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Modeling and Simulation of Flood Hazard Scenarios on Lowly Morphometric Drainage Terrain in Rivers State, Nigeria

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Abstract

The continuous flooding of Rivers State drainage basins is as a result of rapid rate of population growth, increased economic activities, land cover change, urbanization and urban expansion, infrastructural and housing development leading to encroachment on the flood plains and natural drainage basins. This has caused grave socio-economic impacts on the human society. This study Model and Simulate Flood Hazard Scenarios on Lowly Morphometric Drainage Terrain in Rivers State, Nigeria. The study adopted study adopted the GIS based hydrological and hydraulic model of Run off and river flow research design employing the use of employing the Watershed Modeling System (WMS). The modelled hydrological and drainage basin parameter and data was simulated using C++ computer programming language. Findings of the study revealed that seven (7) lowly morphometric drainage basins exist in Rivers State with varying levels elevations ranging from -10m to 41.3m affecting the rate of storm water – stream flow length and velocity thus depicting the variations in the level of flood hazards. The study thus recommends that a ten-year routine and regular catchments and digital elevation modeling be carried out as well as reactivation of the drainage Master Plan of Rivers State be done to tackle flood issues and ameliorate its socio-economic impacts.

Keywords: Modeling; Simulation; Hazard; Morphometry and Terrain

1. Introduction

Forecasting flood behavior and its effects required modelling. Modelling is an important tool in flood hazard assessment (Kumar *et al.*, 2023). This, to anticipate the geographical and temporal distribution of flood waters, as well as the probable related damage and hazards, modeling and the mathematical replications of the hydrologic and hydraulic processes that lead to flood therefore becomes imperative (Kumar *et al.,* 2023). Thus, flood forecasting, risk assessment, flood mitigation, and response planning and management are just a few of the uses for flood models (Norizan *et al.,* 2021). Thus, one Dimensional (ID) hydraulic models, two Dimensional (2D) hydraulic models and hydrologic models are among the several types of flood models (Kumar *et al.,* 2023). Hydrologic models are used to calculate the quantity, volume and timing of catchment run-off flow, and simulate the precipitation – runoff processes that result in floods occurrence (Kumar *et al.,* 2023).

These models might be on physically based methods like the distributed hydrologic model, or empirical techniques such as the rain fall – run off relationship (Mbabazi, 2022). The volume and timing of catchment run off may be estimated using hydrologic models which can also be used to help in the creation of flood predictions and warnings (Kumar *et al.,* 2023).

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"Morphometry represent the topographical expression of the land terrain of a drainage basin by way of area, slope, shape, length etc., and affect catchment stream flow pattern through their influence on concentration time (Ajibade *et al.,* 2010). The significance of the morphometric parameters has been observed to influence stream flow which can be expressed as a general function of geomorphology of a watershed. Given the above, Ifabiyi (2004), has reported that the geomorphic characteristics of a drainage basin plays a key role in controlling the basin morphology and hydrology. Therefore, the morphometric analysis of drainage basins provides not only an elegant description of the landscape, but also serve as a powerful means of comparing the form and process of drainage basins that may be widely separated in space and time (Ajibade *et al*., 2010).

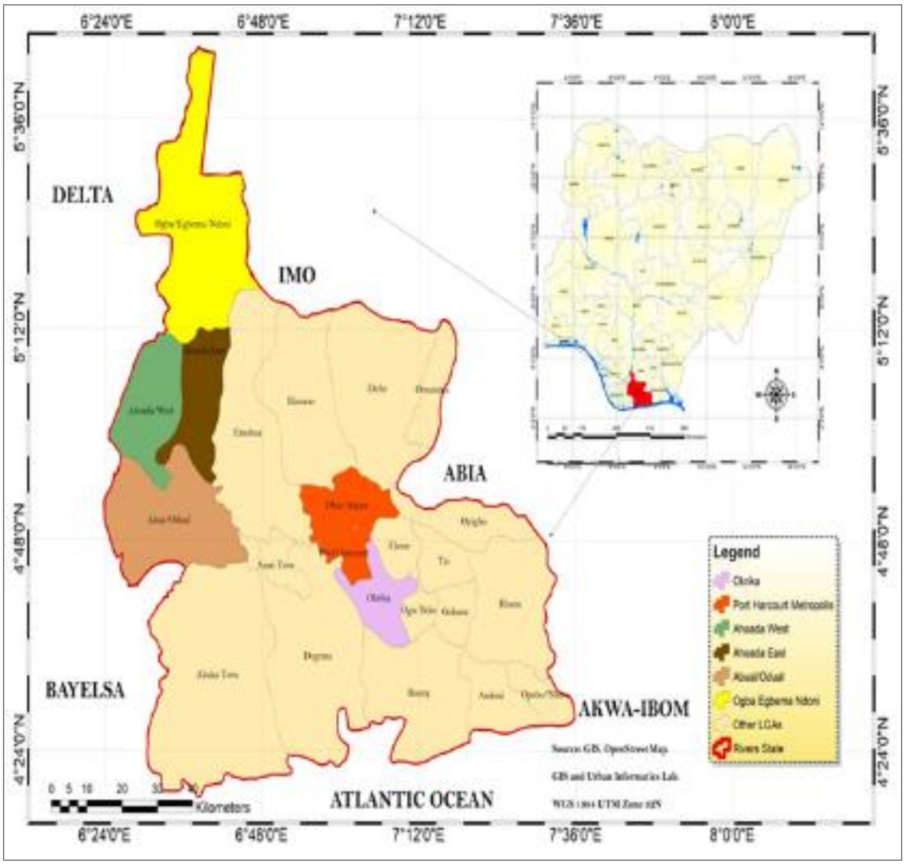
To Anya*, et al.,* (2018), the morphology of Rivers State drainage basins and channels describes the geomorphic parameters of its channel/gully and by its implication explains how the river profile has changed in shape and direction over time. A given river channel dynamics can result out of a number of processes amidst the pressing environmental conditions such in the geologic composition of the region, the river bed and banks rock structures, vegetation availability, volume and rate of Horton's overland flow, the available upland loose sediments, in channel sediment sizes and composition, net sediment transportation with the channel and the consequent depositions on the river flood plain, bed and banks, and the general basin net denudation event (Zhu *et al.,* 2017). Apart from these natural factors as mentioned, most rivers such as Woji River, are predominantly haunted by anthropogenic causes (Anya *et al.*, 2018)."

A basic flow of flood model and simulation as defined by Kumar *et al.* (2023) involves defining the study area, do a proper data collection; engage in hydrologic analysis/hydraulic analysis; do a risk assessment; flood mitigation planning and implementation and monitoring strategies. However, the most dependable technique and measures of doing flood modeling is the Remote Sensing and GIS-Based Flood Modeling (Nsiegbe *et al.*, 2022a). Flood models are developed using remote sensing and GIS technologies to simulate storm water flow. Remote sensing gather data about the surface of the Earth from a distance using sensors such as satellites or air craft (Kumar *et al.*, 2023). Hence, to handle, and visualize geographic data, the GIS Software system is used (Nsiegbe *et al.*, 2022b). Using remote sensing and GIS flow models can simulate how flood water would behave during a flood event as the model will analyse and assess the topography, elevation of the Earth surface, hydrology, meteorology, and land use of the area sing data from a variety of sources, including satellite images, aerial photography, and ground based (Costache *et al.*, 2019). The model can be used to evaluate the effectiveness of recommended flood mitigation measures, as well as to simulate the consequences of various flood scenarios. For instance, satellite imagery is used to map flood extents and locate flood prone areas, DEM generated from remote sensing data are used to create flood inundation maps that forecast the area that are likely to flood during a given flood event. Hence GIS is used to examine the spatial relationships, between various variables that contribute to flooding such as land use, soil type, and topography as well as to generate flood hazard maps that represent the extent and depth of possible flood inundation, and to aid in flood risk assessment and decision-making (Saha & Agrawal, 2020). This study therefore examined Modelling and Simulation of Flood Hazard Scenarios on Lowly Morphometric Drainage Terrain in Rivers State, Nigeria.

2. Methodology

2.1. Study Area

The drainage basins and catchments of Rivers State is the study area for this research. The study area is located in the Niger Delta region of Nigeria and covers an estimated area of 11,077 square kilometer (Chiadikobi *et al.,* 2011). It is defined by selected broad basins and catchments that usually experienced flooding due to their low lying elevations and physiographical features. The study area is located approximately on latitude $4^{1}8396^{o}$ and 4^{0} 824167^{o} north of the equator and longitude 6^{1} 9112^{o} and 7^{1} 033611^{o} east of the Greenwich meridian (Ajie & Dienye, 2014) (Fig. 1.1). It has a tropical monsoon climate with lengthy and heavy rainfall season and very short dry season (Uko & Tamunoberetou-Ari, 2013).



Source: GIS Lab, Department of Urban and Regional Planning, Rivers State University (2024)

Figure 1 Rivers State Showing Lowly Morphometric Drainage Basins Locations

2.2. Research Design

```
# include <10stram>
# include < (math)>
using name space std;
Int main  (    )
{Enter Flood  Hazards, vulnerability Analysis
If The Rules for Irrigation and Risk Management
double Spatial Data, Distance Data/impact on infrastructure, population Data
Ecological Data, Flood Impact Variables.
C  count << " what are spatial data, Distance Data,
 Ecological Data and Flood Impact Variable?" << end
Cin >> Spatial Data-SD;
   Cin >> Distance Data – DD;
   Cin >> Population Data P D; infrastructure Data ID;
  Cin >> Ecological Data; ED;
  Cin >> Flood Impact Variables FFIV;
 St = (< Spatial Data * (SD – FIV) * t)/ (SD (DD* PD)/ED)) + FIV+ID;
{Cin >> all Components/variables of study)
St = (CSD, DD, P-D; FIV; ID;
Cout << St;
}Return 0
End Simulation
```

Source: Researcher's Analysis of Operation Flow Chart, (2024).

Figure 2 Structure of the Model Simulation

This study adopted the GIS based hydrological and hydraulic model of Run off and river flow research design utilising the GIS Software ArcGIS 10.7 version developed by the Environmental System Research Institute (ESRI) USA, employing the Watershed Modeling System (WMS), a hydrological model that is used for processing digital watershed data, watershed delineation, analyses Digital Elevation Model (DEM), rainfall intensity, drainage density, slope/elevation, land use and soil permeability; preparation of input data for the hydrologic and hydraulic modeling and analysis of the model output (Johnson *et al.*, 2021). The modeled drainage basin and catchment variables were simulated using C++ programming language as shown in Figure 2.

3. Results

The lowly morphometric drainage elevation of the area was analysed and the terrain pattern data of the area was modeled and simulated to show the areas liable to flooding. Figures 3 and 4 show the elevation maps of the lowly river basins overlaid. It is shown in Figures 3 and 4 while Table 1 shows the simulated spatial extent and mean elevation of lowly drainage basin in Rivers State. The modelling and simulation analysis showed that there are 22 lowly morphometric basins with the southern part of the state falling between -10m and 12m while the urban part like Port Harcourt town falls between 35.01m and 41.3m. The western part of the state around Etche and Omuma LGAs falls between 23.01m and 30m while the north eastern part like Ahoada are between 12.01m and 18m. The percentage rise of Rivers State is 21.599m and the spatial extent and mean elevation of the drainage basin of Rivers State is 27.65sqkm while the maximum is 1688.47sqkm. The minimum elevation is 6.54m while the maximum is 43.06m and the mean elevation is 21.04m.

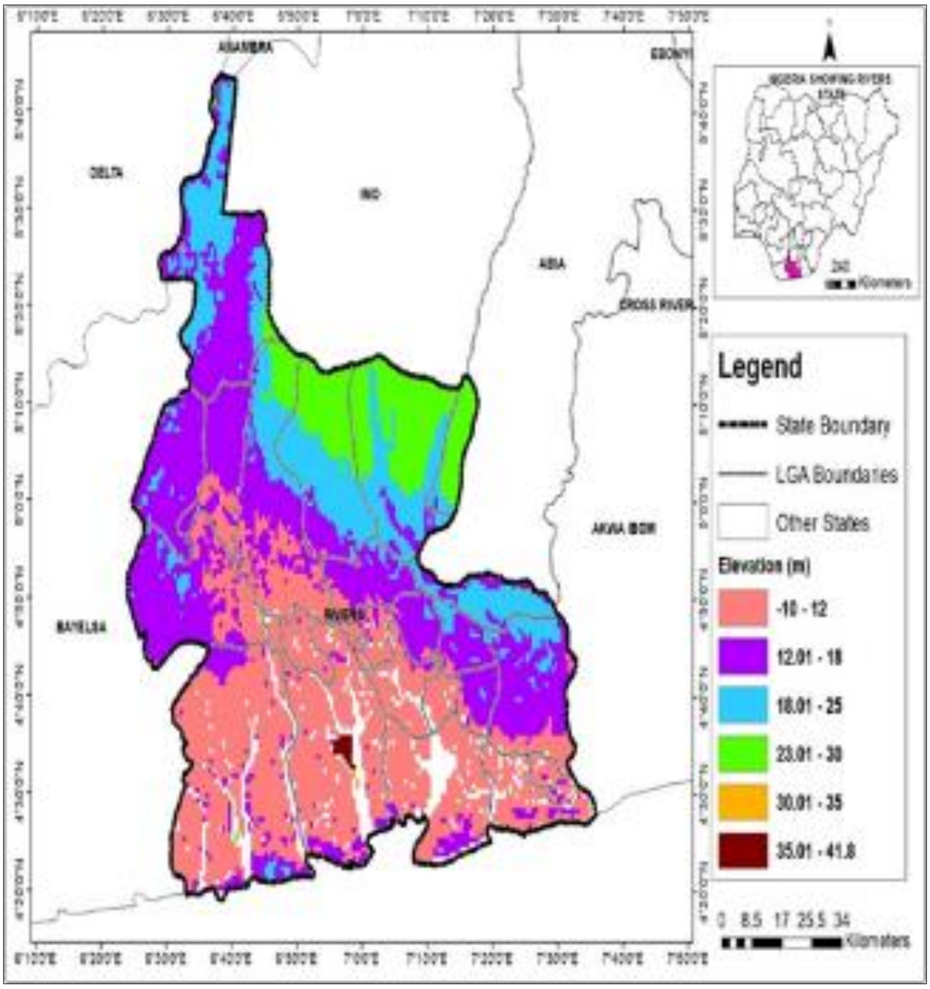


Figure 3 Elevation Levels of Rivers State drainage basins(2024)

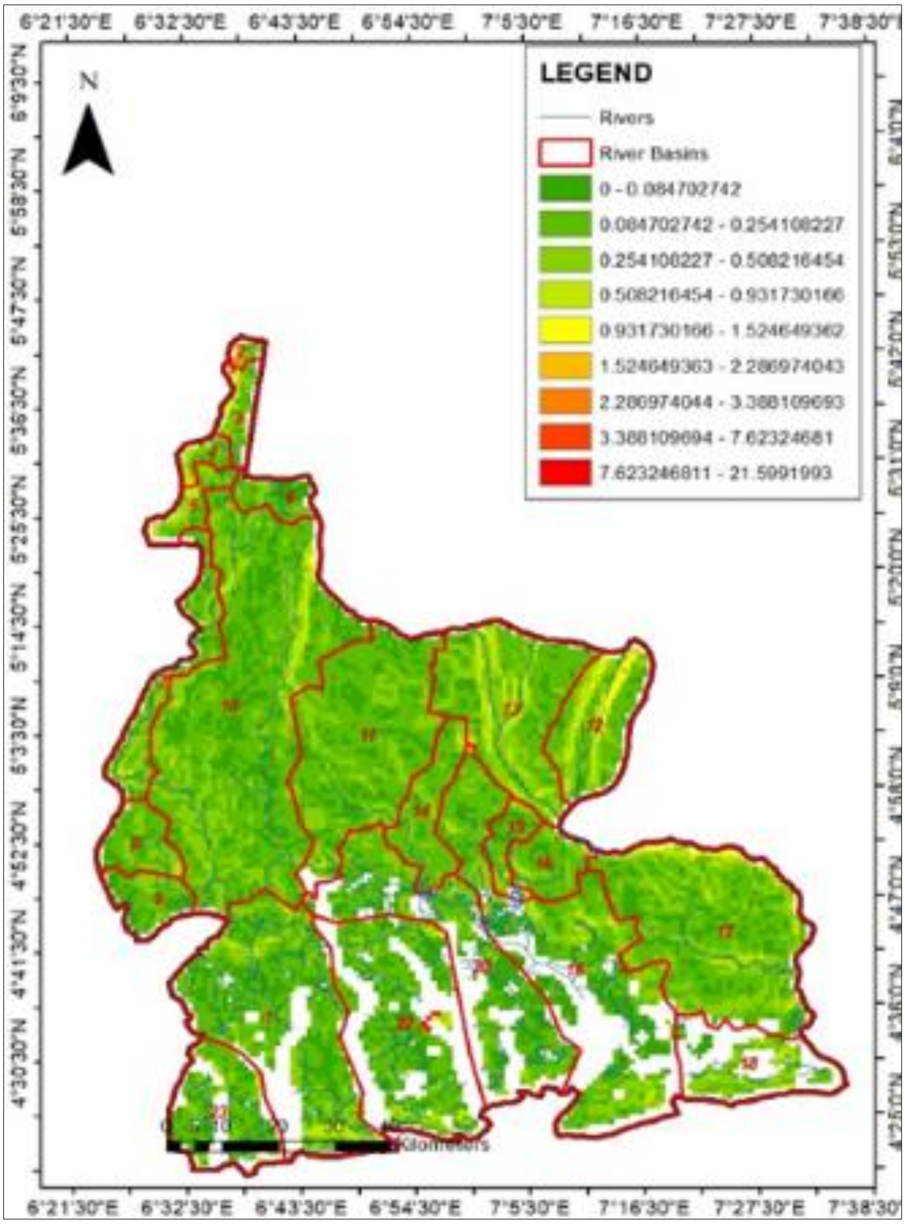


Figure 4 Percent Rise of Elevation of Rivers State drainage basins (2024)

Table 1 Spatial Extent and Mean Elevation of Drainage Basins in Rivers State

ID_Sub-catchment	Area Covered by Drainage Basin (sq km)	Mean Elevation (m)
S1	999.19	9.27
S2	27.65	30.4
S3	98.18	26.50
S4	56.58	25.02
S5	100.52	23.44
S6	97.98	22.92
S7	255.97	20.78

S8	155.25	19.95
S9	138.19	18.02
S10	1688.47	18.73
S11	852.96	27.84
S12	349.28	43.06
S13	628.35	40.31
S14	217.21	20.73
S15	98.78	19.29
S16	152.02	20.31
S17	975.45	20.01
S18	346.02	7.41
S19	1149.91	11.84
S20	777.52	6.54
S21	857.02	22.31
S22	366.29	8.23
Minimum	27.65	6.54
Maximum	1688.47	43.06
Mean	472.21	21.04
Standard Deviation	451.28	9.4

4. Discussion

The results show that majority of the southern part of Rivers State falls between -10 and 12 m while the urban part like Port Harcourt Town falls between 35.01m and 41.3m. The result of the analysis is in tandem with the work of Ede (2014) who reported that the elevation ranges of Rivers State were between 0m in the south and 21m above mean sea level in the north suggesting lower elevation towards the southern part of the State. As a result of this variation in the elevation, the tendency of Southern part to be subjected to more flood is possible because the gradient is on the smaller range. According to Ede (2015), the consequence of absence of gradient is that of an area susceptible to flooding; however, the root of these observations is the reliance on topographic maps whose contour intervals is 15.24m in elevation. Thus, the lower elevation could lead to higher wetness and less roughness of majority of Rivers State. It is thus corroborated by Manfreda, *et al.*, Sole (2011), Pourali *et al.* (2016), and Lawal and Umeuduji (2017) that the wetness index and the roughness index can be used for rapid assessment of potential vulnerability to flooding in the study area. These previous works agreed that while hydrodynamic modelling and simulation is extremely valuable for flood risk assessment, hydrological and geo-morphometric indices are tools for rapid assessment of flood prone areas. More importantly, the shape of a drainage basin influences the efficiency of water conveyance to the main river. Circular basins are more efficient in transferring water, leading to quicker responses to rainfall and a sharper, higher peak discharge in the hydrograph. Elongated basins show a more delayed response due to the varied travel times across different parts of the basin.

5. Conclusion and Recommendations

This study examined Modelling and Simulation of Flood Hazard Scenarios on Lowly Morphometric Drainage Terrain in Rivers State, Nigeria. The study delineated 7 lowly morphometric drainage basins, revealing significant variations in elevation and drainage density. The modeling and simulation results provided insights into the characteristics of storm water flow and stream length, with significant variability in stream dimensions and flow patterns across the basins. The study also identified key flood vulnerable areas related to land use, proximity to river channels, and elevation, showing a predominance of high vulnerability areas in the southern regions.

In conclusion, the study underscores the importance of flood modelling and simulation effective determination of flood hazard occurrence and mitigation measures. The study thus recommends for a ten-year routine and regular catchment and digital elevation modeling flood prone area should be carried out by the government for flood disaster mapping and analysis to determine the areas liable to flooding within the Rivers State drainage basins and catchment as well as reactivation of the drainage Master Plan of Rivers State be done to tackle flood issues and ameliorate its socio-economic impacts.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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