft excel program and thereafter arranged in ascending order of magnitude.

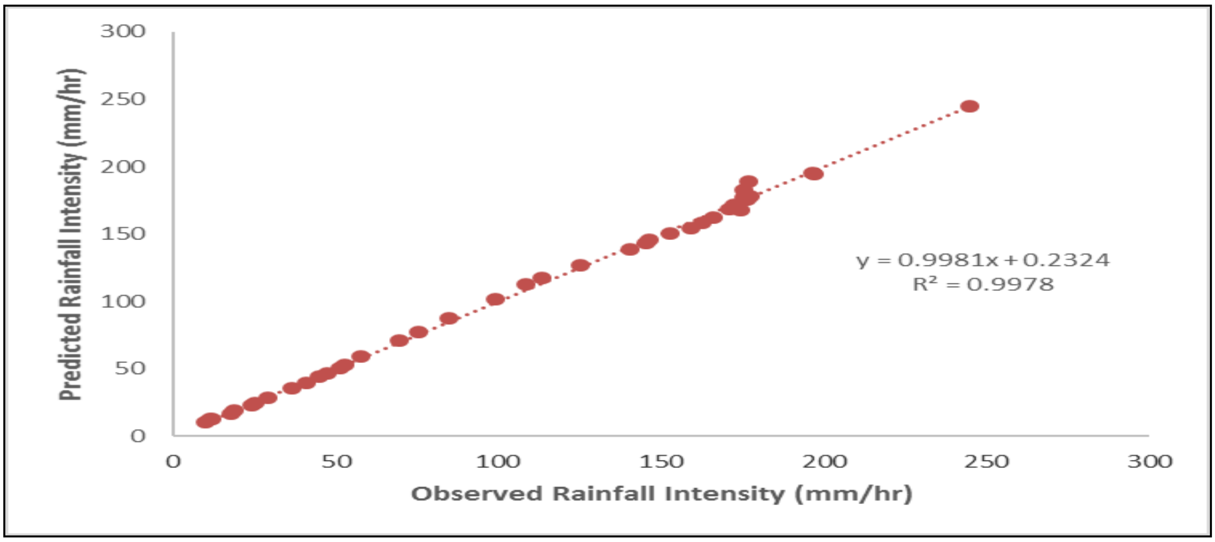


Figure 4. Observed versus predicted rainfall intensity for Benin

The rainfall depth for selected rainfall durations were estimated using the empirical reduction formula given by Indian Meteorological Department (IMD) reported in the works of Rashid et al. (2018) and thereafter the rainfall intensity was then estimated.

Using the mathematical relationship presented in Table 3, the predicted intensities at the selected durations were computed and the values were regressed against the observed rainfall intensities in order to develop a regression equation between the observed and predicted rainfall intensity. To model the flood event around the study area, intensity duration frequency (IDF) analysis was done in order to estimate the rainfall depths at various durations and at various return periods. Using the estimated rainfall depths, hydrological modelling software (Flood modeller) was then employed to map the flood event within the study area at different recurrent intervals. The choice of flood modeller is based on the fact that large errors can occur in estimating low flow event using statistical approach especially when the sample size is not long enough. Statistical approach using measured annual peak discharge data is considered the standard method for estimating a flood quantile (Von et al. 2020; Muis et al. 2015). However, a large error may occur in estimating low-frequency floods when the sample size is not long enough. Furthermore, due to changes in land use, achieving stationarity of data for flood frequency analysis has become more difficult since changes in land use that occur with urbanization affect the frequency of floods. Change in land use clearly affects the hydrological responses of watersheds. Alternatively, the design storm method can also be employed. Design storm method is used to estimate flood quantiles by applying rainfall quantiles determined from rainfall frequency analysis to the rainfall-runoff model. This method requires three basic assumptions; the selection of the design rainfall hyetograph (rainfall duration and time distribution), the selection of the antecedent soil moisture conditions before the storm event, and the equality of the return periods between the rainfall quantiles and computed flood quantiles (Ali et al. 2016; Guan et al. 2015).

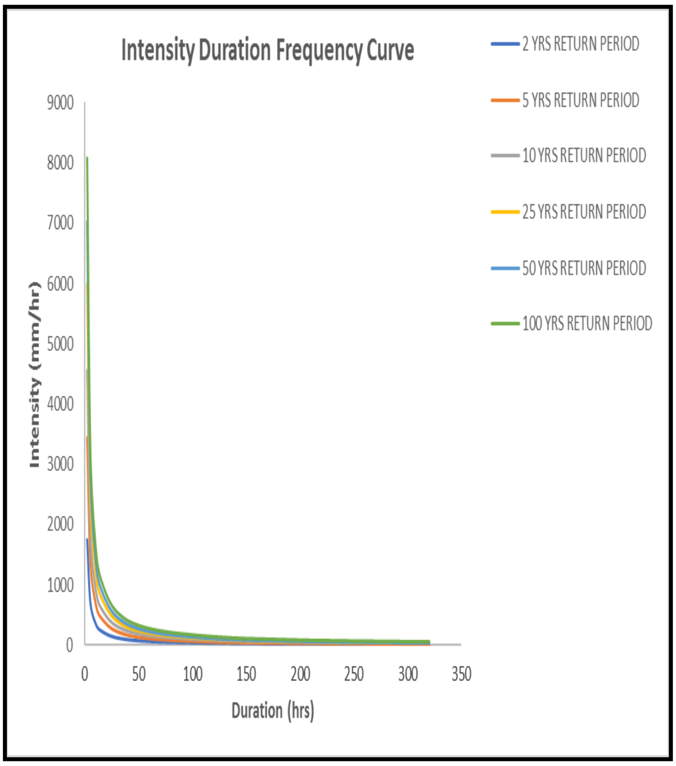


Figure 5. IDF curve for Benin based on Gumbel distribution

Even though the assumption that the return periods are equal between rainfall quantiles and simulated flood quantiles is not always acceptable, some researchers have found that the design storm method can produce acceptable peak discharge for a given return period if this method is used properly. As a long-term run-off model or water balance analysis model, the continuous simulation method was suggested as an alternative to overcome the limitations of the design storm method. However, due to the extensive data and computation requirements for the simulation, daily rainfall time-series are normally used. These explanations support the choice of hydrological flood modeller for use in this study. With a coefficient of determination R2 value of 0.9978 it was concluded that the model generated and presented in Table 3 is adequate. Similarly, using the model equation, rainfall intensities for time durations (t = 2minutes, 5 minutes, 10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes, 240 minute and 320 minutes) were estimated. Using the estimated rainfall intensities and employing the procedures based on the popular Gumbel probability distribution model, the rainfall intensities for the selected return periods was calculated and intensity duration frequency (IDF) curves was generated and presented in Figure 5.

Result of Figure 5 indicates that rainfall intensity decreased with increase in duration for a given return period and increased with return period for a given duration of rainfall.

Likewise, to build the Flood inundation map of the study area, 2D numerical solvers in flood modeller software was used. In addition to the rainfall depth, other data employed to build the flood inundation map of the study area are presented in Table 2.

Table 2. Data employed for flood inundation mapping

Road Layer	Open street data for road infrastructure
Building	Open street data for built-up area
Land Use Land Cover	The land cover type
Rainfall Depth	2yrs, 5yrs, 25yrs, 50yrs and 100 yrs Return period
Manning's Value	Roughness of the various surface
Digital Elevation Model (DEM)	Topographical data

Flood Modeller incorporates an integrated Muskingum flow routing solver and a comprehensive range of hydraulic structures, including gates, abstractions and pumps operated by logical rules. Besides that, it also provides three integrated 2D numerical solvers, tried and tested on projects throughout the world for various hydraulic and environmental studies (Ablain et al. 2020; Meng et al. 2016). Flood Modeller 2D solver, and many other models of its type, represent shallow water hydraulics. The Manning's coefficient of roughness; and ν [m/s] is the kinematic eddy viscosity used to parameterize horizontal turbulent momentum transport, with a value between 0 and 1. An important property of shallow water flows is the different behaviors of subcritical and supercritical flows (Remondi et al. 2016; Dariw et al. 2018). Supercritical flows tend to develop jumps (sudden changes in velocity and water level), which are difficult to represent in the model without causing instability. The difficulty of modelling these jumps is the reason 2D solver has the Total Variation Diminishing (TVD) solver which provides accurate representation of two dimensional 'shocks' (rapid changes in water surface profile) as well as the more commonly used Alternating Direction Implicit (ADI) solver which can be applied to riverine, overland, estuarine, and coastal modelling problems where the flow is not rapidly changing. Taking advantage of these features of flood modeller and using a 10hr duration period for different return periods, the flood statistics which includes; the maximum rainfall depth corresponding to the number of wetted cells and the final volume of runoff were calculated using the Alternating Direction Implicit (ADI) solver and result obtained is presented in Table 3.

Table 3. Result of flood statistics using flood modeler

Recurrence Interval (Years)	Maximum Rainfall Depth (mm)	No. of Wetted Cells	Final Volume of Runoff (m^3/s)
2	37.4	19720	0.42 x 10^7
5	120	22487	0.70 x 10^7
10	136.5	25310	0.89 x 10^7
25	125.8	25830	0.11 x 10^8
50	278	26171	0.14 x 10^8
100	278	26171	0.14 x 10^8

From the result of Table 3, it was observed that there is an increase in the number of wetted with corresponding increase in recurrence interval. For example, for 50yrs and 100 years return period, the number of wetted cells was observed to be 26171with a runoff volume of value of 0.14 x 108m3/s. Using the computed volume of runoff and the corresponding number of wetted cells, the spatial extent of flooding for each return period was generated and presented in Figures 6 – 9 respectively.

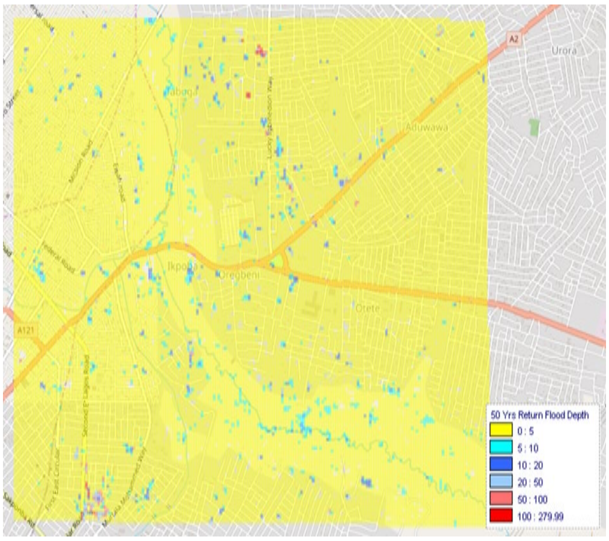


Figure 6. Flood risk map of 2years recurrence interval

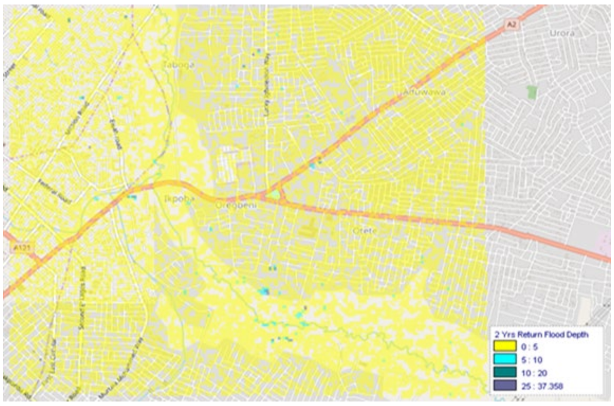


Figure 7. Flood risk map of 25years recurrence interval

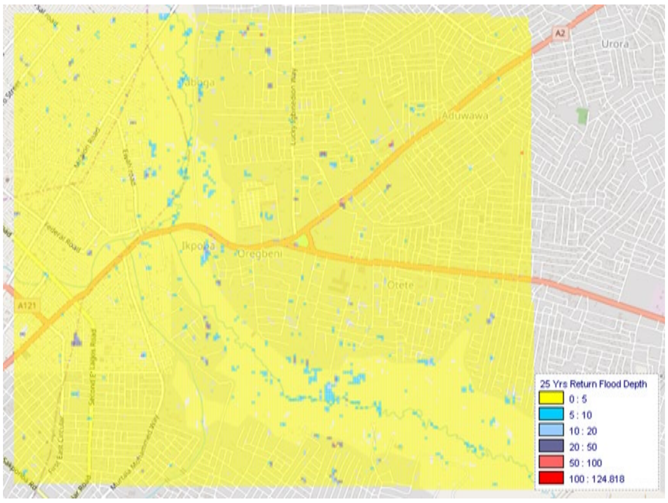


Figure 8. Flood risk map of 50years recurrence interval

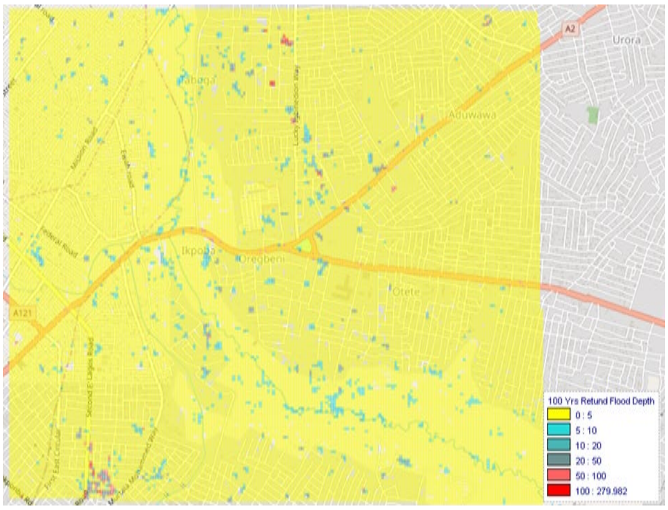


Figure 9. Flood risk map of 100years recurrence interval

The appearance of red spots as observed in the flood risk map of 50yrs to 100yrs return period is an indication of imminent flooding of the area with time. The red spots which are seen in areas such as Lucky Igbinedion Way, Temboga, Second Lagos Road, Mission Road, Ewah Road, Federal Road, Ikpoba, Oregbeni and MM Way shows that these areas are flood prone areas and requires adequate attention and effective early warnings systems in order to alleviate the magnitude of destruction that is caused by flood.

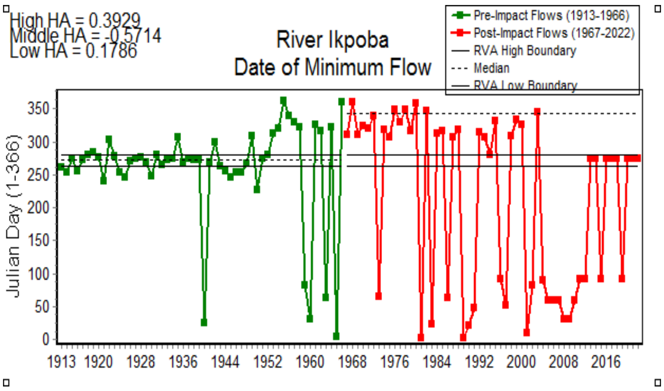
Flood inundation and flood hazard maps employed to identify areas that are likely to be flooded due to high flood event from a watershed. They are mostly used use as tools for early warning signals in order to prevent the havoc that is sometimes caused by high flooding event. Floods are a natural phenomenon which always and which will continue to occur. Though floods cannot be entirely prevented, appropriate planning and protection measures helps in the reduction of the severity of floods and reduction of the damage they cause and one of such measures is the development of flood inundation maps which can help identify areas that are likely to be flooded (Ciupak et al. 2021; Von et al. 2020).

Floods have the greatest impacts on low lying areas, river valleys and coastal zones and floods have potential to cause great damage to land infrastructure and can result in disastrous short term consequences for people and economies. Damages include loss of lives and damage to property, displacement of people, disruption of socio-economic activities and loss of valuable agricultural lands. Human activities have been identified as aggravating the problems of flooding. For instance, the location of housing and industrial estates in flood prone areas exacerbate flooding problems just as soil degradation and deforestation contributes to more serious impacts and damages occasioned by floods. Therefore, appropriate initiatives are needed at country and community levels to implement necessary measures structural and non- structural so as to minimize the threats posed by water related disasters.

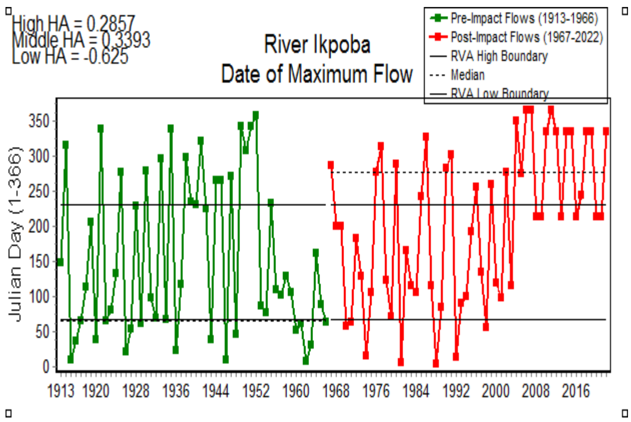
3.4. Hydrological Alteration Indication

Figures 10a-f displays the low and high pulse duration, minimum and maximum, high and low pulse count within the catchment.

Statistics data set the RVA Category Boundaries and High Flow Pulse and Low Flow Pulse Thresholds, both defaults and, optionally, specific values for individual river nodes, but RVA is not calculated for single-period analyses. Although, Monthly flow duration curves (FDCs) is used to assess the effects of the climate model ensemble on different segments of the hydrograph. Wider ranges of PCP are projected for both future periods. With respect to the medians, less precipitation is projected to occur in the future (Fatemeh et al. 2019; Legeais et al. 2018; Aura et al. 2020). This reduction in PCP is higher at the end of the century when medians are reduced to almost 200 mm the smaller amount of precipitation causes a water limitation and counterbalances this effect. The results of the historical simulation indicate that almost half of the total amount of water entering the main channel originates from the lateral flow (30 mm), around 10 mm from surface runoff, and 5 mm from groundwater. There are remarkable differences in the magnitude of changes in hydrological components between corrected and raw climate model data. Change signals in hydrological components are smaller when the bias correction methods are applied. Nevertheless, higher reduction in precipitation, water yield and consequently in surface runoff, groundwater flow and lateral flow is projected by raw models under both emission scenarios.



(a)



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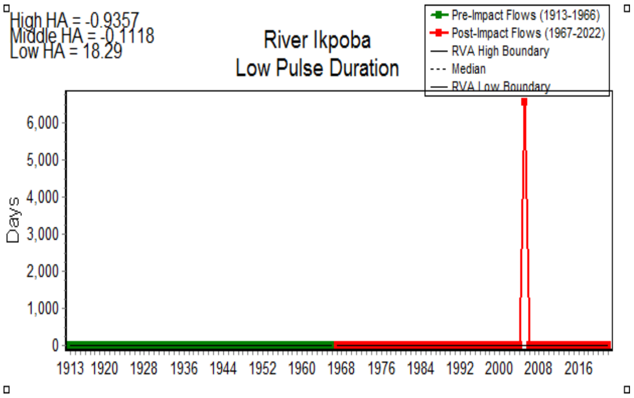

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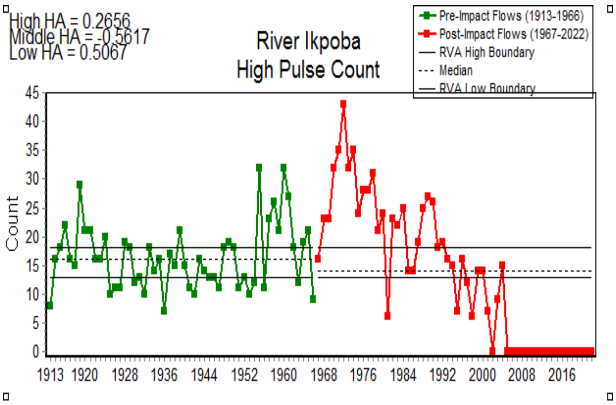

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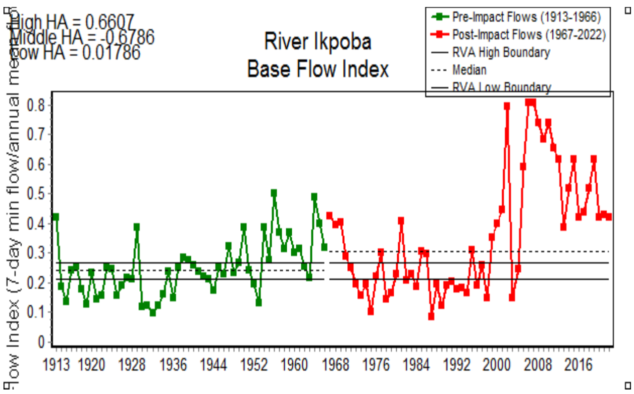
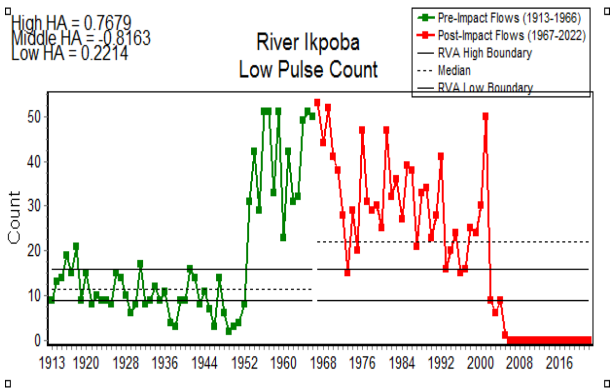


(e)



(f)

Figure 10. a) Date of minimum flow, b) Date of maximum flow at River Ikpoba, c) Low pulse duration of River Ikpoba, d) High pulse duration of River Ikpoba, e) Base flow index of River Ikpoba, f) Low pulse count of River Ikpoba

4. Conclusion

This research has attempted to use a hydrological model in conjunction with projected climate and land-use data to evaluate the effect of urbanization on the discharge and peak flow of the Ikpoba Edo area, which is located upstream of the Ciliwung River, Indonesia. The HEC-HMS model, which is a semi distributed as well as a lumped hydrological model, was calibrated and validated using observed river discharge data from January 1996 and February 2007. The results showed that the daily peak flow and flood volumes will rise along with urbanization due to increases in impervious areas. The alarming amount of runoff volume based on the outcome of the 2D model using the Alternating Direction Implicit (ADI) solver clearly shown that most parts of the study area may not exist in the next 50 to 100years if adequate and proactive measures are not taking by the government including private organization and NGOs which are saddled with such responsibilities. Finally, it is worth noting that the results of this study (discharge generations) will be used as. Comparison of the simulated peak flows based on 50-year return periods for the historical and projected future climate data revealed an increase in peak flow of up to 130%by the year 2030. This estimated peak flow and the relevance of flood volume should be considered when designing flood control systems in the region and optimizing the current flood management systems. Overall, land-use changes upstream of the basin altered hydrological behavior and may result in flooding downstream, where the Benin city is located. Deforestation and urbanization are the main causes of rising flooding volume and peak flow in this watershed. Therefore, it is important to protect the forest in this area. Finally, it is worth noting that the results of this study (discharge generations) will be used as input data for the further study of flood inundation modeling in the Benin city, Ikpoba and the environs.

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Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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