Journal Of Engineering Research Innovation And Scientific Development
1(2): 1-11, 2023, https://doi.org/10.61448/jerisd12231
Print ISSN 2971-6594 Online ISSN 2971-6608
www.jerisddelsu.com

Application of GIS and HEC-RAS for flood risk assessment of Ofu River catchment in Nigeria

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Article History

Received: 27/ 7/2023
Revised: 27/ 9/2023
Accepted: 30/9/2023
Published: 4/ 10/2023

ABSTRACT

While flood inundation mapping and risk assessment have been identified as non-structural measures for the control of floods, the application of GIS-based techniques has been identified as better alternatives to the traditional methods used over time. GIS tools and HEC-RAS models were utilized for a comprehensive flood risk assessment of the Ofu River Catchment as a case study. A total land area of 265.436 km^2 and 92,016 persons are at risk of a 100-year flood return period, while a land area of 265.916 km^2 and 1,959,288 persons are at risk of a 200-year flood in addition to roads, built and scattered settlements, forest reserves, oil palm plantations, churches, mosques, schools, police stations, primary health clinics, markets, and wireless masts that will be at risk. The study demonstrated that the application of the GIS and HEC-RAS models is an effective tool for accurate flood risk assessment at the catchment level.

Keywords: Flood Inundation Mapping; GIS; HEC-RAS; SRTM DTM; Ungauged Catchment

1.0 INTRODUCTION

Flood refers to a temporal condition of partial or total inundation of normally dry areas as a result of the overflow of inland or tidal waters or from the unusual and rapid accumulation of runoff (Alfa *et al.*, 2022; Kumne& Samanta, 2023). This may be attributable, among other factors, to the flow of water above the carrying capacity of a river.

The consequences of floods are far-reaching, ranging from water- and vector-borne diseases, injuries, chemical hazards, mental health effects associated with emergency situations, damaged basic infrastructure, and death in some extreme cases (WHO, 2022). There is a consensus among various authors that flooding is one of the most widespread natural disasters globally and has caused the greatest damage to human life and social developments, which has resulted in monumental economic losses globally (Komolafe *et al.,* 2015; Chmutina & Von Meding, 2019; Giudice et *al.,* 2021). The World Health Organization recently reported that between 80 and 90% of all documented disasters from natural hazards during the past 10 years have resulted from floods, droughts, tropical cyclones, heat waves, and severe storms (WHO, 2022). On a global scale, floods have affected more than 2 billion people between 1998 and 2017 (WHO, 2022).

Flooding in Nigeria is not new, as it has almost become an annual occurrence in many parts of the country. The flood of 2022 was, however, reported as the most severe in the past 50 years of Nigerian history. According to the National Emergency Management Agency (NEMA), the 2022 flood in Nigeria claimed 665 lives, affected 4,476,867 persons in one way or another, displaced 2,437,411 persons, injured 3,181 persons at varying degrees, and damaged 174,281 houses, in addition to numerous farmlands that were destroyed (NIHSA, 2023).

The most vulnerable people to the occurrence of floods are those who live in floodplains or non-resistant buildings or lack warning systems and awareness of flooding hazards (Geldenhuys, 2022). Flood inundation mapping and risk assessment is therefore a required non-structural measure towards either total prevention or reduction of the impact of flood disasters to the barest minimum (Tariq *et al.,* 2020; Mishra & Sinha, 2020).

While this knowledge is not new, the challenge is that the traditional methods that have been used over the years are time-consuming, tedious, and could be prone to human errors (Alfa *et al.,* 2023). However, technological advancement in the area of geospatial analysis has helped to overcome these challenges, which has paved the way for more accurate floodplain mapping and flood risk assessment in an easy and more time-efficient way. The aim of this study, therefore, is to apply geospatial techniques and the River Analysis System of the Hydraulic Engineering Centre (HEC-RAS) to carry out a comprehensive flood risk study of the Ofu River Catchment in Nigeria. While the application of these techniques may not be novel, the comprehensive flood study of the Ofu River Catchment as well as the application of the technique to the study area are novel. This becomes important as the occurrence of floods within the Ofu River Catchment has become a national economic concern.

From the foregoing, it is evident that appropriate delineation of floodplains as well as comprehensive flood hazard, vulnerability, and risk assessment will be a step in the right direction towards solving the problem of flooding. This involves the analysis of large amounts of data, requiring the application of recent data analytics technologies such as GIS and HEC-RAS models since the use of traditional techniques is very tedious and time-consuming. This study therefore explored the use of GIS and HEC-RAS models for comprehensive flood risk assessment, with the Ofu River Catchment as a case study. The focus of this assessment was restricted to only the river flood, while floods outside the floodplain of the river were not included.

Conceptual Framework

1. Concept of Hazard

Baas *et al.* (2008) defined a hazard as a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation. This can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro-meteorological, and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential, or combined in their origin and effects. Each hazard is characterized by its location, intensity, frequency, and probability. Consequently, Alkema and Westen (2005) defined a flood hazard as 'the chance that a flood event of a certain magnitude will occur in a given area within a given period of time'. Flood hazard assessment is the identification, quantification, and communication of the hazards due to flooding, seeking to identify areas subject to particular hazards, such as deep or fast-flowing water, and assess the likelihood of them occurring both now and in the future (Jeb, 2014).

2. Concept of vulnerability

Vulnerability, on the other hand, has been defined differently by various authors and researchers. However, the working definition adopted in this study is that of the Food and Agricultural Organization (FAO), which defined vulnerability as the conditions determined by physical, social, economic, and environmental factors or processes that increase the susceptibility of a community to the impact of hazards (Baas *et al.,* 2008). Flood vulnerability is therefore the extent to which a system is susceptible to floods due to exposure, a perturbation, in conjunction with its capacity or incapacity to be resilient, to cope, recover, or adapt (Balica *et al.*, 2009).

3. The concept of risk

Risk refers to the probability of harmful consequences or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted, or the environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions (Baas *et al.,* 2008). Conventionally, risk is expressed by the notation

Risk = Hazards x Vulnerability (Figure 1).

Figure 1: Flood risk as a combination of Hazard and vulnerability (adapted from Eleuterio, 2012).

2.0 MATERIALS AND METHODS

2.1 Study Area

The watershed of the Ofu River lies between latitudes 6°46ˈ N to 7°39ˈ N and longitudes 6°42ˈ E to 7°21ˈ E (Fig. 2). It falls within Nigeria's Lower Benue River Basin Development Authority, covering parts of Dekina, Ofu, Igalamela/Odolu, Idah, and Ibaji Local Government Areas (LGAs) in Kogi State and Uzo-Uwani Local Government Area in Enugu State, within the humid tropical rain forest of Nigeria (Alfa *et al.*, 2018a; Alfa *et al.*, 2018b). It falls within the Nigerian Hydrological Zone IVa, with mean annual rainfall ranging between 1224 mm and 1800 mm (FMW, 2013), concentrated in one season lasting from April/May to September/October (AR-AR, 2004). According to data from the Nigeria Meteorological Agency (NiMet), the catchment has an average temperature of 26 °C ranging from a minimum of 22°C to a maximum of 31°C

The catchment is underlain by cretaceous sediments. Basement complex rocks,mainly granites and granitic gneisses, are found upstream of the river, the outcrops of which appear to be scarce or absent (AR-AR, 2004). The area is nearly level to undulating, with dominant slopes between 0 and 2% clay plains, which are largely subject to seasonal water logging owing to impeded drainage. Rockoutcrops of sandstone and volcanic cones occur on the high grounds of the plains (ARAR, 2004).

The main river within the sub-basin (Ofu) is perennial and parallel in pattern to the Imabolo and Okura rivers, which are close to the study area. It took its root from Ojofu, in the Dekina Local Government area of Kogi State, flowing in an eastward direction with a catchment area amounting to about 1,604 km^2 most of which is covered by dense forest (Alfa *et al.*, 2019). The Okura River joined the Imabolo River in Egabada (Kogi State) and further flowed southward before joining the Ofu River, and the 'three-in-one' river empties into the famous Anambra River in Anambra State (Gideon et al., 2013).

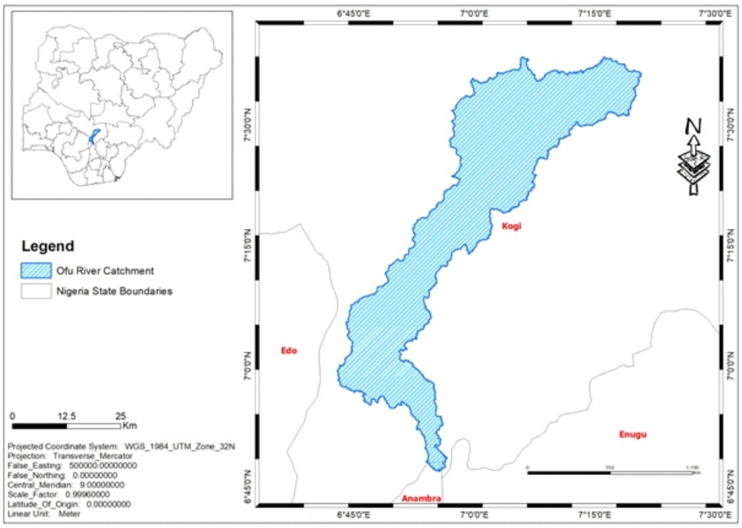

Figure 2: Map of Nigeria Showing Ofu River Catchment

2.2 Data collection

The data used for this study were those of rainfall, soil, satellite imagery, and a digital elevation model. A summary of the characteristics of the data obtained is presented in Table 1.

Table 1: Characteristics of data used for the study

S/No	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared		Average Ranking
		Statistic	Rank	Statistic	Rank	Statistic	Rank	
1	Log-Pearson 3	0.0808	2	0.5077	2	1.9469	2	2.0
2	Lognormal	0.0801	1	0.5536	4	1.9989	3	2.7
3	Lognormal (3P)	0.094	3	0.5025	1	2.8139	5	3.0
4	Fréchet (3P)	0.0969	4	0.5132	3	2.7159	4	3.7
5	Fréchet	0.1133	6	0.6031	5	1.4659	1	4.0
6	Normal	0.1138	7	0.6901	6	2.8809	6	6.3
7	Gumbel Max	0.1047	5	0.6973	7	4.5289	7	6.3

The Log Pearson's Type III distribution, which was determined to be the best, was used to carry out the flood frequency analysis of the Ofu River stream flow data according to methods previously described by various authors (Dalrymple, 1960; Salimi *et al.*, 2008; Patra, 2008; Mustapha and Yusuf, 2012; England Jr. et *al.*, 2017). The distribution was used to forecast extreme streamflow for 2, 5, 10, 25, 50, 100, and 200-year return periods, respectively.

2.4 Hydraulic modeling and inundation analysis of the Ofu River

The hydraulic modeling and flood inundation analysis of the Ofu River were carried out using a combination of HEC-GeoRAS extensions in ArcMap 10.7 and HEC-RAS 5.0.3. The data pre-processing was carried out using the HEC-GeoRAS 10.7 extension in ArcGIS 10.7, where the required layers (stream centerlines, bank lines, flow path centerlines, and XS cut lines) were created, stored in a specified geodatabase, and exported for one-dimensional hydraulic modeling in HEC RAS 5.0.3. The principal dataset for the analysis is the triangulated irregular network (TIN) surface created from the 1 arc second (30 m) resolution SRTM Digital Elevation Model (DEM) of the project area (Figure 3).

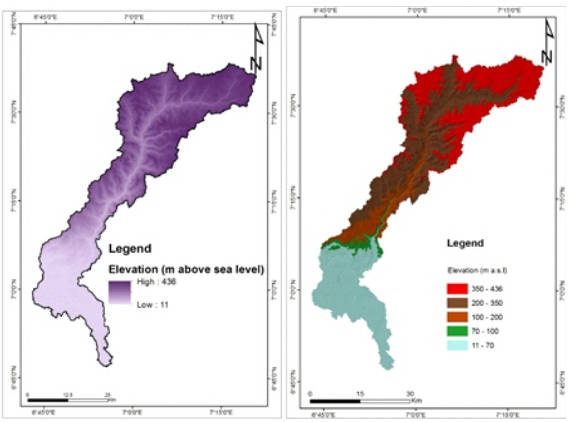

Figure 3: DEM and TIN surface of the Ofu River Catchment

The one-dimensional steady flow hydraulic modeling was carried out using HEC-RAS 5.0.3 using the layers created and exported in the pre-processing stage. These layers were imported into HEC-RAS as geometric data. Manning's n-values of 0.035 and 0.05 were respectively assigned to the channel (near stream) and banks based on the recommendations of Arcement Jr. and Schneider (1989). The peak runoff values estimated for the 100 and 200-year return periods were imputed as two profiles. The steady flow simulation run was successfully carried out, and the results were exported to GIS for inundation and velocity mapping using the HEC-GeoRAS extension in ArcGIS 10.7. HEC-GeoRAS is a GIS-based 2-dimensional hydrodynamic model.

The output of the hydraulic modeling of the two scenarios in HEC-RAS was imported as input for flood inundation mapping using the HEC-GeoRAS 10.7 extension in ArcGIS 10.7. The RAS mapping tools were used for layer set-up, import of RAS files, generation of water surfaces, and inundation mapping (extent and depth) for the 100 and 200 year return periods. Global best practices recommend the 100-year flood event as the design flood for hydraulic structures such as those required in this project (Novak et al., 2004; Systems et al., 2007; Bedient et al., 2013).

2.5 Methods of Flood Risk Analysis

The flood risk assessment in this study combines both hazards and vulnerability, as stated previously. The method of flood hazard classification described by Daffi *et al.* (2014) was adopted with slight modifications. The modification is the exclusion of velocity from the hazard criteria since all the flow velocities observed were far below 1 m/s, which is the lowest hazard velocity limit for flood-inundated water. Besides, the major flood challenge within the Ofu River floodplains has been that of inundation, which probably could be the reason why no loss of life has ever been recorded. Thus, the inundation raster maps for the respective events were reclassified into 'High,' 'Moderate' and 'Low' based on Daffi *et al. (2014)*.

The procedure for determining social vulnerability developed by Cutter *et al.* (1997) for the South Carolina Emergency Preparedness Division was adopted in this study. The vulnerability was derived based on age, disability, gender, and economic status. The method was developed for vulnerability assessment at the county level, which is equivalent to the LGA system in Nigeria, thus making it appropriate for the present study. Details of the method and its application have been described previously in Alfa *et al.* (2018b). Using this method, 10 vulnerability maps representing 10 social classes (Table 3) were developed and integrated using respective vulnerability weights (Table 4) derived using Saaty's Analytical Hierarchical Process (Saaty, 1980) to give the vulnerability map in ArcGIS 10.7. The vulnerability map was first converted to a float by dividing by the maximum value using the Raster Calculator in Spatial Analyst (Map Algebra) tool. Thus, the final Flood Vulnerability Map was produced with 1 as the maximum value. Similar to the hazard map, it was reclassified into three (3) vulnerability classes: 'High Vulnerability', 'Moderate Vulnerability,' and 'Low Vulnerability'.

Table 3: Social vulnerability weights for the Ofu River Catchment

State	LGA	Vulnerability Weight *100									
		Under 15 Years		Above 65 Years		15 - 65 Years		Poverty		Gender	
		WD	ND	WD	ND	WD	ND	Poor	Non-Poor	Male	Female
100 Years Return Period											
Kogi	Dekina	1	1	1	1	1	1	1	1	1	1
	Ofu	8	9	8	9	8	9	9	9	9	9
	Idah	46	43	46	43	46	43	43	43	44	43
	Igalamela/Odolu	100	100	100	100	100	100	100	100	100	100
	Ibaji	1	1	2	1	1	1	1	1	1	1
Enugu	Uzo-Uwani	1	1	1	1	1	1	1	1	1	1
200 Years Return Period											
Kogi	Dekina	1	1	1	1	1	1	1	1	1	1
	Ofu	17	19	17	19	17	19	19	19	19	19
	Idah	46	43	46	44	47	44	44	44	44	43
	Igalamela/Odolu	100	100	100	100	100	100	100	100	100	100
	Ibaji	0	0	1	1	1	0	0	0	0	0
Enugu	Uzo-Uwani	1	1	1	1	1	1	1	1	1	1

With disabilities (WD);No disabilities (ND)

Table 4: Overall weights for all vulnerability Maps derived by AHP

S/No	Social Class	Weight*100
1	Under 15 Years WD	13
2	Under 15 Years ND	12
3	Above 65 Years WD	13
4	Above 65 Years ND	11
5	15 – 65 Years WD	10
6	15 – 65 Years ND	7
7	Poor	10
8	Non-poor	7
9	Male	7
10	Female	10
	Total	100
	CR	0.00

The flood risk map, R_m was produced as a product of the hazard map, H_m and the vulnerability map, V_m(Baas *et al.,* 2008; Eleuterio, 2012). The multiplication was done using the *Raster calculator* in the Map Algebra Spatial Analyst tool in ArcGIS 10.7. The flood risk map for 100 and 200 year return periods was then produced and reclassified into three risk zones ('High Risk,' 'Moderate Risk', and 'Low Risk) based on natural breaks (Cutter *et al.,* 1997).

The flood risk map was overlaid on the digitized topographic map of the watershed to determine the risk status of the features. The areas of the respective risk zones and the population densities of each constituent LGA obtained from NPC (2010) and NBS (2012) were used to estimate the populations at risk. A flow diagram of the method of flood risk assessment is shown in Figure 4.

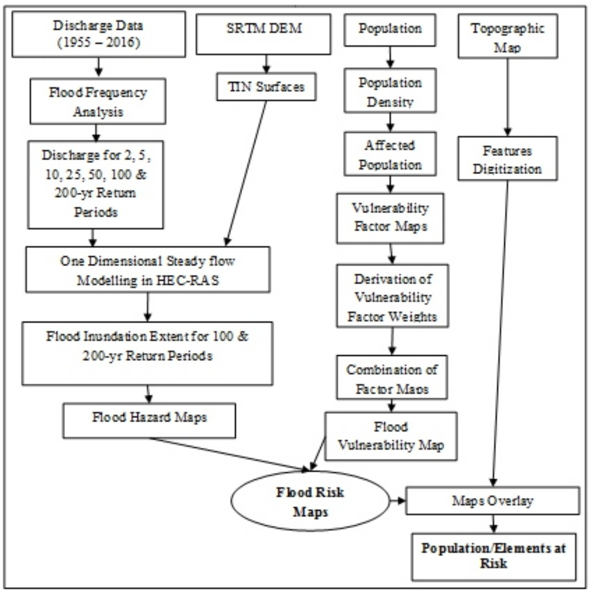

Figure 4: Flow diagram of the method of flood risk assessment

3.0 RESULTS AND DISCUSSIONS

3.1 Morphometric Characteristics and Design Flood Values

The catchment boundaries of the Ofu River as well as other morphometric characteristics are shown in Figure 5 while a summary of the watershed characteristics is presented in Table 5.

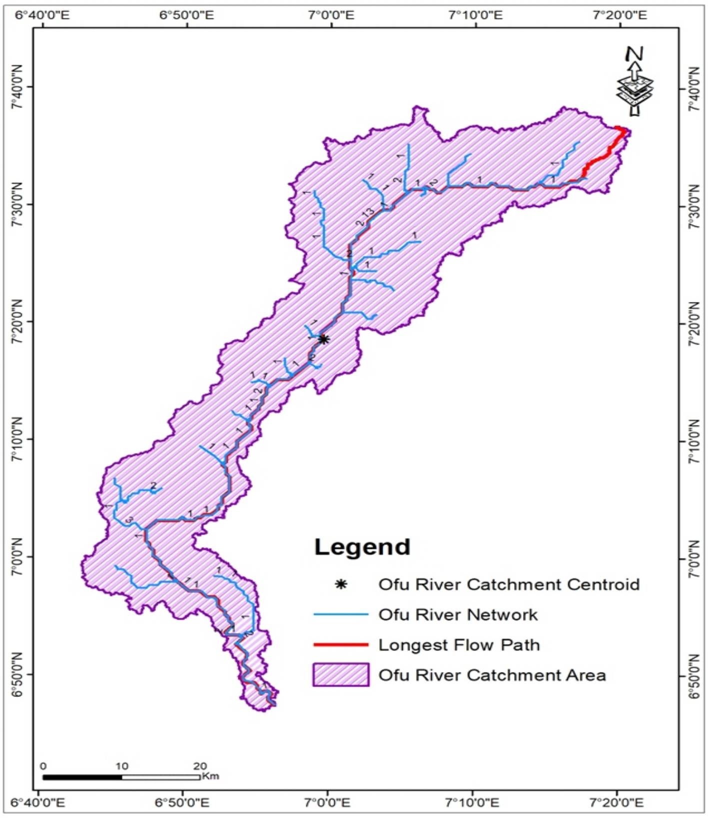

Figure 5: Boundary, Areal Linear Characteristics of the Ofu River Catchment

Table 5: Summary of the River Ofu Watershed Characteristics

S/No	Catchment Characteristics	Category	Symbol	Unit	Value
1	Area	Areal	A	km^2	1604.56
2	Basin Length	Areal	L_b	Km	100.93
3	Longest Flow Path	Areal	L_{fp}	Km	159.14
4	Main Stream Length	Areal	S_L	Km	121.37
5	Elongation ratio	Areal	R_e	-	0.45
6	Circularity ratio	Areal	R_c	-	0.07
7	Form factor	Areal	F_f	-	0.16
8	Compactness coefficient	Areal	C_c	-	3.92
9	Shape Factor	Areal	B_s	-	6.35
10	Stream frequency	Areal	F	km^{-2}	0.11
11	Drainage Density	Areal	D_d	km/km^2	0.26
12	Constant of Channel Maintenance	Areal	C_m	km^2/km	3.9
13	Length of Overland Flow	Areal	L_o	Km	1.95
14	Channel Sinuosity	Areal	S_c	-	2.59
15	Time of Concentration	Areal	T_c	Hrs	6.17
16	Time from peak to Recession	Areal	N	Days	3.68
17	Stream order system	Linear	U	-	3rd Order
18	Stream Number	Linear	N_u	-	39
19	Total Stream Length	Linear	L_u	M	241.4
20	Av. Bifurcation ration	Linear	R_b	-	3.29
21	Av. Stream Length Ratio	Linear	R_L	-	0.72
22	Basin Relief	Relief	H	M	425
23	Basin Slope	Relief	S	-	0.19

The catchment of the Ofu River covers an area of 1,604.56 km2 with streams up to the 3rd order. The basin has a gentle slope of 19%. The time of concentration of the watershed is 6.17 hours, while the time to recession from peak is 3.68 days. These imply that while it takes a drop of water about 6.17 hours to flow from the remotest part of the catchment to the outlet, it will take almost 4 days for flood water to recede from the watershed. The detailed morphometric characteristics of the watershed have, however, been previously reported in Alfa *et al. (2019)*.

Furthermore, the peak discharge values for 2–200-year return periods obtained via the Log Pearson III analysis are presented in Table 6.

Table 6: Estimated Discharge Values for Respective Return Periods

Return Period (years)	Skew Coefficient K(-0.0104)	Discharge, Q (m^3/s)
2	0.00	444.57
5	0.84	499.23
10	1.28	530.35
25	1.75	565.61
50	2.05	589.59
100	2.32	611.96
200	2.57	633.25

The values of 611.96 cumecs and 633.25 cumecs respectively obtained for 100 and 200 years return period were used for the flood inundation studies of the aforementioned return periods as stated previously.

3.2 Flood Inundation Extent

The flood inundation extent maps for 100 years and 200 years return periods are shown in Figure 6. While the details are presented in Table 7.

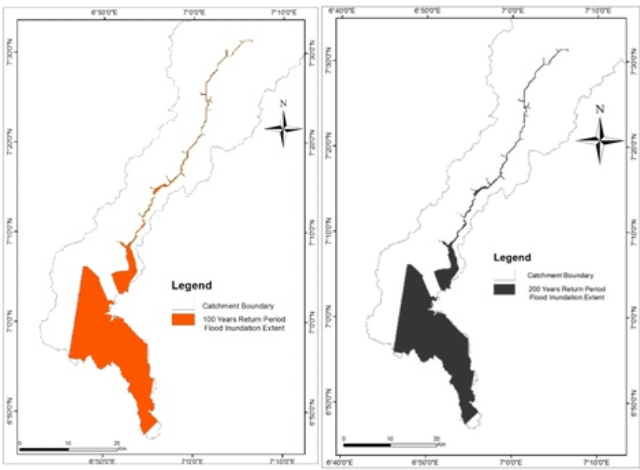

Figure 6: Flood Inundation extent for 100 and 200 years return periods respectively

Table 7: Area, Depth and Velocity of Flood Inundated water

Return Period/Scenario	Area (km^2)	Depth (m)		Velocity (m/s)	
		Range	Average	Range	Average
100	266.84	0.000015 - 11.70	8.12	0 - 2.62	0.46
200	267.37	0.000092 - 11.76	8.28	0 - 2.75	0.46

Table 7 shows that the average velocity of flood water is less than 1 m/s for the scenarios analyzed, which implies that the challenge of flooding within the Ofu River catchment is not actually a function of the velocity but just the inundation. This explains why no death or injury has ever been recorded.

3.3 Flood Hazard, Vulnerability, and Risk Assessment

The output flood hazard maps for 100 and 200-year return periods are shown in Figure 7, while the details are presented in Table 8.

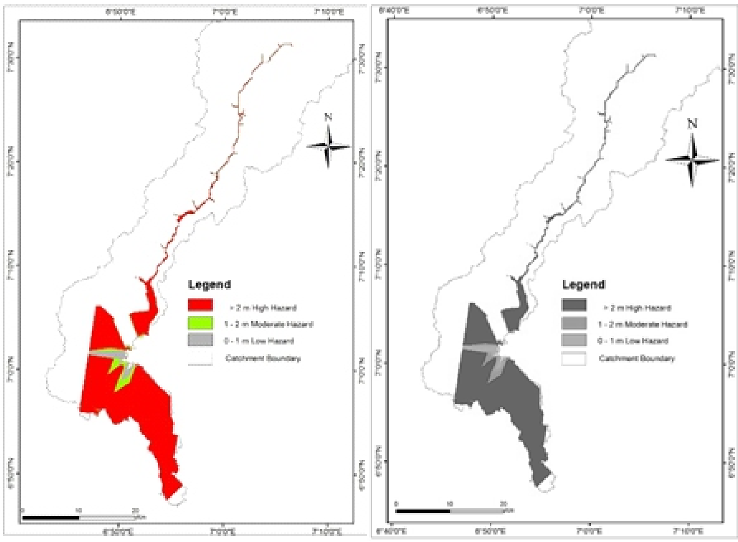

Figure 7: Flood Hazard Maps for 100 years and 200 years return periods

Table 8: Flood Hazard Zones/extent for 100 years and 200 years Return Periods Floods

Scenario/Return Period	Hazard Zone (km^2)			Total
	High	Moderate	Low	
100 Years	242.366	12.711	12.756	267.833
200 Years	244.939	11.496	11.937	268.372

Table 8 shows that the high-hazard zone covered an area of 242.366 km^2 and 244.939 km^2 for the 100-year and 200-year return periods, respectively. The moderate hazard category covered 12.711 km^2 and 11.496 km^2, respectively, while the low hazard category covered 12.756 km^2 and 11.937 km^2, respectively. This implies that the area with the Very High Hazard Zone has a very high potential of being affected by a flood disaster (Ajin*et al.,* 2013; Daffi *et al.,* 2014; Alfa *et al.,* 2018b). As stated previously, the hazard map only shows the potential extent of harm that can be caused by the flood. However, vulnerability is a factor that determines the actual exposure.

The output flood vulnerability extents for 100 and 200-year return periods are therefore presented in Table 9 and Figure 8.

Table 9: Flood Vulnerability Zones/extent for 100-year and 200-year Floods

Scenario/Return Period	Vulnerability Zone (km^2)			Total
	High	Moderate	Low	
100 Years	256.501	0.000	10.164	266.665
200 Years	256.819	6.818	3.361	266.998

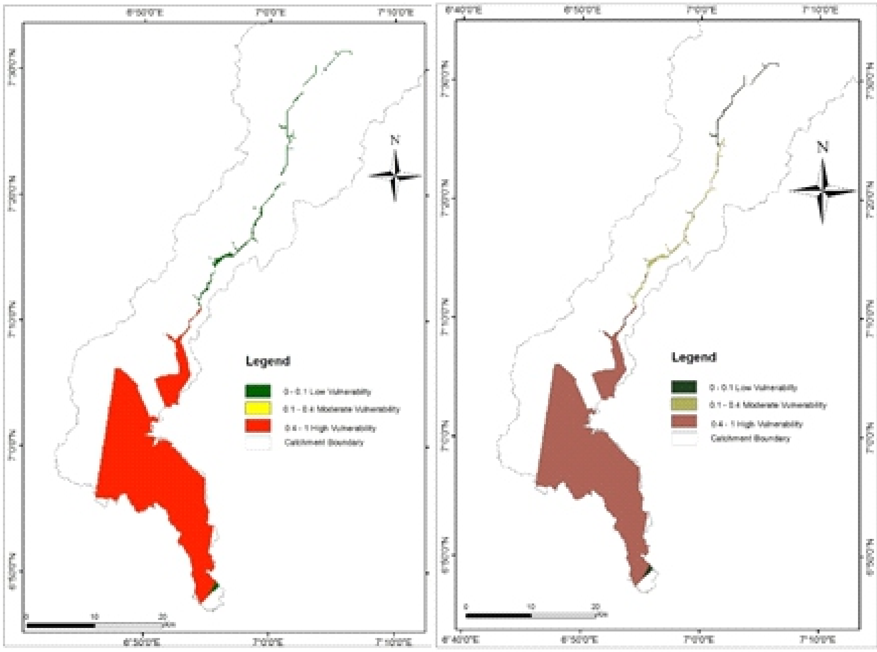

Figure 8: Flood Vulnerability Maps for 100 years and 200 years return periods

Table 9 shows that the high vulnerability zone covered an area of 256.501 km^2 and 256.819 km^2 for floods with 100-year and 200-year return periods, respectively. There was no moderate vulnerability zone for the 100-year return period for the flood, but it covered an area of 6.818 km^2 for the 200-year flood. Lastly, the low vulnerability category covered 10.164 km^2 and 3.361 km^2, respectively. Vulnerability is often a reflection of exposure, susceptibility, and resilience (Balica *et al.,* 2009).

The flood risk maps for 100 and 200-year return periods obtained as a product of flood hazards and vulnerability are presented in Figure 9. More so, the elements at varying degrees of risk to the floods of 100 and 200 years return periods are presented in Table 10, while the population at varying degrees of risk to the floods of 100 and 200 years return periods is presented in Table 11.

The results reveal that various elements of economic value are at high risk of flood disaster. Similarly, a total of 9,429 persons and 88,335 persons are at high risk of the 100 and 200-year return periods, 3,754 persons and 271,488 persons are at moderate risk, while 78,833 persons and 1,599,466 persons are at low risk of the 100-year and 200-year floods, respectively.

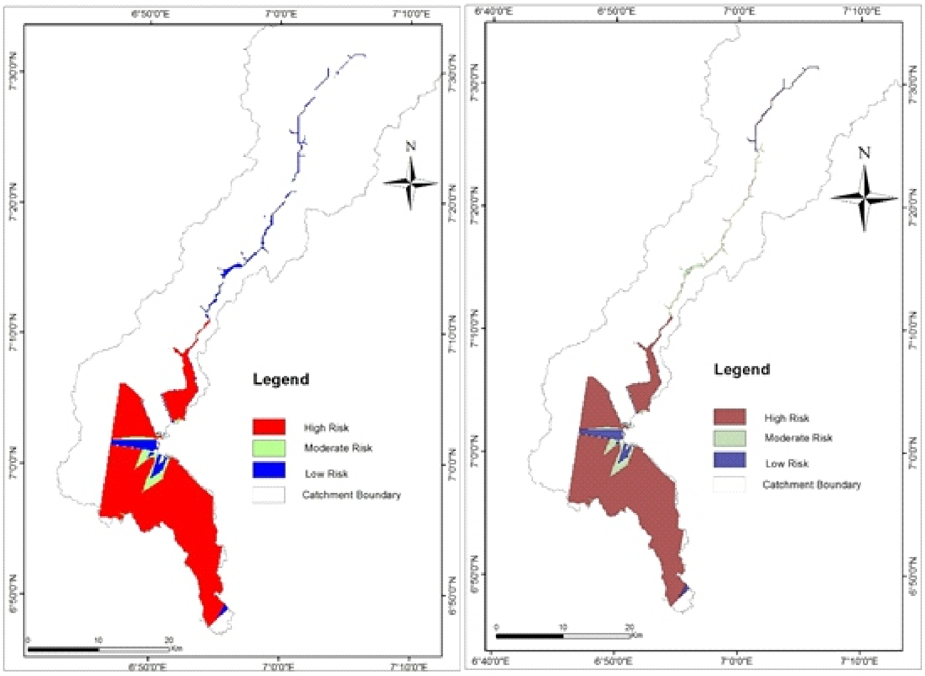

Figure 9: Flood Risk Mapsfor 100 years and 200 years return periods

Table 10: Elements at Risk of Floods of 100 and 200 years Return Periods

Category	Elements	Risk Zone 100-Years Flood				Risk Zone 200-Years Flood			
		High	Moderate	Low	Total	High	Moderate	Low	Total
Land	Surface Area (km^2)	231.645	12.164	21.627	265.436	234.189	17.021	14.706	265.916
Road	Main Road (km)	1.575	1.417	1.76	4.752	1.578	1.555	0.214	3.347
	Minor Road (km)	23.539	0.3	0.477	24.316	23.534	0.67	0.101	24.305
	Main Path (km)	108.138	1.418	2.167	111.723	108.761	2.024	1.019	111.804
Human Settlements	Built Areas (no)	6	0	1	7	7			7
	Built Areas (ha)	30.548	0	41.535	72.083	30.557	38.338	2.954	71.849
	Scattered (no)	8			8	8			8
Agricultural	Forest Reserve (ha)	699.336	37.238	15.711	752.285	706.197	31.627	15.238	753.062
	Oil Palm Plantation (ha)	0.132	0	0	0.1324	0.132	0	0	0.1324
Others	Church (no)	1	0	0	1	1	0	0	1
	Mosque (no)	1	0	0	1	1	0	0	1
	School (no)	1	0	0	1	1	0	0	1
	Police Station (no)	1	0	0	1	1	0	0	1
	PHC (no)	1	0	0	1	1	0	0	1
	Market (no)	1	0	0	1	1	0	0	1
	Wireless Mast (no)	1	0	0	1	1	0	0	1

Table 11: Population at Risk of Floods of 100 and 200 years Return Periods

State	LGA	Population at Risk (persons)							
		100 Years Return Period				200 Years Return Period			
		High	Moderate	Low	Total	High	Moderate	Low	Total
Kogi	Dekina	753	-	-	753	10,490	10	-	10,501
	Ofu	4,700	-	7	4,707	7,035	204,718	307	212,061
	Igalamela/Odolu	3,382	2,414	20,218	26,014	64,795	43,989	415,695	524,478
	Idah	-	-	-	-	-	-	-	-
	Ibaji	172	1,339	58,606	60,117	1,357	22,770	1,183,438	1,207,566
Enugu	Uzo-Uwani	422	-	2	425	4,657	-	26	4,683
	Total	9,429	3,754	78,833	92,016	88,335	271,488	1,599,466	1,959,288

3.4 Ground Truthing and Validation

In order to ground the truth and validate the flood inundation extent obtained in this study, field observation in 49 houses was carried out within the Oforachi community, which has the longest history of flooding within the Ofu River catchment. A total of 30 houses had evidence of flood marks at varying depths, while the remaining 19 have never been flooded. An overlay of these points on the flood inundation extent for the 100 and 200-year return period showed that while 30 locations were within the flooded area based on the field survey, 36 were within the inundated area based on this study (Figure 10), which is within 20% accuracy.

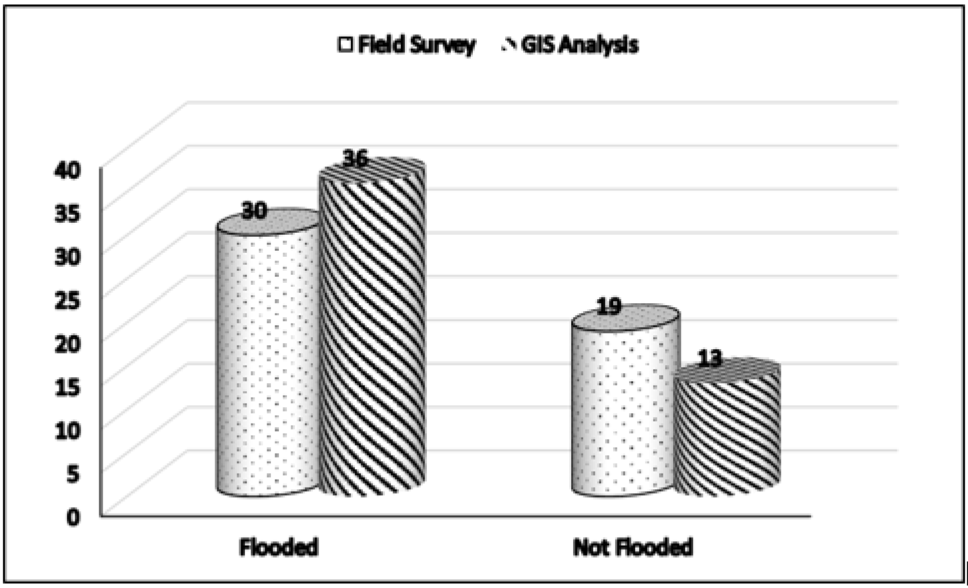

Figure 10: Comparison of Inundation Extent from Field Survey and GIS Analysis

Based on the foregoing, a strategic plan for management of flood at Ofu River catchment is hereby proposed as presented in Table 12.

Table 12: Strategic Plan for Ofu River Catchment Flood Management

S/N	PLAN	ACTION	RESPONSIBILITY
1.	Ofu River catchment management team	Set up a management team comprising of a representative of LBRBDA, at least one official from each of the component LGAs, the counsellor of component wards and the village heads of communities along the river course or their representatives	LBRBDA, Government, NEWMA
2.	Channelization of Ofu River to accommodate more flood waters	Dredging and widening of the Ofu River channel	State Government with support fro Federal Government through LBRI Headquarters Makurdi
3.	Clearing of Ofu River to accommodate more flood waters	Periodic clearing of excessive vegetative cover on the Ofu River water course	Ofu River catchment Management Team
4.	Increase public awareness of flooding	Public enlightenment campaigns, town hall meetings and stakeholder's forum	Information Office of the Respecti LGAs in collaboration with the Sta Ministry responsible for water reso and rural development and Ofu Riv catchment management team.
5.	Set up an early warning and emergency preparedness scheme	Design and implement emergency and early warning scheme that will involve the community leadership, paying particular attention to ease of understanding of the communities	LBRBDA Headquarters Makurdi S Government, Ofu River Catchment Management Team and the commu Leadership
6.	Set up a flood plain management programme	Engage floodplain managers to train people to meet up with current and growing challenges in floodplain management.	LBRBDA Headquarters Makurdi a Ofu River Catchment management

4.0 CONCLUSION

This study concludes that HEC-RAS and HEC-Geo-RAS extensions in ArcGIS are effective tools for flood inundation mapping using hydrologically generated stream flow, which can clearly determine inundation extents, depths, and velocities. The flood inundation extents for floods of 100 and 200 years return periods were, respectively, 266.84 km^2 and 267.37 km^2. Furthermore, the 100-year flood will put 265.436 km2 of land and 92,016 people at risk, while the 200-year flood will put 265.916 km^2 and 1,959,288 people at risk, in addition to roads, built and scattered settlements, forest reserves, oil palm plantations, churches, mosques, schools, police stations, primary health clinics, markets, and wireless masts that will be at risk.

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