

Flood Inundation Mapping of Calabar River Using Hec-Ras and QGIS

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Abstract

Floods pose significant challenges worldwide, affecting communities, ecosystems, and economies. In Cross River State, Nigeria, the Calabar River, with its complex river network and climate conditions, is particularly vulnerable to recurrent floods. Recent events, such as the destructive flood in Cross river Local Government Areas highlight the urgent need for comprehensive flood management in the region. This study addresses the ongoing flood problem by utilizing a combination of HEC-RAS and QGIS for detailed flood mapping. Geospatial data extraction from Google Earth Pro, Digital Elevation Model (DEM) development in QGIS, and high-precision floodplain mapping using HEC-RAS form the core of the research scope. Three simulation Profiles with varying discharges of 1189.31, 1727.33 and 2491.88 cubic meters per second were used. The study found that the flow in the channel is subcritical, with a Froude number between 0.2 and 0.72. The results revealed that Profile 1, 2 and 3 resulted in an inundation area of 3365733.24, 3770894.64 and 3994215.90 square meters respectively with Profile 3 resulting in the highest flooding area. The findings reveal subcritical flow in the Calabar River, indicating slow and calm flow conditions. The study's key contribution lies in providing a detailed Flood map, offering crucial insights for disaster preparedness and risk mitigation. These findings highlight the importance of comprehensive flood mapping and robust risk assessment in flood-prone regions provides practical tools for enhancing flood resilience in the Calabar River region and beyond.

Keywords: QGIS, HEC-RAS, Discharge, Calabar River, Nigeria.

I. INTRODUCTION

Floods are recurrent natural disasters with significant effects on human populations and the environment. Flooding has had a profound and wide-ranging effect on communities, ecosystems, and the economy in the Nigerian state of Cross River. Using both local and worldwide viewpoints, this section gives a general overview of floods and their effects on the region. A naturally occurring hydrological phenomenon, floods are defined as the flooding of normally dry areas. Numerous things can cause them, such as excessive rain, snowmelt, storms, river overflows, and coastal locations [1]. Floods are a major obstacle to sustainable development in areas like Cross River State, where

a complicated network of rivers and climate conditions are prevalent. With so many rivers, notably the Calabar River, Cross River State is especially prone to floods [2]. Floods in the state have an effect that goes beyond only immediate property destruction; they also interfere with livelihoods, infrastructure, and agriculture, which feeds a vicious cycle of social and economic problems [3].

HEC-RAS, the Hydrologic Engineering Center's River Analysis System is a crucial instrument in hydraulic modelling for risk assessment and flood mapping in the Calabar River region. This specialist program was developed by the U.S. Army Corps of Engineers [4] and enables

a thorough study of river systems under various situations. Its features, which include sediment transport modelling, one-dimensional steady and unsteady flow, and water quality analysis, make it adaptable and ideal for intricate situations such as flood mapping. With its tools for modelling infrastructure like Flood Inundations, culverts, bridges, and channel alterations, HEC-RAS allows for a comprehensive knowledge of river dynamics. The program uses crucial data, such as topography, bathymetric, and cross-sectional information, to generate accurate hydraulic models. Flood mapping is made possible by HEC-RAS, which simulates how rivers react to various flow circumstances. This allows for the prediction of inundation extents, water velocities, and depths during flood occurrences. Because of the integration of data from many sources, such as GIS and cross-sectional surveys, HEC-RAS can provide crucial insights for the region's flood risk assessment.

Flood analysis may be approached more effectively with the combined use of HEC-RAS and QGIS, two crucial tools for flood mapping. The U.S. Army Corps of Engineers created HEC-RAS, a hydraulic modelling tool that is used to properly simulate the characteristics of flood occurrences as well as model river systems, bridges, culverts, and Flood Inundations. However, data integration, visualization, and analysis are areas where QGIS, an adaptable open-source GIS program, shines [5]. These two instruments work together to offer a holistic approach to comprehending and controlling flood occurrences in the Calabar River basin.

Floodplain mapping in Pakistan's Kabul River, providing a valuable tool for policymakers and urban planners in the region to identify and mitigate flood risks. Using the model, the study generates floodplain maps that delineate vulnerable areas, enabling informed decision-making for flood preparedness and disaster prevention. Radar Topography Mission digital elevation model and flood frequency analysis techniques was used to calculate extreme flows, revealing a significant 400% increase in flood risk, particularly in agricultural areas [6].

The application of HEC-RAS and ArcGIS for floodplain mapping in Segamat Town, Malaysia, emphasizing a risk-based approach to flood mitigation was carried out using Interferometric

Synthetic Aperture Radar (IFSAR) data to analyze flood frequency and employed five distribution models to calculate extreme flows [7]. The Generalized Pareto distribution was found to best represent the flood characteristics of the Segamat River. Peak flood data from frequency analysis was used as input for the HEC-RAS model to determine corresponding flood levels, and ArcGIS was used to create floodplain maps for different return periods.

Comprehensive approach to flood modelling on a regional scale can be developed by combining Geographic Information Systems (GIS) with a rainfall-runoff model (HEC-HMS) and a hydrologic model (HEC-RAS) [8]. HEC-RAS produces Flood inundation maps that highlight areas at risk and delineate regions prone to flooding. It emphasizes 2D modelling of flood problems and demonstrates the significance of employing flood risk reduction measures to prepare for and manage future flood events.

This research aims to generate a flood inundation map of the Calabar River using QGIS and HEC-RAS. The research helps to enhance disaster preparedness, promote climate resilience, and engage local communities in flood mapping and management efforts.

II. METHOD

The geospatial coordinates of the stretch of Calabar River, spanning from Ikot Okon to Ikot Ekpene, were extracted using Google Earth Pro. Subsequently, QGIS was employed to generate a Digital Elevation Model (DEM) for the study area through interpolation methods. The DEM served as a crucial foundation for understanding terrain variations. Leveraging HEC-RAS, steady flow simulations were conducted, allowing the delineation of essential hydraulic parameters such as discharge, velocity, and water rating curves. The flood mapping process involved the use of three profiles, contributing to a comprehensive understanding of the river's behaviour.

2.1. STUDY AREA

The geographic coordinates of Calabar River are around 04°54'15"N to 08°16'08"E in latitude and 04°56'40"N to 08°18'14"E in longitude. This region is in South Eastern Nigeria, inside the Cross

River system. Fig. 1 shows the map containing the Calabar River, in Cross River State, Nigeria. According to [9], the Calabar River rises in the Oban Hills in Akamkpa, Nigeria, and runs south through the verdant rainforest of the country's southeast coast before joining the Cross River Estuary at Calabar. There are distinct rainy and dry seasons in this area, which is part of the humid tropical rainforest belt. Generally speaking, the dry season runs from December to March, while the wet season lasts from April to November.

Dense vegetation characterizes the coastal shoreline along the Calabar River, which eventually transitions to mangrove swamps close to the estuary from freshwater to swamp environment. The nipa palm (*Nypa fruticans*), a member of the *Areaceae* family, is the predominant vegetation along the riverbanks [10].

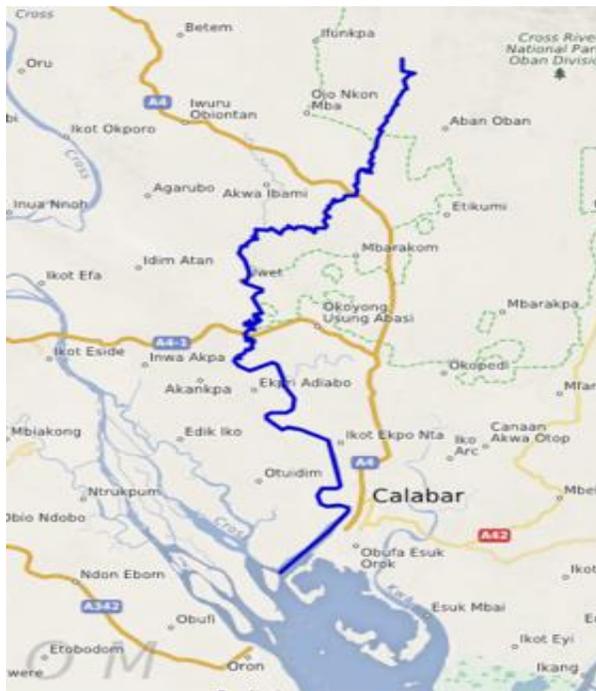


Fig. 1: Calabar River, Cross River State, Nigeria [11]

2.2. QGIS DATA PREPARATION AND PROCESSING

In the Calabar River flood mapping research, QGIS plays a pivotal role in data preparation and processing. QGIS centralizes data integration, harmonizing various types of data like topographic, hydrological, meteorological, remote sensing, and

GIS data. Georeferencing assigns spatial coordinates to non-spatial data, facilitating accurate overlay with GIS layers. QGIS ensures data cleanliness and validation through cleaning processes, enhancing the accuracy of Flood Inundation maps. Supporting both raster and vector data, QGIS is essential for tasks like terrain analysis and river network definition. Spatial analysis tools identify flood-vulnerable areas, overlay layers, and assess patterns. QGIS allows flexible data conversion and export for enhanced accessibility and compatibility. The software also designs the final Flood Inundation maps to effectively communicate results and integrates seamlessly with HEC-RAS for efficient data transfer.

2.3. SETTING UP HEC-RAS MODELS AND KEY PARAMETERS

HEC-RAS, a versatile hydraulic modelling software developed by the U.S. Army Corps of Engineers, is vital for simulating flood events. The process involves the following key steps:

HEC-RAS Overview: The software aids in the river and flood inundation hydraulics modelling, conducting hydrological and hydraulic simulations to understand Calabar River's behaviour during floods.

2.3.1 KEY PARAMETERS AND STEPS

River Geometry: Defining river geometry involves inputting cross-sections, banks, and channel data obtained from surveys, maps, or remote sensing.

Terrain Data: Detailed terrain data, including DEMs, is processed in QGIS for accuracy in understanding floodwater propagation.

Flow Data: Flow data, including rates, hydrographs, and boundary conditions, is derived from historical records, rainfall data, or simulated scenarios.

Hydraulic Structures: Integration of relevant hydraulic structures, like bridges, considers dimensions and characteristics.

Initial Conditions: Setting initial conditions establishes water surface elevation, velocity, and flow direction under normal conditions.

Boundary Conditions: Boundary conditions, such as downstream water levels, mimic river behaviour during floods.

Hydraulic Computations: HEC-RAS computes water surface elevations, flow velocities, and flood extents, considering terrain, river geometry, flow data, and boundaries.

Model Calibration and Validation: Model accuracy is validated by comparing simulated results with observed or historical data, adjusting as needed.

Simulation Scenarios: Multiple scenarios examine the river's response to different floods, evaluating various return periods and generating Flood Inundation maps.

III. RESULTS AND DISCUSSION

3.1. RIVER GEOMETRY

The geometry of the river, the selected study area which is the Calabar River from Ikot Okon to Ikot Ekpene has been delineated and shown in Fig. II. This was obtained using DEM generated from QGIS using EPSG 4326 W84 and the coordinates of the Minna/ Nigeria Middle Belt. The DEM is shown in Fig. III.

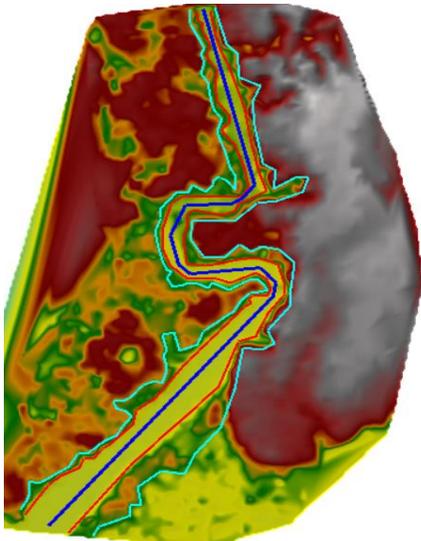


Fig. II: RIVER GEOMETRY



Fig. III. DEM for Study Area

3.2. STEADY FLOW SIMULATION

Steady flow analysis was carried out for the simulation of flood occurrence according to the documentation of HEC-RAS Software. Three profiles were used for the simulation to visualize the flood extents of the river in an increased flow. The parameters used for simulation are shown in Table I.

Table I: INPUT VARIABLES FOR HEC-RAS STEADY FLOW SIMULATION

S/N	Parameters	Value
1	Flow for Profile 1	1189.31 cumecs
2	Flow for Profile 2	1727.33 cumecs
3	Flow for Profile 3	2491.88 cumecs
4	Manning coefficient at River Bed	0.03
5	Manning coefficient at River Bank (left and right)	0.05
7	Downstream Slope at normal depth	0.0003

3.3. CROSS SECTION FOR STUDY AREA

Delineating cross sections have been delineated at the river centerline in HEC-RAS software which is essential for creating a hydraulic model that

closely represents the real-world river behavior. It ensures that the model considers variations in channel geometry, flow distribution, and the impact of hydraulic structures, all of which are critical for accurate flood simulations and Flood Inundation mapping. The cross-section used for the Calabar River study area is shown in Fig. IV.

Blue line denotes the River Centerline while the green line is the cross-section line. The numbers labelled at the green lines are the river stations of the cross-sections. The Cross-section values from the resulting simulations for Each of these stations are shown in Table II.

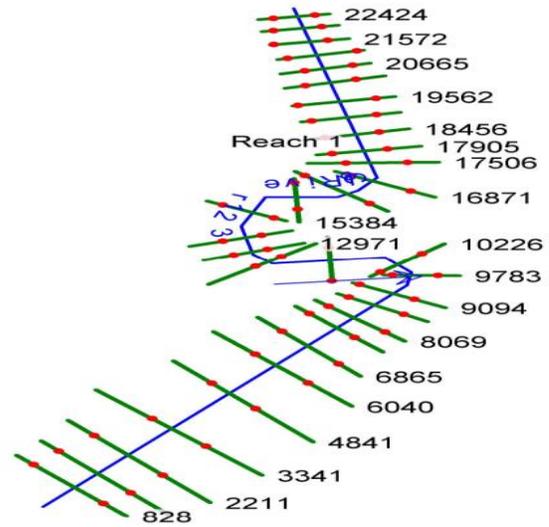


Fig. IV: CROSS SECTION USED FOR CALABAR RIVER STUDY AREA

Table II: CROSS-SECTION OUTPUT OF THE THREE PROFILES

Reach	River Sta	Profile	Q Total (m ³ /s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Channel Vel (m/s)	Flow Area (m ²)	Top Width (m)	Froude # Chl
Reach 1	22424	PF 1	1189.31	2.12	6.29		6.38	0.000308	1.40	973.68	343.06	0.23
Reach 1	22424	PF 2	1727.33	2.12	6.98		7.11	0.000348	1.66	1219.53	366.40	0.25
Reach 1	22424	PF 3	2491.88	2.12	7.79		7.96	0.000387	1.96	1515.50	366.40	0.28
Reach 1	22029	PF 1	1189.31	2.08	6.23		6.34	0.000426	1.46	871.41	309.88	0.26
Reach 1	22029	PF 2	1727.33	2.08	6.92		7.06	0.000450	1.71	1085.64	318.02	0.28
Reach 1	22029	PF 3	2491.88	2.08	7.71		7.91	0.000484	2.02	1342.34	327.72	0.30
Reach 1	21572	PF 1	1189.31	2.15	6.06		6.24	0.001005	1.88	632.38	275.24	0.39
Reach 1	21572	PF 2	1727.33	2.15	6.74		6.96	0.000941	2.12	826.27	301.24	0.39
Reach 1	21572	PF 3	2491.88	2.15	7.52		7.81	0.000901	2.39	1086.23	352.49	0.40

Reach 1	21120	PF 1	1189.31	2.07	6.08	6.14	0.000283	1.13	1102.80	449.76	0.21
Reach 1	21120	PF 2	1727.33	2.07	6.77	6.86	0.000281	1.30	1414.51	449.76	0.22
Reach 1	21120	PF 3	2491.88	2.07	7.58	7.69	0.000287	1.51	1778.44	449.76	0.23
Reach 1	20665	PF 1	1189.31	2.11	6.03	6.10	0.000342	1.28	1078.84	378.02	0.24
Reach 1	20665	PF 2	1727.33	2.11	6.71	6.81	0.000358	1.50	1340.15	384.91	0.25
Reach 1	20665	PF 3	2491.88	2.11	7.51	7.64	0.000382	1.77	1649.59	392.42	0.27
Reach 1	20199	PF 1	1189.31	2.07	6.00	6.06	0.000215	1.12	1216.47	392.36	0.19
Reach 1	20199	PF 2	1727.33	2.07	6.68	6.76	0.000242	1.34	1490.15	408.77	0.21
Reach 1	20199	PF 3	2491.88	2.07	7.48	7.59	0.000272	1.59	1826.09	438.19	0.23
Reach 1	19562	PF 1	1189.31	2.06	5.97	6.01	0.000181	0.94	1313.16	496.92	0.17
Reach 1	19562	PF 2	1727.33	2.06	6.65	6.71	0.000189	1.11	1656.36	504.40	0.18
Reach 1	19562	PF 3	2491.88	2.06	7.45	7.54	0.000201	1.30	2062.73	512.98	0.19
Reach 1	19029	PF 1	1189.31	2.06	5.91	5.98	0.000275	1.18	1048.25	374.97	0.21
Reach 1	19029	PF 2	1727.33	2.06	6.58	6.67	0.000300	1.39	1301.37	379.16	0.23
Reach 1	19029	PF 3	2491.88	2.06	7.36	7.49	0.000331	1.64	1598.75	384.03	0.25
Reach 1	18456	PF 1	1189.31	2.14	5.83	5.92	0.000358	1.35	993.49	369.76	0.24

Reach 1	18456	PF 2	1727.33	2.14	6.50		6.61	0.000386	1.58	1239.55	373.10	0.26
Reach 1	18456	PF 3	2491.88	2.14	7.26		7.42	0.000423	1.85	1527.38	376.97	0.28
Reach 1	17905	PF 1	1189.31	2.14	5.77		5.86	0.000373	1.35	956.61	352.02	0.25
Reach 1	17905	PF 2	1727.33	2.14	6.42		6.54	0.000404	1.59	1188.53	356.12	0.27
Reach 1	17905	PF 3	2491.88	2.14	7.18		7.35	0.000445	1.87	1460.09	360.86	0.29
Reach 1	17506	PF 1	1189.31	1.91	5.74		5.81	0.000347	1.19	1198.34	539.71	0.23
Reach 1	17506	PF 2	1727.33	1.91	6.41		6.49	0.000326	1.34	1563.40	554.19	0.23
Reach 1	17506	PF 3	2491.88	1.91	7.18		7.28	0.000321	1.53	1997.36	568.84	0.24
Reach 1	16871	PF 1	1189.31	2.05	5.70		5.75	0.000235	1.05	1263.89	474.71	0.20
Reach 1	16871	PF 2	1727.33	2.05	6.36		6.43	0.000246	1.23	1585.50	493.71	0.21
Reach 1	16871	PF 3	2491.88	2.05	7.13		7.23	0.000263	1.45	1970.97	510.78	0.22
Reach 1	16273	PF 1	1189.31	2.34	5.64		5.70	0.000319	1.10	1100.47	501.41	0.22
Reach 1	16273	PF 2	1727.33	2.34	6.30		6.38	0.000300	1.25	1442.21	526.54	0.22
Reach 1	16273	PF 3	2491.88	2.34	7.07		7.17	0.000294	1.43	1857.96	553.45	0.23
Reach 1	15384	PF 1	1189.31	2.07	5.47		5.59	0.000487	1.50	851.48	351.04	0.28
Reach 1	15384	PF 2	1727.33	2.07	6.12		6.27	0.000515	1.76	1091.54	436.05	0.30
Reach 1	15384	PF 3	2491.88	2.07	6.86		7.06	0.000533	2.04	1416.07	436.05	0.31

Reach 1	14324	PF 1	1189.31	2.18	5.32		5.41	0.000498	1.38	971.81	419.86	0.28
Reach 1	14324	PF 2	1727.33	2.18	5.97		6.09	0.000480	1.58	1255.15	451.65	0.28
Reach 1	14324	PF 3	2491.88	2.18	6.72		6.87	0.000478	1.82	1593.91	451.65	0.29
Reach 1	13452	PF 1	1189.31	1.47	5.23		5.30	0.000320	1.33	1220.80	522.84	0.23
Reach 1	13452	PF 2	1727.33	1.47	5.88		5.97	0.000331	1.52	1576.32	545.81	0.24
Reach 1	13452	PF 3	2491.88	1.47	6.64		6.75	0.000346	1.75	1988.19	545.81	0.26
Reach 1	12971	PF 1	1189.31	1.23	5.15		5.24	0.000415	1.51	1097.33	482.33	0.26
Reach 1	12971	PF 2	1727.33	1.23	5.79		5.91	0.000447	1.76	1416.54	542.97	0.28
Reach 1	12971	PF 3	2491.88	1.23	6.54		6.69	0.000450	1.98	1825.16	542.97	0.29
Reach 1	12537	PF 1	1189.31	1.43	5.12		5.18	0.000343	1.37	1377.34	643.83	0.24
Reach 1	12537	PF 2	1727.33	1.43	5.77		5.84	0.000341	1.54	1813.69	687.63	0.25
Reach 1	12537	PF 3	2491.88	1.43	6.53		6.62	0.000331	1.71	2337.24	687.63	0.25
Reach 1	11472	PF 1	1189.31	1.23	5.01		5.08	0.000295	1.19	1030.97	389.18	0.22
Reach 1	11472	PF 2	1727.33	1.23	5.63		5.73	0.000325	1.41	1284.25	422.18	0.24
Reach 1	11472	PF 3	2491.88	1.23	6.36		6.50	0.000355	1.67	1607.08	448.91	0.26

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m ³ /s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m ²)	(m)	
Reach 1	10226	PF 1	1189.31	1.23	4.80		4.92	0.000562	1.53	806.17	358.31	0.30
Reach 1	10226	PF 2	1727.33	1.23	5.40		5.56	0.000589	1.79	1041.72	406.79	0.32
Reach 1	10226	PF 3	2491.88	1.23	6.10		6.32	0.000615	2.09	1332.00	417.77	0.33
Reach 1	9783	PF 1	1189.31	2.09	4.23		4.72	0.003905	3.11	394.58	248.32	0.73
Reach 1	9783	PF 2	1727.33	2.09	4.78		5.36	0.003401	3.40	536.03	261.94	0.71
Reach 1	9783	PF 3	2491.88	2.09	5.38		6.10	0.003250	3.83	694.85	266.89	0.72
Reach 1	9094	PF 1	1189.31	1.04	4.16		4.30	0.000802	1.68	706.09	296.21	0.35
Reach 1	9094	PF 2	1727.33	1.04	4.73		4.93	0.000842	1.96	892.44	344.81	0.37
Reach 1	9094	PF 3	2491.88	1.04	5.37		5.64	0.000911	2.29	1115.12	352.68	0.39
Reach 1	8604	PF 1	1189.31	0.65	4.06		4.19	0.000616	1.60	750.36	304.13	0.31
Reach 1	8604	PF 2	1727.33	0.65	4.63		4.81	0.000687	1.91	937.78	345.62	0.34
Reach 1	8604	PF 3	2491.88	0.65	5.25		5.51	0.000785	2.28	1154.09	349.11	0.37
Reach 1	8069	PF 1	1189.31	0.87	4.01		4.09	0.000448	1.27	945.31	429.69	0.26
Reach 1	8069	PF 2	1727.33	0.87	4.59		4.70	0.000456	1.48	1209.60	478.91	0.27
Reach 1	8069	PF 3	2491.88	0.87	5.23		5.38	0.000486	1.74	1530.44	521.95	0.29

Reach 1	7631	PF 1	1189.31	0.79	3.85		4.00	0.000930	1.75	680.76	313.26	0.37
Reach 1	7631	PF 2	1727.33	0.79	4.39		4.61	0.000962	2.04	862.34	348.00	0.39
Reach 1	7631	PF 3	2491.88	0.79	4.98		5.27	0.001060	2.40	1077.02	385.45	0.42
Reach 1	6865	PF 1	1189.31	0.58	3.80		3.86	0.000304	1.10	1094.59	531.11	0.22
Reach 1	6865	PF 2	1727.33	0.58	4.36		4.45	0.000329	1.29	1432.34	607.46	0.23
Reach 1	6865	PF 3	2491.88	0.58	4.97		5.08	0.000369	1.52	1804.08	615.58	0.25
Reach 1	6040	PF 1	1189.31	0.59	3.74		3.79	0.000213	0.98	1422.97	736.20	0.18
Reach 1	6040	PF 2	1727.33	0.59	4.30		4.36	0.000228	1.14	1869.07	823.28	0.20
Reach 1	6040	PF 3	2491.88	0.59	4.91		4.99	0.000255	1.35	2386.17	885.35	0.21
Reach 1	4841	PF 1	1189.31	0.60	3.63		3.69	0.000329	1.14	1407.79	925.51	0.23
Reach 1	4841	PF 2	1727.33	0.60	4.20		4.27	0.000301	1.25	1942.58	948.53	0.22
Reach 1	4841	PF 3	2491.88	0.60	4.80		4.88	0.000306	1.41	2520.12	974.75	0.23
Reach 1	3341	PF 1	1189.31	0.57	3.41		3.48	0.000607	1.31	1158.90	719.02	0.29
Reach 1	3341	PF 2	1727.33	0.57	4.01		4.08	0.000489	1.34	1774.12	1200.70	0.27
Reach 1	3341	PF 3	2491.88	0.57	4.63		4.71	0.000403	1.42	2522.42	1200.70	0.26
Reach 1	2211	PF 1	1189.31	0.60	3.18		3.26	0.000615	1.30	1031.43	652.68	0.30
Reach 1	2211	PF 2	1727.33	0.60	3.81		3.90	0.000540	1.34	1496.44	831.84	0.28

Reach 1	2211	PF 3	2491.88	0.60	4.46		4.55	0.000459	1.44	2122.86	1035.92	0.27
Reach 1	1422	PF 1	1189.31	-0.12	3.11		3.16	0.000270	1.01	1242.78	610.77	0.20
Reach 1	1422	PF 2	1727.33	-0.12	3.73		3.80	0.000292	1.13	1685.16	821.93	0.22
Reach 1	1422	PF 3	2491.88	-0.12	4.38		4.46	0.000298	1.27	2258.31	980.14	0.22
Reach 1	828	PF 1	1189.31	0.21	3.05	1.32	3.11	0.000300	1.03	1189.34	593.10	0.21
Reach 1	828	PF 2	1727.33	0.21	3.68	1.61	3.74	0.000300	1.15	1610.15	718.26	0.22
Reach 1	828	PF 3	2491.88	0.21	4.32	1.96	4.40	0.000300	1.32	2093.33	817.66	0.23

The discharge of water for the three simulations is shown in Fig. V, where the water surface elevation and the energy radiant line are plotted against the main channel distance.

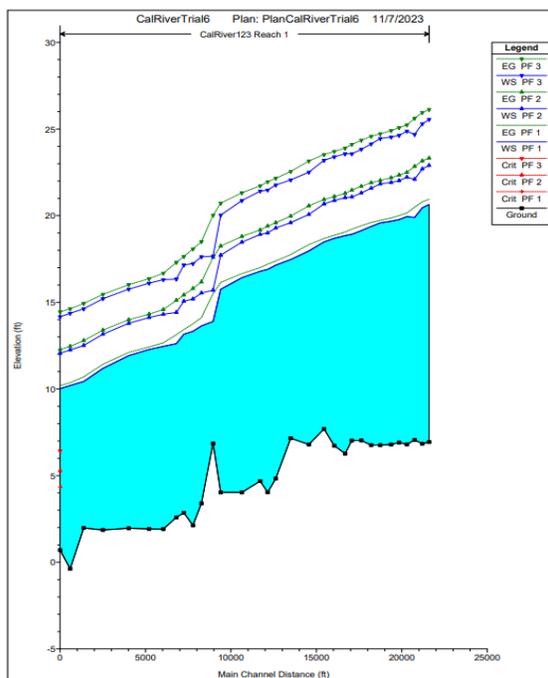


Fig. V: PROFILE PLOT OF STUDY AREA

3.4. GENERAL VELOCITY

The water velocity in the river is influenced by three primary factors: discharge, depth, and location within the river channel. The velocity increases with discharge due to the larger volume of water flowing, resulting in faster-moving water molecules. Conversely, velocity decreases with depth as frictional forces between water molecules and the riverbed become more pronounced. Additionally, velocity is highest around the center of the river, gradually decreasing towards the banks, where frictional forces from the riverbed and banks impede water flow. The general velocity plot from the simulation is shown in Fig. VI.

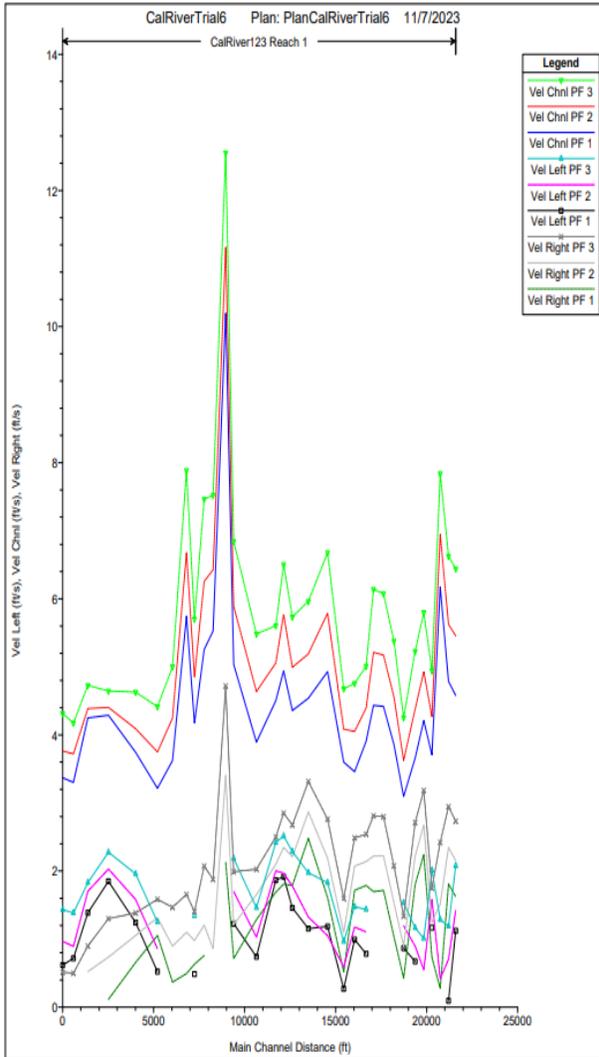


Fig. VI: GENERAL VELOCITY PLOT FOR THE STUDY AREA

3.5. WATER RATING CURVE

The water rating curve plot provided by HEC-RAS is a graphical representation of the relationship between the depth (water level) and discharge (flow rate) of a river or stream. The water rating curve plot typically shows depth on the y-axis and discharge on the x-axis. The curve itself is usually a smooth, upward-sloping line, indicating that discharge increases as stage increases. This is because when the water level rises, more water is able to flow through the river channel. There are several factors that can affect

the shape of the water rating curve, including the geometry of the river channel, the roughness of the channel bed and banks, and the presence of any obstructions in the channel. It is a valuable tool for hydrologists and water resource managers, who use it to monitor and predict streamflow, forecast floods and droughts, and design water control structures. The water rating curve for river station 22424 is shown in Fig. VII.

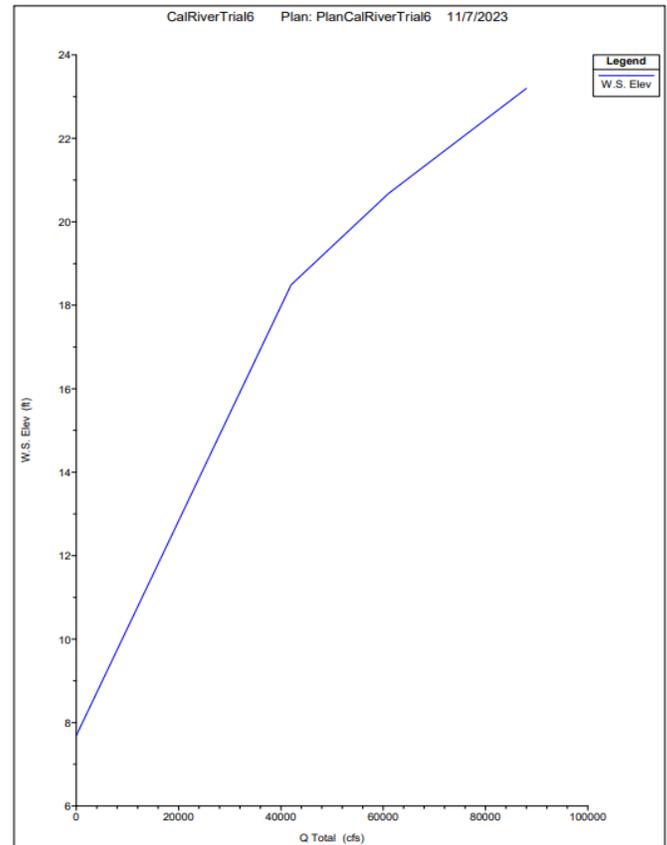


Fig. VI: WATER RATING CURVE FOR STATION 22424

3.6. FLOOD INUNDATION MAP

The flood inundation map is a map that shows the areas that would be flooded under different flood scenarios. The Flood inundation maps for our study area are created using a DEM from QGIS and HEC-RAS software. Fig. VIII to Fig. X shows the Flood Inundation Map for profile 1, 2 and 3 respectively

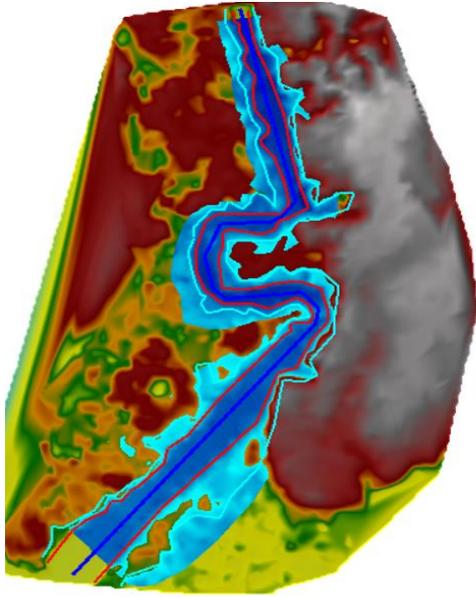


Fig. VIII. FLOOD INUNDATION MAP OF PROFILE 1

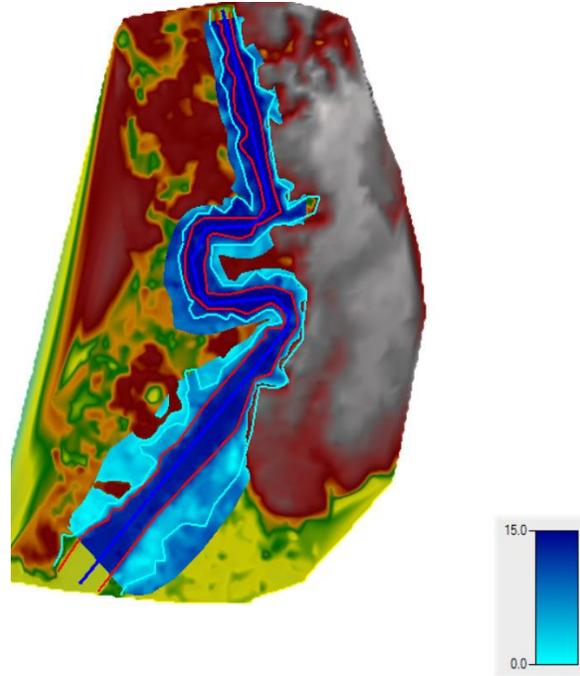


Fig. X. FLOOD INUNDATION MAP OF PROFILE 3

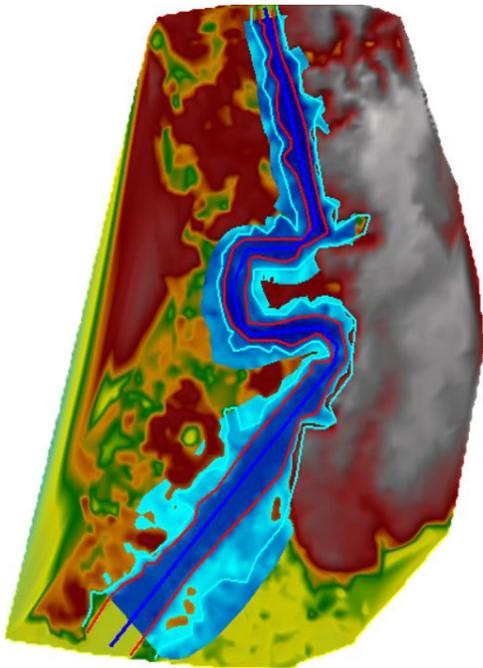


Fig. IX. FLOOD INUNDATION MAP OF PROFILE 2

The inundation area of a profile is the area of land that would be flooded at a given water level. It is calculated by integrating the water depth over the area of the profile. The inundation area of Profile 1 is 3365733.24 square metres, the inundation area of Profile 2 is 3770894.62 square metres, and the inundation area of Profile 3 is 3994215.89 square metres.

IV. CONCLUSION

The study's foremost accomplishment lies in its ability to provide a detailed and data-driven Flood Inundation map for the Calabar River, a region grappling with recurrent flood events. By combining HEC-RAS (Hydrologic Engineering Center's River Analysis System) and QGIS (Quantum Geographic Information System), the research has successfully portrayed the dynamic interaction between the river's geomorphology and hydrodynamics. The high-precision Flood Inundation maps offer valuable insights into the potential extent of flooding under varying conditions, crucial for disaster preparedness and risk mitigation.

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