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Integration of Hec-Ras Hydraulic Model and Geographic Information System for Flood Vulnerability Modelling of Ogbese Catchment in Akure-North, Nigeria

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Abstract

Flood vulnerability modeling has become essential due to the impact of climate change on the environment. The Ogbese area of Nigeria frequently experiences significant flooding, primarily caused by torrential rainfall that leads to the overflow of local rivers. This study aims to model and map flood vulnerability in the Ogbese Catchment area in Ayede-Ogbese. Advanced analytical techniques, including Remote Sensing (RS), Hydraulic Engineering Center-River Analysis Software (HEC-RAS), and Geographical Information System (GIS) software (ArcGIS 10.7), were utilized for flood modeling and mapping in the study area. The data used in this research includes a topographic map of Ondo State for delineating the study area, Operational Landsat Imageries (OLI) for extracting land use and land cover (LULC), hydrological data (river discharge) for flood frequency analysis, and Advanced Land Observing Satellite (ALOS) Digital Elevation Map (DEM) for geometric data extraction and generating a Triangulated Irregular Network (TIN) dataset. Fourteen ground truthing points were acquired from the flooded areas to validate the accuracy of the HEC-RAS 6.2 hydraulic model in assessing the buildings and features at risk. The findings indicate that bare land (14.863 hectares), farmland (6.742 hectares), built-up areas (3.810 hectares), internal roads (2.27 km), and major highways (0.383 km) were the most severely affected features in the study area during the simulation of a 100-year return-period flood. The study also reveals expected stream discharges for various return periods: 1.686 m^3/s, 1.896 m^3/s, 2.1601 m^3/s, 2.356 m^3/s, and 2.551 m^3/s for return periods of 5, 10, 25, 50, and 100 years, respectively. Trend line analysis shows an R^2 value of 0.85, indicating that the pattern is scattered and follows

Gumbel's distribution, making it suitable for predicting expected river flow. Flood inundation maps for different return periods (5 and 100 years) were categorized based on the probability of occurrence: very high (return period ≤ 100 years), high (50 years), moderate (≥ 25 years), low (10 years), and very low (5 years). The inundation extent for the 100-year return period showed that the flood covered the largest area of 95.18 hectares with an inundation depth of 11.76 m, while the 5-year return period covered the smallest area of 94.54 hectares with an inundation depth of 11.69 m. Highly vulnerable areas include Odo-Oriokuta, Isalekenyo, Rasco, and Agunla Road (1.6%), while moderately vulnerable areas are Sabo and Ile-Ologbo, Oke-odo (58.8%). Alayere and Faloye are classified as low vulnerability areas (38.4%), and Owonikoko Layout is considered very low vulnerability (1.3%). The findings of this study can be utilized for drainage system planning in Nigeria and serve as a decision support system for government officials, stakeholders, and policymakers in managing flood disasters. Given the anticipated increase in anthropogenic activities and climate change, the Ogbese River watershed may face greater flood risks in the future. Therefore, further research is necessary to develop advanced flood alleviation measures, including improved flood monitoring, river channelization and dredging, expansion of drainage facilities, early warning systems, public awareness campaigns, and the removal of buildings encroaching on the river right-of-way (15 m) to prevent property and life losses.

Keywords: Flood; Geographic Information System; Hydraulic Modeling; Catchment; Inundation

Introduction

In recent times, extreme weather conditions, such as intense precipitation events, have the potential to cause unusual and unexpected natural disasters like floods and their associated hazards [45, 18, 40]. The quantity and rate of floodwater flow depend on various interacting factors, including the frequency and characteristics of rainfall, the morphometric properties of drainage basins (such as catchment shape and the number and length of streams), the physical properties of the soil (including depth, texture, and hydraulic conductivity), land use and land cover characteristics, and anticipated conditions like soil moisture levels [39]. Floods are considered one of the most common natural disasters affecting people and urbanization in various ways globally [6, 38]. The impacts of river floods and storm surges in urban areas can include fatalities, displacements, severe health issues, and significant economic losses.

The United Nations Environmental Protection [35], opined that in adapting to climate change and managing the resulting damages may cost developing countries between $140 billion and $300 billion per year by 2030, and between $280 billion and $500 billion per year by 2050. From 1985 to 2014, flooding in Nigeria displaced over 11 million people, leading to approximately 1,100 deaths and property damages exceeding $17 billion [22]. In the 21st century, most weather models and their empirical advancements have demonstrated that a warmer climate can increase atmospheric water vapor, resulting in more intense and frequent precipitation [5]. This increased precipitation leads to excess runoff, which many existing drainage systems cannot accommodate [12, 3]. Additionally, inadequate development planning, random infrastructure construction in floodplains, and river obstructions all contribute to a higher likelihood of flooding. Consequently, floods are regarded as one of the most severe and frequent water-induced natural disasters globally, causing significant damage to habitats, infrastructure, and properties, regardless of geographical or hydrological location [37, 14, 9]. They also have a direct impact on the socio-economic conditions of affected areas. For several years, researchers worldwide have preferred to investigate flood extents using computer models, such as the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS) [36, 13, 10]. HEC-RAS is an integrated software system designed for interactive use in a multi-tasking and multi-user network environment. It comprises a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, as well as graphics and reporting facilities [36, 17, 29]. HEC-RAS offers a quick and precise method for flood mapping by utilizing available hydrological data [4, 8].

Flood modeling and flood inundation maps are essential for understanding the potential impacts of significant floods and for prompting actions to minimize damage [10, 2]. Hydrodynamic models have played a crucial role in determining flood characteristics such as magnitude, duration, and spatial distribution. Recent advancements in hydrodynamic modeling have greatly improved its ability to simulate flooding scenarios [31, 11, 31, 19]. Numerous studies have focused on modeling floodplains in various river basins in Nigeria. For instance, [42] study utilised geospatial technologies to create a flood hazard model for medium-sized cities in developing countries, with particular attention to Nigeria. This approach aimed to identify flood hotspots and develop measures to mitigate flood occurrences. Another study employed remote sensing, the HEC modeling packages (HEC-HMS and HEC-RAS), and GIS software (ArcGIS 10.1) to model and map floods in the adjoining areas of Lagos Island and parts of Eti-Osa Local Government Area in Lagos State [42]. Additionally, research characterized the 2014 flood of the Indus River in Pakistan using the HEC-RAS model, integrated with GIS and satellite images from Landsat-8, to estimate the spatial extent of the flood and assess damage by examining changes in land use/land cover types within the river basin [43]. Similarly, [15] analysed the vulnerability of the 2015 flood in North Central Nigeria using an integrated hydrological model and GIS approach. The results indicated that hydraulic simulation by integrating the HEC-RAS model with GIS is effective for various floodplain management strategies. The methodology developed was efficient in modeling and visualizing the spatial extent of flooding across different scenarios. Lastly, another study performed 1D hydrodynamic flood modeling on the Purna River, particularly through geospatial techniques. Over time, several studies have been conducted in the area, including the work of Obiora [44].

Methodology

2.1 The Study Area

The Ogbese watershed is situated in Ayede–Ogbese village within Ondo State, Southwestern Nigeria. It spans latitudes 6° 43' 00"N to 7° 45' 00"N and longitudes 5° 45' 00"E to 6° 34' 00"E (see Figure 1). The total area of the Ogbese watershed covers 64.156 km^2 and flows through the communities of Agbe-Oyirin, Oke-Odo, Asolo, and Ayede–Ogbese village, which is approximately five kilometers from Akure town in Akure North. Hydrologically, the Ogbese River originates from Apata Hill in Awo Ekiti, Ekiti State [24, 26]. It flows for about 22 km before merging with the Ose River, which is roughly 300 km long and eventually discharges into the Atlantic Ocean via a network of creeks and lagoons [24, 26]. The climate of Ogbese town is characterized by a tropical rainforest zone, with distinct wet and dry seasons. The southwesterly wind current brings a cooler rainy season from April to October, during which the annual rainfall ranges from approximately 1,600 mm to 2,100 mm, with a brief dry spell often occurring in August [23, 24]. The northeasterly wind currents usher in a hot dry season from November to March. The months of August to October typically experience the highest rainfall, which correlates with peak discharge, water stage, and river runoff [28]. Additionally, the harmattan season usually occurs between December and January, characterized by hazy weather. The mean daily maximum temperature in this area ranges from 30°C to 35°C, while the mean daily minimum temperature varies from 21°C to 26°C. Geologically, the area is underlain by crystalline rocks, primarily from the undifferentiated Precambrian basement complex, which includes gneisses and migmatites [3, 23]. Except for a small portion of less than 0.04 hectares in the extreme northwest where these rocks are exposed, the entire bedrock is covered by superficial deposits consisting mainly of gravel, laterite, concrete, sand, silt, and clay materials. The population of the study area is approximately 5,396 [28, 23].

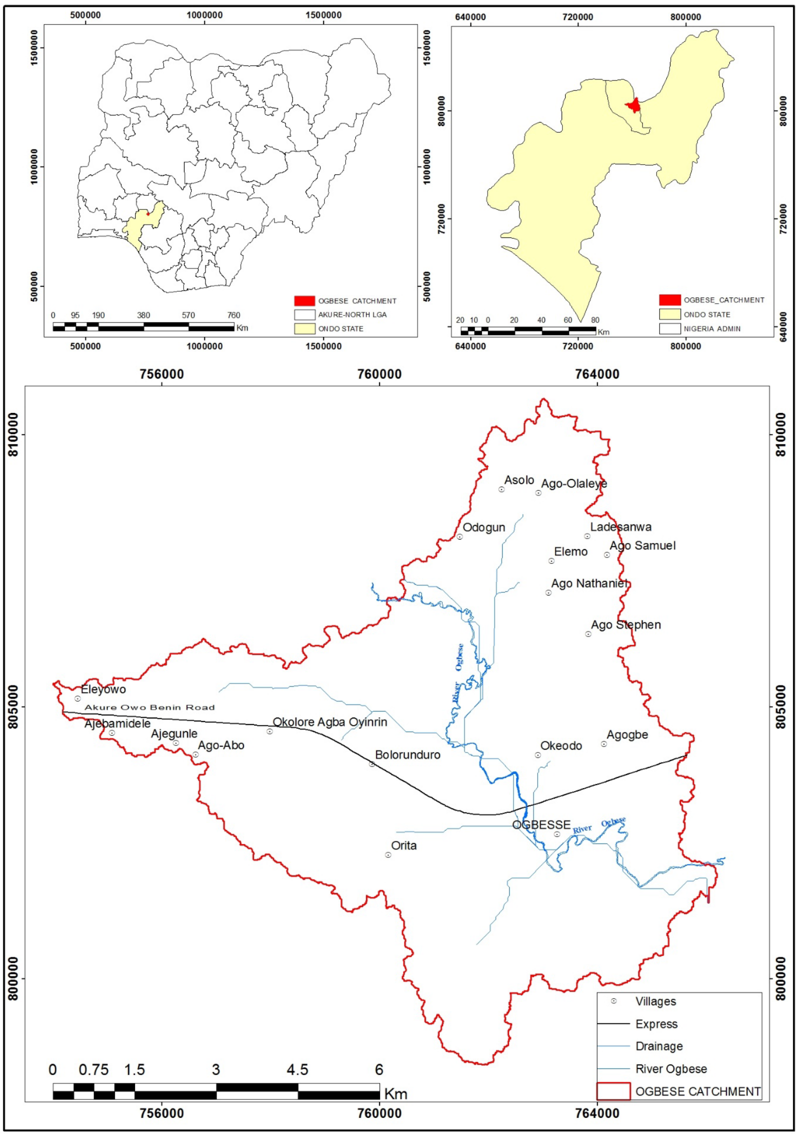

Figure 1: Study Area (Source: Author's Work, 2023)

2.2 Data Acquisition

The study utilized both primary and secondary data sources (see Table 1). These included an administrative map of Ondo State obtained from the Office of the Surveyor General of the Federation (OSGOF), which was used to delineate the study area. Operational Landsat Imageries (OLI) from the United States Geological Survey (USGS) were adopted for the extraction of land use and land cover (LULC) in the floodplain area. Additionally, the Advanced Land Observing Satellite (ALOS) Digital Elevation Map (DEM) from the Alaska Satellite Facility https://vertex.daac.asf.alaska.edu was employed to extract geometric data and generate a Triangulated Irregular Network (TIN) dataset for the one-dimensional flow model in HEC-RAS. Moreover, Infotera Spot imagery from OSGOF was used for the extraction and validation of infrastructural datasets, while hydrological data (River Discharge) from the National Meteorological Agency (NIMET) was utilized to compute peak discharge at different return periods (flood frequency), which served as input flow data for the one-dimensional simulation. A topographic map was also employed to extract the names of various areas. To ensure the validation and accuracy of the land use data acquired within the floodplain of the study area, ground truthing was conducted. This involved extensive fieldwork and thorough field observations. The main analytical technique used was a hydraulic model (HEC-RAS), which integrated Remote Sensing and GIS technologies. The data used in this study were procured from recognized and reliable sources for scientific research, ensuring a high level of data veracity that meets international standards for studies of this nature. However, challenges were encountered in acquiring some of the data, such as cloud cover obstructing satellite imagery, financial constraints related to purchasing GIS data and software, and the lack of common facilities and skills required for implementing the advanced techniques adopted in this study.

Table 1: Characteristics of Data Acquired

Data	Acquisition Date	**Scale / Resolution**	**Sources**	**Type of Data**	**Usefulness for the Research**
ALOS PALSAR DEM	2020	12.5mX12.5m	Alaska Satellite Facility websitehttps://vertex.daac.asf.alaska.edu	Spatial	Delineation of drainage, Basin characterization, and TIN generation
Landsat 8 OLI-TIRS,	September 2019	30m x 30mPath 190Row 55	United States Geological Survey Website: http://earthexplorer.usgs.gov/	Spatial	Extraction of land use/cover in the floodplain area
Infoterra spot high imagery	2014	2.5m x 2.5m	OSGOF	Spatial	Extraction of Infrastructural dataset/validation
Akure Sheet 264 NE	1966	1:50,000	OSGOF	Spatial	Extraction of rivers, waterbody place of names and DEM validation
Discharge Data	1989-2019	Daily discharge	Computed from NIMET data		Compute peak discharge for return periods 5, 10, 25, 50, 100 years. Flow data for simulation.
Ground Truthing	Field work 2021			Spatial	Validate land use within floodplain
Administrative map of Nigeria	2013	1:3,000,000	OSGOF	Spatial	Extraction of Akure South LGA boundary

Determination Flood Inundation

The Hydrologic Engineering Center's River Analysis System (HEC-RAS), developed by the United States Army Corps of Engineers (USACE), is commonly used for investigating flooding, flood-related hazards, and identifying floodplains worldwide [34, 32, 29]. In this research, we utilized hydrodynamic modeling with HEC-RAS version 6.2, along with the HEC-GeoRAS extension tools in ArcMap 10.7, to determine flood inundation. HEC-GeoRAS is a suite of procedures, tools, and utilities for processing geospatial data in ArcGIS, utilizing a graphical user interface (GUI). This interface facilitates the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. Steady flow computations are based on the energy equation, as expressed in Equation 1.

$$Z_2 + Y_2 + \frac{a_2 v_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 v_1^2}{2g} + h_e \quad (Eqn.1)$$

Where,

Z_1, Z_2 = elevation of channel bottom;

Y_1, Y_2 = water depth at cross sections;

V_1, V_2 = average velocities (overall discharge/total flow area);
a_1, a_2 = gravitational acceleration;
and h_e = energy head loss

The energy head loss is given as (1, 6, 7):

$$h_e = LS_f + \left| C\left(\frac{a_2v_2^2}{2g} - \frac{a_1v_1^2}{2g}\right) \right| \quad Eqn.2$$

Where,

L = discharge weighted reach length;

S_f= representative friction slope between two sections;

C = expansion or contraction loss coefficient;

The discharge weighted reach length, L is given as (1, 6, 7):

$$L = \frac{L_{lob}Q_{lob} + L_{ch}Q_{ch} + L_{rob}Q_{rob}}{Q_{lob} + Q_{ch} + Q_{rob}} \quad Eqn.3$$

Where,

L_{lob}, L_{ch}, L_{rob} = cross-section reach lengths specified for flow in the left overbank, main channel, and right over the bank, respectively;

Q_{lob} + Q_{ch} + Q_{rob} = arithmetic average of the flows between sections for the left overbank, main channel, and right over the bank, respectively.

Flood Frequency Analysis

The Gumbel distribution, a stochastic model used to generate random outcomes, was employed to analyze the annual peak discharge data of the Ogbese River at Ayede-Ogbese from 1989 to 2019. This method of frequency analysis is based on extreme value theory and utilizes frequency factors derived from the theoretical distribution. Table 2 presents the computed parameters necessary for applying the Gumbel distribution.

Table 2: Computed Required Parameters

Mean x = ΣX/n	Standard Deviation= √n/n-1 (X^2- X)	Reduced mean ($Y_{n)}$	Reduced standard Deviation ($S_{n)}$
1.41749151	0.31136247	0.5371	1.1159

3.0 Hydraulic Simulation

HEC-RAS 6.2 hydrodynamic modeling involves several steps in both the pre-processing and post-processing stages. During the pre-processing phase, geometric data and other required themes were prepared using HEC-GeoRAS in the ArcGIS environment. This data was then exported in GIS file format into HEC-RAS, where the geometric themes of the hydraulic model are illustrated in Figure 3. The themes included the generation of the river centerline, river banks, and flow paths derived from ALOS-DEM and Info-terra imagery in ArcGIS. These data sets were imported into HEC-GeoRAS layers. For the study area, triangulated irregular network (TIN) and cross-section cut lines were generated for the river using only the ALOS DEM. The geometric data prepared in the pre-processing phase of HEC-GeoRAS was imported into HEC-RAS for hydrodynamic modeling. The hydraulic data input included flow data (peak discharge) and associated boundary conditions for the downstream area (normal depth). The Manning roughness coefficient values for various land uses in the HEC-RAS 6.2 environment are shown in Figure 2, which outlines the flow data and conditions for all river reaches. Additionally, calculated flood frequencies for different return periods, including the maximum peak discharge, were inputted for each return period. The steady-state flow simulation was conducted to determine the water surface profile under subcritical flow conditions. The calculated water surface profiles were then exported to GIS format for post-processing (refer to Figure 3). In the post-processing phase, results from HEC-RAS were imported back into the HEC-GeoRAS platform after configuring the layers with terrain input. Water surfaces for different flow scenarios were generated for each return period along with corresponding flood frequency analyses of the maximum peak discharge. Using the TIN, flood inundation maps and floodplain extents were also produced for each water surface profile.

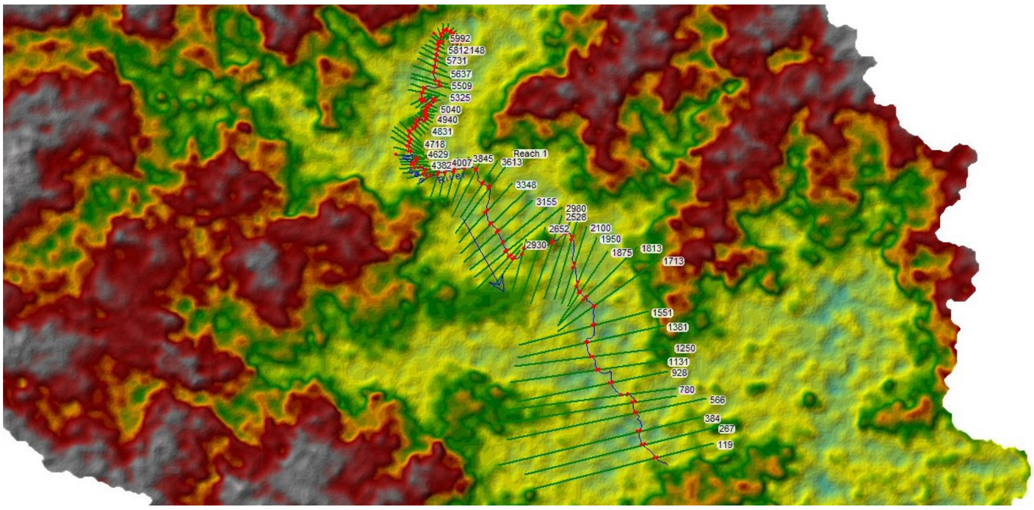

Figure 2: Geometric Data of the Hydraulic Model in HEC-RAS

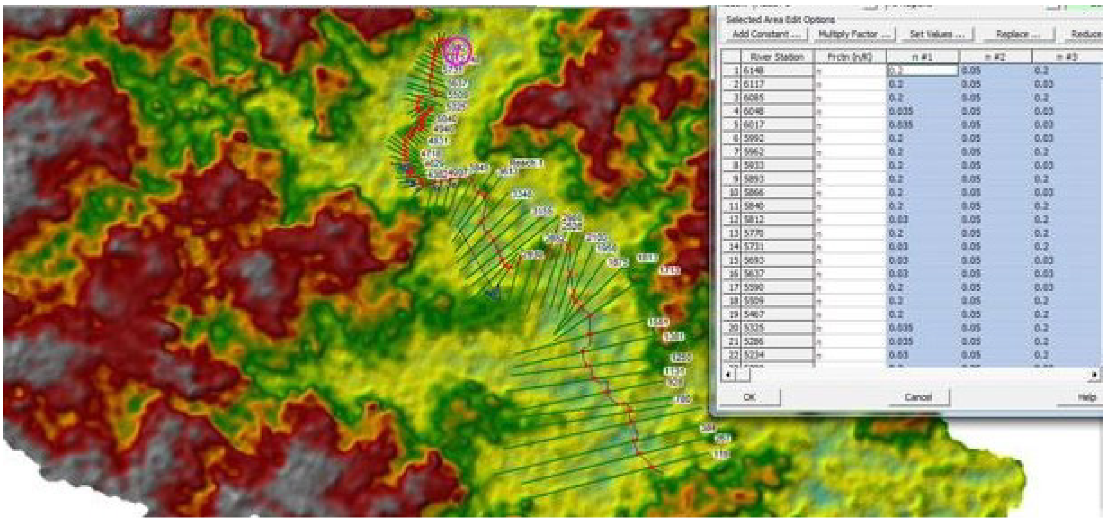

Figure 3: Entering Flow Data and Conditions for all Reaches

3.1 Hydraulic Model Development (HEC-RAS modelling)

Table 3 presents the Manning roughness coefficients used in the study area for various land use classes, which were input into the cross-section cutline in HEC-RAS 6.2. During the hydraulic simulation, different Manning values were assigned to each land use class based on guidelines from the United States Center for Engineering. Figures 4 and 5 illustrate the cross-sectional profile check and display (for the peak flow reach) as well as the methodological flow chart, respectively. After running the model, the data from HEC-RAS was imported into a GIS environment for post-processing and flood mapping of the results. This process utilized the HEC-GeoRAS extension to generate the water surface, delineate the floodplain, and produce the resulting flood inundation maps.

Scheme	Land Use	Manning's 'n'
1	Built up	0.017
2	Waterbodies	0.0305
3	Forest	0.1
4	Bareland	0.03
5	Grassland	0.035

Table 3: Manning's Roughness Coefficient for Different Land Use Classes (36)

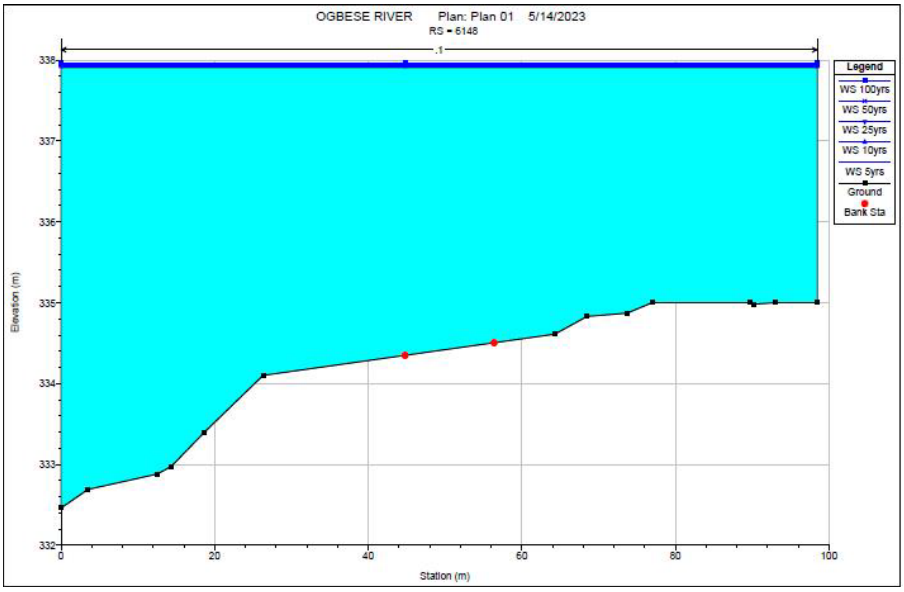

Figure 4: Cross-sectional Profile check for Peak Flows

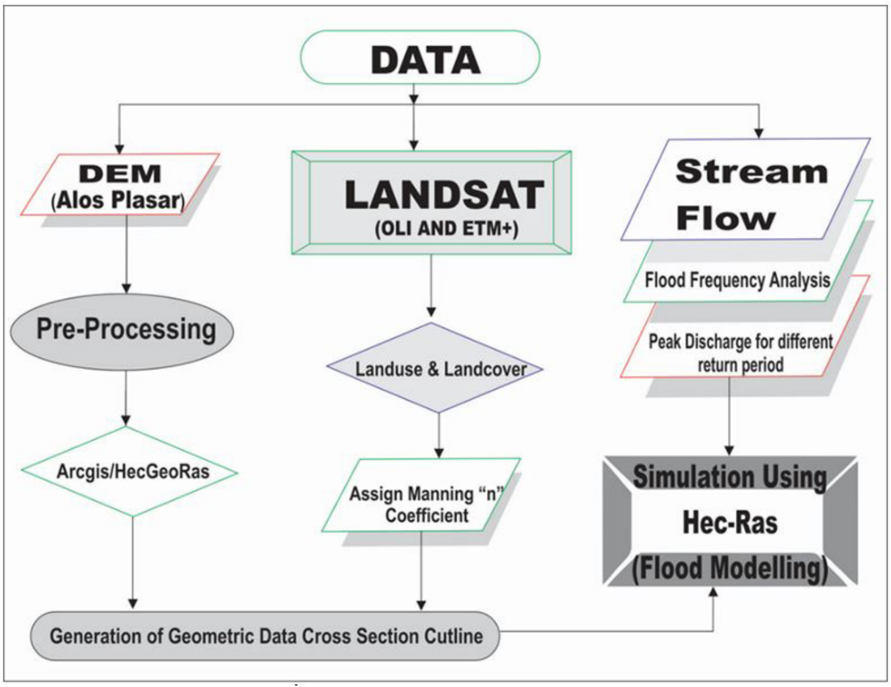

Figure 5: Flow Chart of the Hydraulic Model Development (HEC-RAS Modelling)

4.0 Results

4. 1 Flood Frequency Analysis

The data presented in Table 4 indicates that the expected stream discharges for the return periods of 5 years, 10 years, 25 years, 50 years, and 100 years are 1.686 m^3/s, 1.896 m^3/s, 2.1601 m^3/s, 2.356 m^3/s, and 2.551 m^3/s, respectively. The return period affects rainfall intensity in a given area, which subsequently influences the velocity and flow depth based on the characteristics of the river channel and floodplain. These values are essential for the engineering design of hydraulic structures, such as stormwater drains, culverts, and reservoirs, to ensure the protection of lives and properties downstream of the river.

Table 4: Computation of Expected Flood along Ogbese River at Return Periods

Return Period (T)	Reduced VariateY_T= -ln(ln(T_r /T_r-1))	Frequency FactorK(T) =Yt-Yn/Sn	Expected FloodXT= x+KS (m^3/s)
5	1.499939987	0.86283716	1.6861
10	2.250367327	1.535323351	1.8955
25	3.198534261	2.385011436	2.1601
50	3.901938658	3.015358597	2.3564
100	4.600149227	3.641051373	2.5512

4.2 Gumbel Trend line analysis

The analysis of the trend line equation reveals an R^2 value of 0.85, indicating a strong relationship. The data shows a scattered and narrow pattern, suggesting that Gumbel's distribution is appropriate for predicting the expected flow in the river (see Figure 6). The plot illustrates the relationship between anticipated flow (discharge) and return period, represented by the equation: 0.0082x + 1.817. Values not displayed in the chart can be extrapolated for future engineering designs. Figure 6 provides a graphical representation of the flood frequency curve, while Table 5 indicates that the year 1991 experienced the highest intensity of 96.26 (corresponding to a 32-year return period). This is followed by 2019, which had an intensity of 88.81 (16-year return period), and 2017, which recorded the lowest intensity at 36.18 (1.03-year return period).

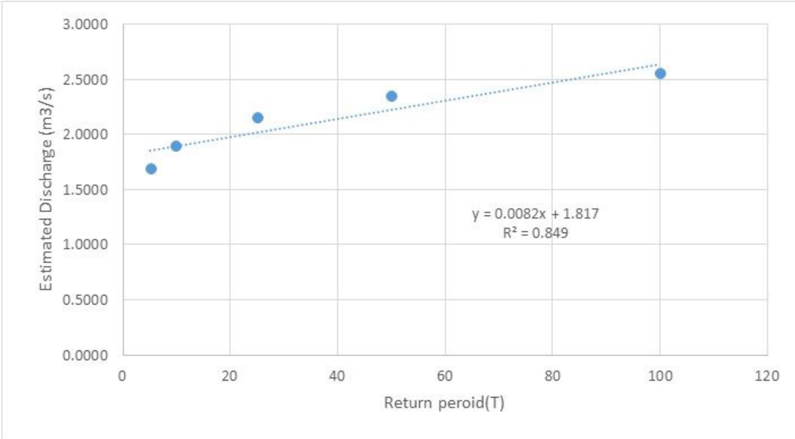

Figure 6: Flood Frequency Analysis by Gumbel's Extreme Value Distribution Method

Table 5: Flood Frequency Analysis by Gumbel Method (n=31 from 1989-2019)

YEAR	Annual Peak Discharge (m3/s)	Order Number (m)	Return Period (T) =n+1/m	Probability (p)=m/n+1	x^2
1991	2.084561378	1	32	0.03	4.345396
2019	1.648626489	2	16	0.06	2.717969
1995	2.243083156	3	10.67	0.09	5.031422
2010	1.815074356	4	8	0.13	3.294495
2008	1.347435111	5	6.4	0.16	1.815581
2013	1.327619889	6	5.33	0.19	1.762575
1996	1.426696	7	4.57	0.22	2.035461
2003	1.628811267	8	4	0.25	2.653026
1999	1.593143867	9	3.56	0.28	2.538107
2005	1.537661244	10	3.2	0.31	2.364402
2011	1.280063356	11	2.91	0.34	1.638562
2009	1.668441711	12	2.67	0.38	2.783698
2004	1.173061156	13	2.46	0.41	1.376072
1989	1.192876378	14	2.29	0.44	1.422954
2001	1.224580733	15	2.13	0.47	1.499598
2007	1.438585133	16	2	0.50	2.069527
2016	1.434622089	17	1.88	0.53	2.058141
2000	1.188913333	18	1.78	0.56	1.413515
2018	1.335545978	19	1.68	0.59	1.783683
1992	1.830926533	20	1.6	0.63	3.352292
2006	1.200802467	21	1.52	0.66	1.441927

1998	1.1413568	22	1.45	0.69	1.302695
2012	1.252322044	23	1.39	0.72	1.568311
1994	1.335545978	24	1.33	0.75	1.783683
1993	0.947167622	25	1.28	0.78	0.897127
2014	1.743739556	26	1.23	0.81	3.040628
1997	1.379139467	27	1.19	0.84	1.902026
1990	0.895648044	28	1.14	0.88	0.802185
2002	1.1413568	29	1.1	0.91	1.302695
2015	1.478215578	30	1.07	0.94	2.185121
2017	1.006613289	31	1.03	0.97	1.01327
Total	**43.9422368**				**65.19615**

4.3 Hydraulic Simulation and Flood Hazard Analysis

Using water surface data and a Digital Elevation Model (DEM) derived from ALOS PALSAR, the flooded areas for different return period floods were identified. Flood inundation maps for return periods of 5 and 100 years are depicted in Figures 7-9. The probability of flood occurrence is categorized as follows: very high (return period ≤ 100 years), high (return period = 50 years), moderate (return period ≥ 25 years), low (return period = 10 years), and very low (return period = 5 years). Water depth is a critical factor in determining the extent of flood hazards and potential damage. In this study, the flood hazard level is assessed by ranking the flood grid depths from lowest to highest. The area encompassed by flood polygons corresponding to these depth intervals was calculated to evaluate the flood hazard level, as presented in Table 6. During the delineation of flood extents, a bounding polygon for the inundation area of each return period was created, and the area of this polygon was calculated based on the simulation results. For a 100-year return period, the total area covered by this polygon was 95.18 hectares, with the highest inundation depth recorded at 11.76 meters. Conversely, the 5-year return period showed the lowest area covered at 94.54 hectares with an inundation depth of 11.69 meters. Areas such as Odo-Oriokuta, Isalekenyo, Rasco, and Agunla Road are classified as highly vulnerable (1.6%). In contrast, Sabo, Ile-Ologbo, and Oke-odo areas fall into the moderately vulnerable category (58.8%). Alayere and Faloye are categorized as low vulnerability (38.4%), while Owonikoko Layout is considered very low vulnerability (1.3%).

Table 6: Inundation Depth of Ogbese River Catchment

Return Period (T)	Inundation Depth	Ranged Depth	Area of Coverage (Hectare)	PPercentage of Area (%)	Inundation depth Percentage (%)	Flooded Areas	Risk Analysis
5	0.012-11.709	11.697	94.542	16.62	19.94	Owonikoko	Very low
10	0.004-11.723	11.719	94.656	16.64	19.98	Alayere, Faloye	Low
25	0.003-11.740	11.737	94.78	16.66	20.01	Sabo.ileolo gbon	Moderate
50	0.001-11.751	11.75	95.052	16.71	20.03	Agunla,, Oke-odo	High
100	0.002-11.762	11.76	95.18	16.73	20.05	Isalekeny, ,Odooriokuta	Very High
Total		**58.663**	**568.752**	**100**	**100**		

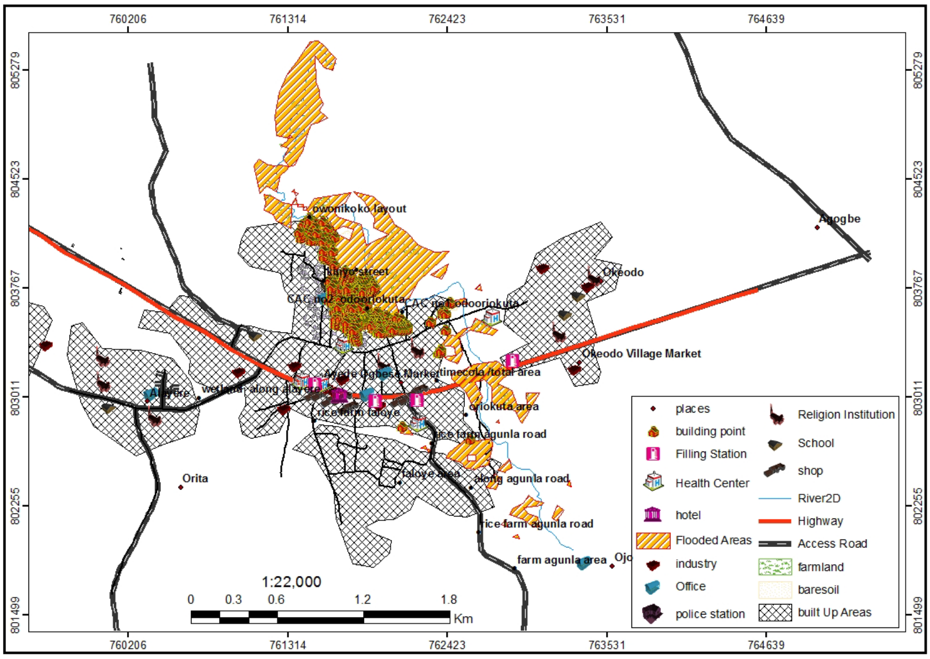

Figure 7: 100 years inundation of River Ogbese (Source: ALOS PALSAR DEM)

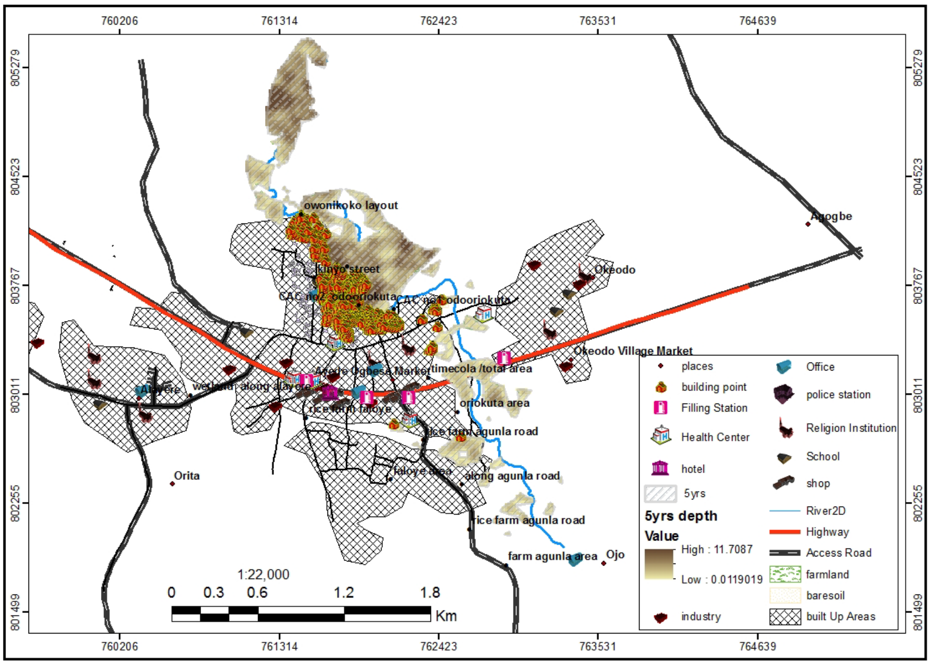

Figure 8: Five years Inundation of River Ogbese (Source: ALOS PALSAR DEM)

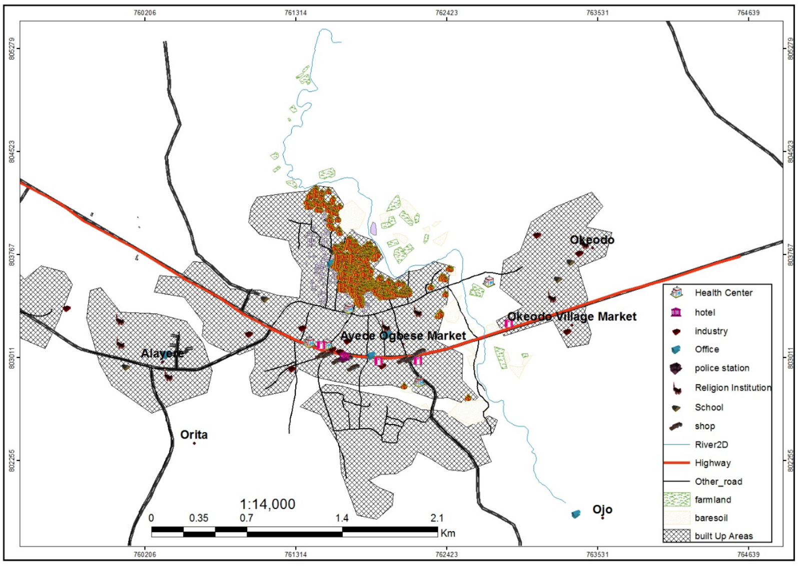

Figure 9: Land use within the Study Area

4.2 Flood Modelling Validation

After analyzing the inundation map for a 100-year flood event over the land use map in ArcMap 10.7, we found that the areas most affected include farmland (6.742 hectares), built-up areas (3.810 hectares, which include about 137 buildings), and some roads, like a major highway (0.383 km) and internal roads (2.27 km), along with bare land (14.863 hectares). We also selected fourteen points in the flooded areas to check the accuracy of the HEC-RAS 6.2 model. Our findings show that the coordinates of these flooded points match the areas marked on the 100-year inundation map, confirming the flooded area outlined in the land use map.

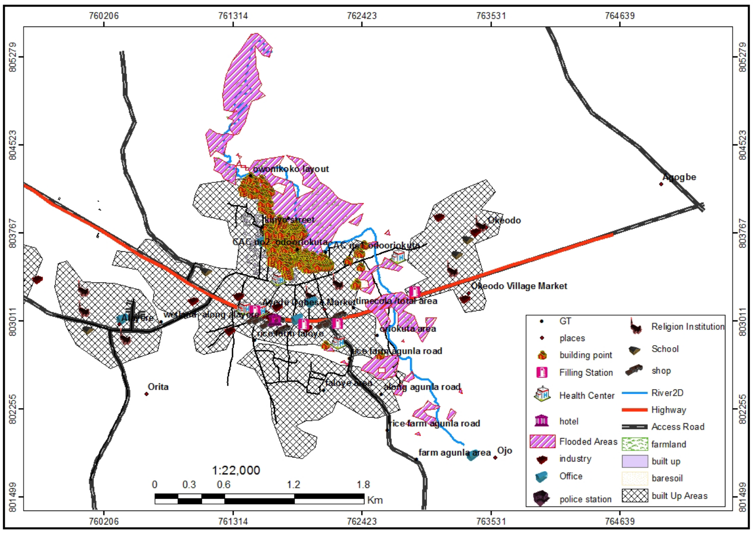

Figure 10: Validation of 100 Year Inundation of River Ogbese (Source: ALOS PALSAR DEM)

4.3 Discussion

Flood modeling was conducted to identify areas at risk, which can help implement necessary measures to prevent future floods in the study area. Locations such as built-up areas, bare land, and grasslands close to the drainage system are extremely vulnerable. The highly vulnerable areas (1.6%) include Odo-Oriokuta, Isalekenyo, Rasco, and Agunla Road, while the very low vulnerable region (1.3%) is Owonikoko Layout. These findings indicate that people living near these vulnerable floodplains are significantly threatened in terms of their lives, property, and socioeconomic activities. Without adequate preventive measures, this situation could severely impact the well-being of the inhabitants and negatively affect the overall GDP of the state. From the flood modeling and validation process conducted, simulations for a 100-year return period flood indicate that the most severely affected features include farmland (6.742 hectares), built areas (3.810 hectares, which contain approximately 137 buildings), major highways (0.383 km), internal roads (2.27 km), and bare land (14.863 hectares).

The results of inundation depth align with findings from previous research. Notably, agricultural land is among the most affected areas, which could significantly impact farmers' socioeconomic activities and productivity, leading to reduced food availability and increased costs for the general public. Natural hazards, including floods, are a significant concern for many nations as they can damage the economy and create hardships for large segments of the population. Over the years, there have been records of loss of life and destruction of farmland due to flooding in the Ogbese catchment area. The flood incidents in this region have particularly affected roads in Ogbese, such as Agunla Road, hindering both vehicular and pedestrian movement during heavy rainfall. Therefore, the Ogbese catchment area requires urgent attention regarding flood management to protect lives, infrastructure, agricultural activities, and farmers' products. In coastal regions like Ondo State, where the Ogbese catchment is located, agricultural products are particularly vulnerable to significant damage during flooding. Flooding is the most common environmental hazard, largely due to the widespread geographical distribution of river valleys and coastal areas, which attract human settlements.

5.0 Conclusion

This study utilized an integrated approach combining HEC-RAS hydraulic simulation and GIS to model flood-prone areas along the Ogbese River. The HEC-RAS 6.2 model employed in this research provides crucial information aimed at raising awareness and preparedness within local communities and the local government, thereby helping to minimize property damage and casualties during flooding events. The hydraulic simulation (HEC-RAS) clearly identifies areas within the study region that are vulnerable to flooding, highlighting the need for government action to implement measures that can prevent and mitigate future flood hazards in the Ogbese area. The results generated from this study, which utilized ALOS DEM data, remote sensing techniques, flood modeling with the HEC-RAS 6.2 model, and GIS analyses, demonstrate the feasibility of producing flood modeling maps categorized by various levels of vulnerability (low, moderate, and high). Additionally, these findings allow for predictions regarding flooding in the area, enabling necessary analyses and insights to be conducted as needed. This study effectively showcases the benefits of integrating the HEC-RAS 6.2 hydraulic model, remote sensing, and GIS in assessing flood vulnerability in the Ogbese region. To ensure the model's performance remains consistent amidst changes in the environment—stemming from both natural events and human activities—periodic updates and validations of the model are essential. For future research, it's recommended to include more ground truth points through extensive fieldwork and to perform a comparative analysis of past and present studies in the Ogbese River catchment. This will help to reveal additional insights into the implications of flooding in the area and its surrounding environment.

6.0 Limitation of the Study

The challenges experienced in this study include uneasy access to the required data, absence of standard and current data as well as high cost of original software for the analysis. Moreover, the environmental condition for the undertaken of this study is not encouraging due to unavailability of the basic amenities and research tools. Thus, for further research, necessary essential paraphernalia are to be accessed and contemporary techniques should be employed for the development of advanced flood alleviation measures, including improved flood monitoring, river channelization and dredging, expansion of drainage facilities, early warning systems, public awareness campaigns, and the removal of buildings encroaching on the river right-of-way (15 m) to prevent property and life losses.

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