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VULNERABILITY ASSESSMENT OF 2015 FLOOD IN NORTH CENTRAL NIGERIA USING INTEGRATED APPROACH OF HYDROLOGICAL MODEL AND GIS

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Abstract

The research aimed at designing and implementing a hybrid approach where flood event was simulated by integrating hydrological model HEC-RAS (Hydrological Engineering Centre) with GIS (Geographical Information System) so as to identify and analyse flood prone zones in Lokoja north central Nigeria. The present study developed a hybrid approach in identifying flood risk zones and assessing the extent of impact of the hazard by integrating HEC-RAS and GIS technologies. This GIS-based approach, which allows visualizing and quantifying the results in a spatial format, was applied to Lokoja. 2015 flood event was simulated to expose the extent of the current infrastructure of the area to flooding. A single data entry of river channel geometry and flow into the HEC-RAS computer program is sufficient to model steady flow, unsteady flow, water surface profiles, sediment transport/movable boundary computations, and water quality. In this research, steady flow was simulated along River Niger and flood hazard extends derived using HEC-RAS/HEC-geo RAS. For simulating, first used HEC-geo RAS to define the river channel and extract cross sections from the TIN, then the results of pre-RAS within the steady flow data and the other required data imported to the HEC-RAS for process and ultimately provided the inundation extends of 2015 flood event.

The results indicated that hydraulic simulation by integrating HEC-RAS model GIS is effective for various kinds of floodplain managements and the developed methodology was efficient in modelling and visualizing the spatial extent of different month's scenarios and in determining flooded areas at risk. It was found that changes in water elevations of the River Niger made the downstream areas more at risk. The simulated output is validated by comparing the simulation output with the observed data of 2015 flood event from the National Waterways Authority (NIWA) Lokoja mentions the inundation depth of River Niger as at the time of the flood event to be 37m. The inundation depth level obtained through HEC-RAS simulation of the flooded month to be 35m. The difference in the estimation (which is less by 2m) of the inundation depth level by HEC-RAS simulation could be attributed to the usage of Land use and Digital Elevation Model (DEM) data in the model. As the results yielded by the HEC-RAS model are close to the observed data of 2015 flood, the model can be assumed as valid to perform assessment of flood event for the study area.

Keyword: Flood, Vulnerability, Assessment, GIS, HECRAS model, Evaluation.

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Introduction

In recent years, the world's attention has been shifted from the flood hazard control to flood impacts/risks assessment Bubeck *et al.*, (2011); Ke *et al*., (2012). Risk according to the United Nations office of disaster risk reduction (UNISDR) is defined as the combination of the probability of an event and its negative consequences UNISDR (2009a; 2009b; 2013a; 2013b). Earlier researchers Hewitt, (1980) have put forward that hazards occurrences do not result into disaster and that for actual assessment of the disaster situations and losses, various element such as vulnerability and exposures have to be included, Birkmann, (2013). This has become the basic methods used today in disaster risk analysis. Flood risk, therefore, is the product of the flood hazards, the vulnerability and the exposure of the people Bates *et al*., (2000); UNISDR, (2009b).

The generality of the research works concentrate on the determination of the flood extent by buffering around the river and/or using satellites imageries of the said flood dates to determine the flood risk level and extents, Ejenma *et al*., (2014); Enaruvbe *et al*., (2012); Nkeki *et al*., (2013). While it is absolutely important to apply remote sensing data and GIS tools, certain fundamental principles in hydrological modelling and prediction has not been incorporated into flood simulation and mapping in the country. Flood mapping by means of only GIS generally belongs to flood model group called 0- Dimensional models; these models lack basic physical laws and cannot be regarded as simulation, Akinnola *et al*., *(*2015). This method, which is predominant in most studies in the country, utilizes a Digital Terrain Model (DTM), overlaid on pre-determined high flood water level. The distance between the water level and the terrain (surface) elevation is assumed to be the flood or inundation depth. Although, this seems a logical idea in deriving flood extent and depths, it however lacks basic governing hydrological principles and physical laws. Certain hydrological and physical components such as rainfall, infiltration, channel flows, evaporation, nature of soil, roughness, hydraulics etc., which determines the propagation of flood waves, cannot be incorporated in such a model.

Several numerical and distributed models and packages (MIKE Flood, Flo 2D, HEC RAS, which incorporates the fundamentals of hydrology and water volume conservation for flood simulations are available in many countries. Bates *et al*., (2000); Dutta *et al*., (2003); Dutta *et al*., (2009); Flo-2D., (2009); NKT., (2011); Yin *et al*., (2015); these are capable of calculating rainfall runoff and modelling urban flood inundation with some degree of accuracy. None of these have been effectively utilized to estimate the flood inundation level in Nigeria, which undermine the accuracy of the previous mappings. Due to the uncoordinated urban growth, poor and complex river systems, high level vulnerability of the communities and lack of river prevention and management in Nigeria and its communities, it is rather important to incorporate many boundary conditions for effective understanding of flood hazards and the intensity of their occurrences. This would definitely extend beyond just the use of remote sensing and GIS, but will incorporate other spatial data inputs. In order to enhance understanding of the flood hazards for effective risk assessment and management, estimation and simulation of flood events will not only determine the extent of flooding, but

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also basic characteristic of flood (e.g. water depths, velocity, duration, sediments, wind etc.) that accounts for the degree of damages and devastations encountered during flooding.

The present research aims at designing and implementing a hybrid approach where flood event is simulated by integrating hydrological model (HEC-RAS) with GIS so as to identify and analyse flood prone zones in Lokoja north central Nigeria.

Study Area: Lokoja Nigeria

The study area Lokoja, is located between latitude 7°45´27.56´N and 7 °51´04.34´´N and longitude 6 ° 41´55.64´E and 6 ° 45´36.58´´E, with a total land area of 29,833km^2. It shares political boundaries with Niger, Kwara, Nassarawa States and the Federal Capital Territory Wikipedia, (2012). The annual rainfall in the area is between 1000 mm and 1500 mm with its mean annual temperature not falling below 27°C. The Onset of rains is April and Cessation is late October. Orographic (relief) rain is also common in and around Lokoja due to the presence of the mountain range. Temperature during the Hamattan in the night can drop up to 12°C between Decembers and January. While the temperature during the heat period can be as high as 42°C between March and April in the day time because Lokoja is somewhat fenced in by intimidating highlands. Also significant is the differences in temperature changes effect of large water bodies like the Niger River Confluence with about 5km width and the surrounding shore land areas like Lokoja. The heat accumulated by the water body during the day is released in the night to the town. The flood plains of the Niger and Benue river valleys in Lokoja have the hydromorphic soils which contain a mixture of coarse alluvial and colluvial deposits. The alluvial soils along the valleys of the rivers are sandy, while the adjoining laterite soils are deeply weathered and grey or reddish in colour, sticky and permeable. Lokoja town is not only a river side settlement but also a hill side settlement. Also it is clear that new development activities are growing along the river banks that are unstable. On the issue of flooding, it become obvious that during the raining seasoning, water flows from the hill side settlement into the low side settlement thereby causing flood in the st newly developed areas along the Niger River. It has witnessed several devastating floods, occurring almost on an annual basis, in its recent history, especially from 1991, due to rapid and uncontrolled urbsanization of the town. The release of waters from Ladgo dam in Cameroon into the River Benue flood plain, and similar releases from Kainji, Jebba and Shiroro dam on the Niger River were largely responsible for the 2012 flooding in Nigeria, of which Lokoja, a confluence town of Rivers Niger and Benue was adversely affected. The study area is as shown in Figure 1.

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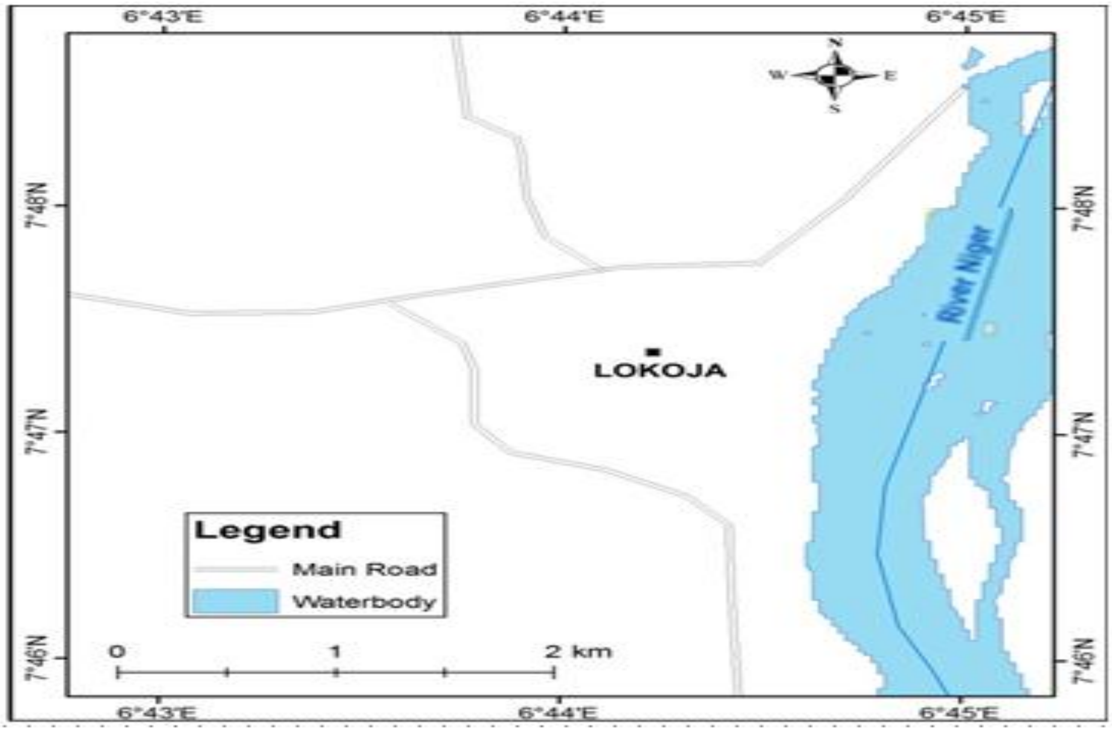

Figure 1: Map of the Study Area and it environment.

Data collection and Methodology

The methodology involved in the integration of GIS and HEC-RAS flood simulation models is shown in Figure 2. It shows the method involved in this research work. Three types of data (ASTER Imagery, Landsat Imagery and Stream flow data) are used to achieve the research work. The ASTER Imagery was process to get the DEM of the area and it was also processed using the hydrological tool in the arc GIS to get the drainage pattern (Flow direction, Flow accumulation and stream order) of the study area. This is done to achieve the first objective of this research work. The Landsat Imagery is then classified into different category to obtain the Land use Land cover map of the area. This is done to achieve the second objective of the research work. The DEM and the land use classification is used in the creation of the river geometry through Hec Geo Ras extension in the ArcGIS environment. The stream flow data is lastly simulated in the HEC-RAS model and ArcGIS to map out the flood prone areas. This is done to achieve the third objectives of the research work.

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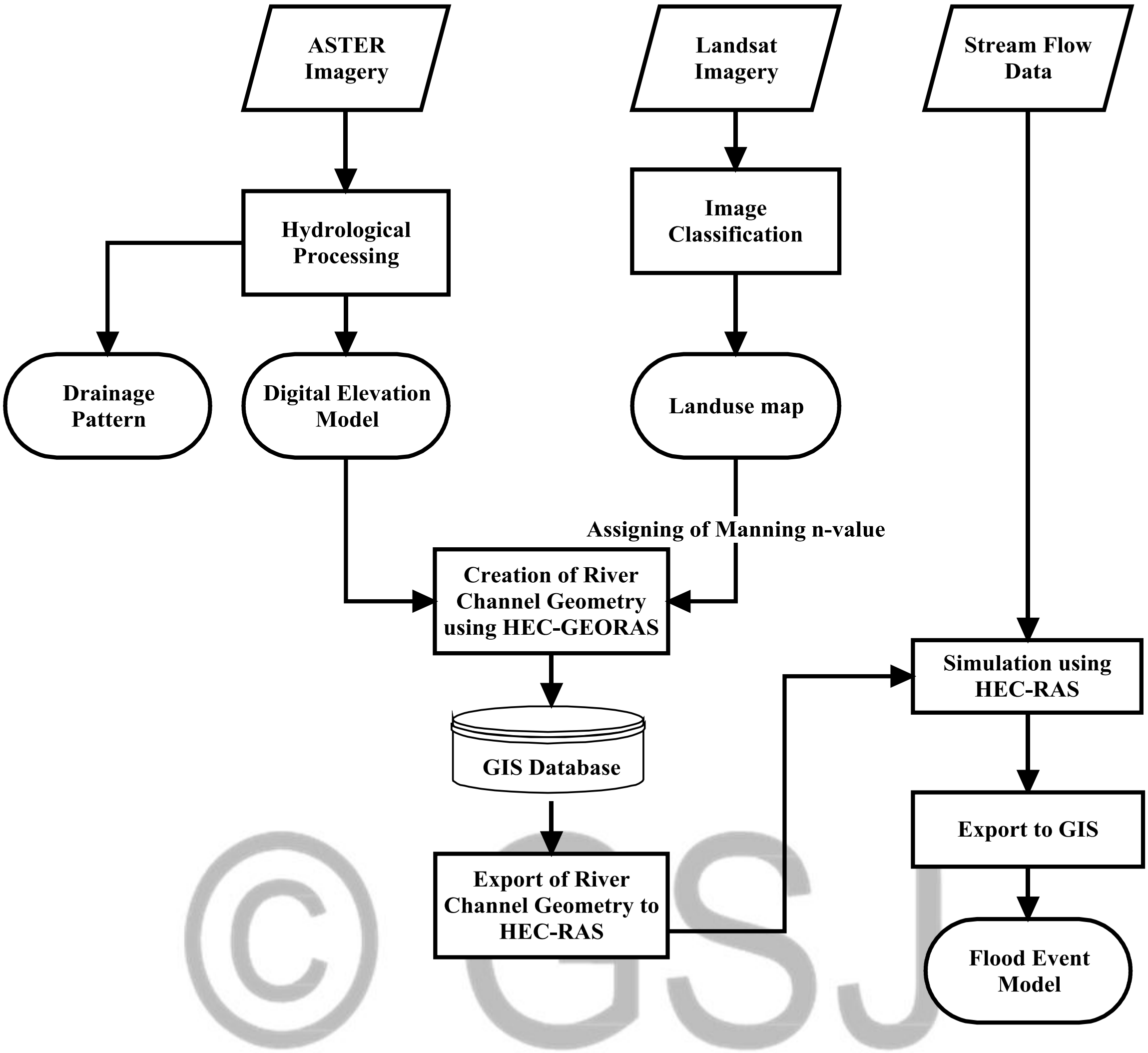

Figure 2: Flowchart of the process involved in the flood risk assessment.

Hydraulic Simulation

HEC-RAS is a numerical model that designed for hydraulic simulation. This software allows the user to perform one dimensional steady flow, unsteady flow calculations (HEC-RAS manual) the system is comprised of graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphical and reporting facilities.

In this study, steady flow analysis is applied and calculating water surface profiles for steady gradually varied flow is performed. Additionally the steady flow component is capable of modelling sub critical, supercritical and mixed flow regime water surface profiles (Snead, 2000). The basic computational procedure in HEC-RAS model is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (that is, hydraulic jumps), hydraulics of bridges and evaluating profiles at river confluences (stream junctions). The steady flow system is designed for application in flood plain management and flood. Water

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surface profiles are computed from one cross section to the next by solving the energy equation with an interactive procedure called the standard step method

Capability of modelling common types of hydraulic control structures with appropriate on and off features and having a GUI with pre and post-processing are strengths of this model, but HECRAS have some limitations such as it cannot simulate water quality processes and relatively difficult to use in conjunction with other water quality models. Likewise another limitation is that it cannot simulate groundwater levels. The basic data requirements for simulation are included: geometric data, study limit determination, river system schematic, cross section geometry, ineffective flow areas, reach lengths, energy loss coefficients, Manning's n, Equivalent Roughness'k', contraction and expansion coefficients, steady flow data, boundary condition, flow regime. In this study the results that HEC-geo RAS extracted from TIN in ArcView, import to the HEC-RAS model for simulation. Then some additional required data that HEC-RAS needs for running, like steady flow data, boundary condition, Manning's n and contraction and expansion coefficients must be imported. Selection of a suitable value for Manning's n is very significant to the accuracy of the computed water surface profiles.

There are several references that can access Manning's n value for typical channel. In this study applied slide source that agreed with Chow's tables was used. Boundary conditions are another part of model that must be completed. Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the program to begin the calculations. In a sub critical flow regime, boundary conditions are only required at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime calculation is going to be made, then boundary conditions must be entered at all open ends of the river system. One of the HEC-RAS capabilities is providing user cross section interpolation in some part that is necessary that have been used in this modelling. Ultimately after completing all

Results and Discussion

The River Geometry of the Study Area

The river geometry was drawn on a reach-by-reach basis using the Arc map tools and the Hec geo Ras extension. River reaches were drawn upstream to downstream in a positive flow direction using multi segmented lines. Each reach is identified by a river name (i.e. stream name) and reach name Figure 3 represent the channel geometry of River Niger as imported from GIS to HEC-RAS.

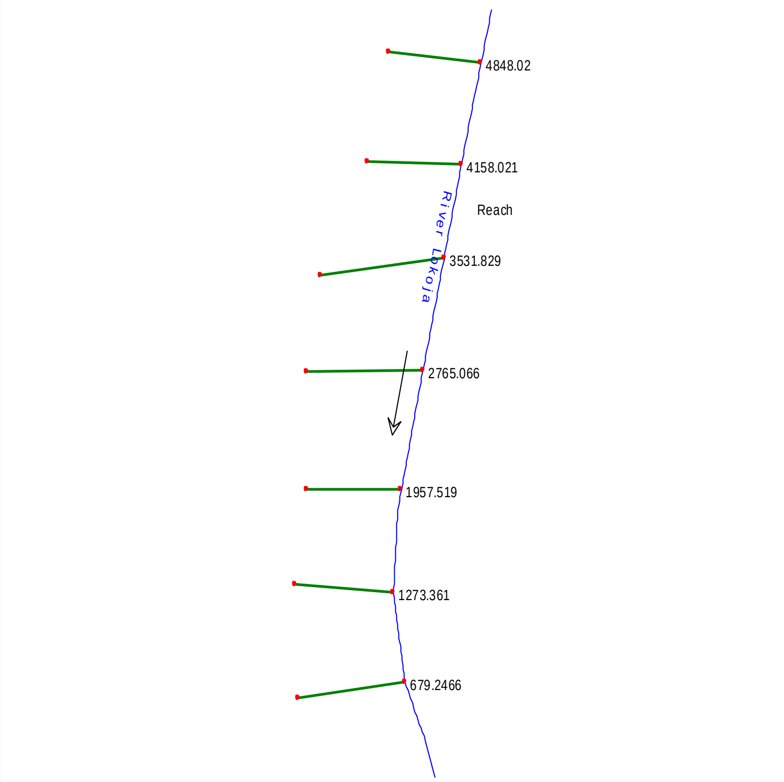

Figure 3: The river geometry imported from GIS to HEC-RAS

Following the modelling of the river geometry imported into HEC-RAS, the mean cross section for the flooded month and non-flooded month is shown in Figure 4. It represent River Niger in the month of august, September, October and November One of the most important results of HEC-RAS simulation is preparing different water surface profiles of different-year floods. It can be observed in Figure 4(a) and 5(d) that the mean water level did not exceed the bank station, hence it will be concluded that the River Niger is effectively contained in the non-flooded month and there was no indication of flooding in the in the month of August and November of the study area. The lower region was also characterized by severe water discoloration, foul doors, and an abnormally high mosquito population. Previous research by (Sangodoyin 1996, 2002) had identified this region as the most vulnerable to flooding, and HEC-RAS modelling performed during this study confirmed the finding.

Figure 4 presents the differences between cross section profiles of flooded and non-flooded months of River Niger in 2015. Where: (a) is mean profile for the month of August; (b) is mean profile for the month of September; (c) is mean profile for the month of October; and (d) mean profile for the month of November. It is obvious that in the flooded months, water September (b) and October (c) respectively, water overflows its boundary. In a similar manner for better comparison, Figure 5 is the simulated water elevation from HEC-RAS for the flooded and non-flooded months, The highest water elevations was measured in these months with the highest stream flow (i.e. the higher the stream flow, the higher the water elevation), as the flow of water increases, the elevation of water also increases as shown in Figure 5 (a) and (d). The HEC-RAS model has been able to identify those particular sections of the River Niger course that are susceptible to high water elevation levels which are significant indicators to flooding events (Adewale, 2010). Areas around the flood plain were inundated due to encroachment into flood plains.

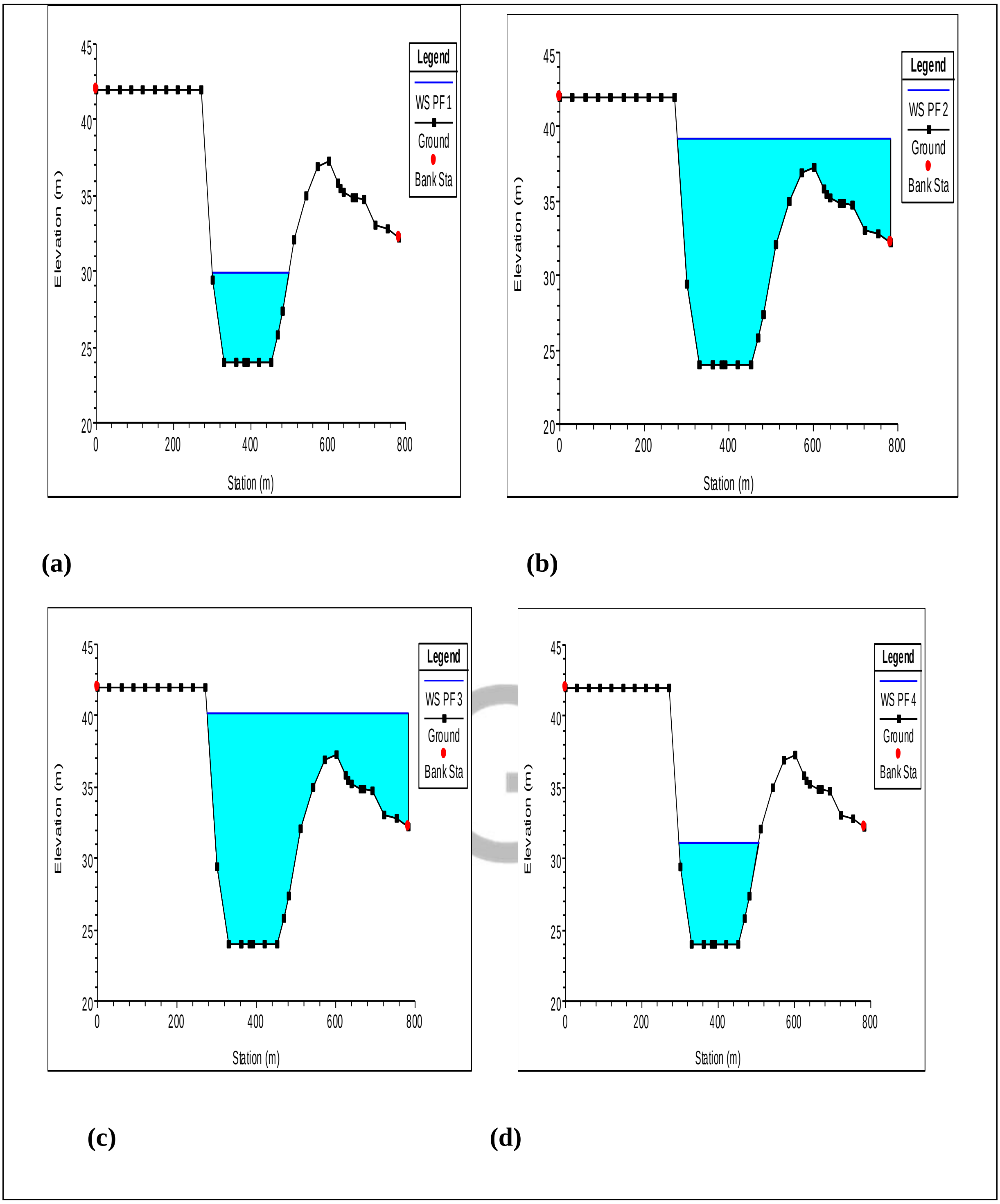

Figure 4: Differences between cross section profiles of flooded and non-flooded months of River Niger in 2015. (a) mean profile for the month of August, (b) mean profile for the month of September, (c) mean profile for the month of October, (d) mean profile for the month of November.

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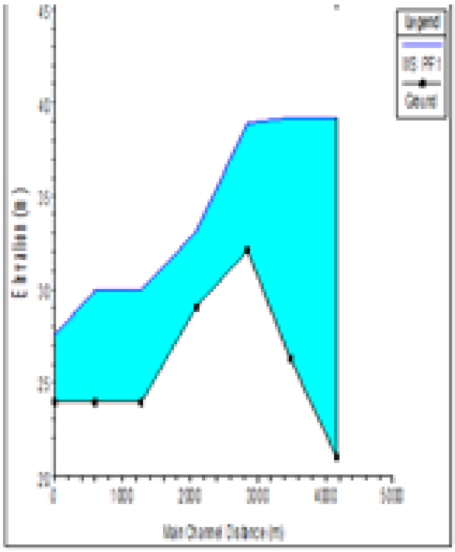
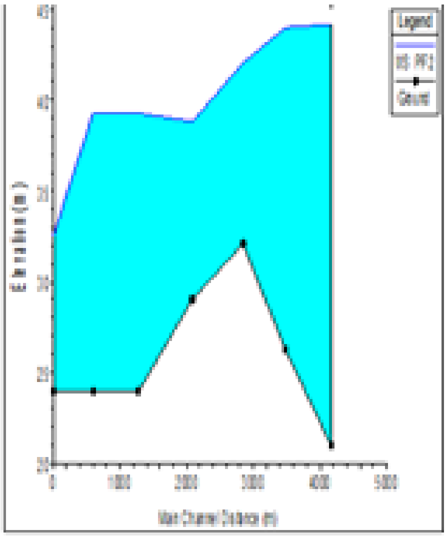
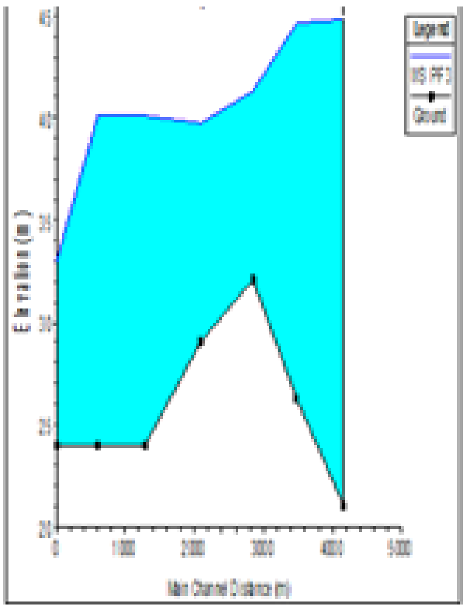


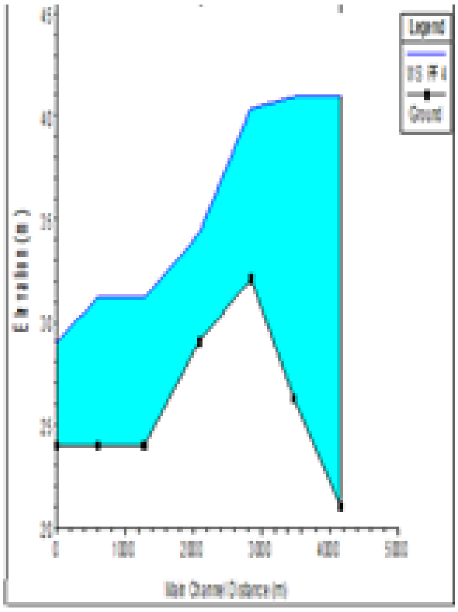
(a) Depth profile for August



(b) Depth profile for September,



(c) Depth profile for October



(d) Depth profile for November.

Figure 5: Same as Figure 4 but for depth profiles of the respective months..

Figure 6 was obtained from HEC-RAS simulations and it depicts the extent and depth of inundation occurred during the flood of 2015. The depth of flood waters obtained ranges from 0.00455856m to 35.1279m and thus generates the water depths as a raster data. Figure 6 reveal the highest water depth recorded is also 35.1m. It also reveals the intensity of risk to which Lokoja is exposed to. The exposure of the area to a higher magnitude flood event is amplified with higher number of critical facilities getting affected by flood waters

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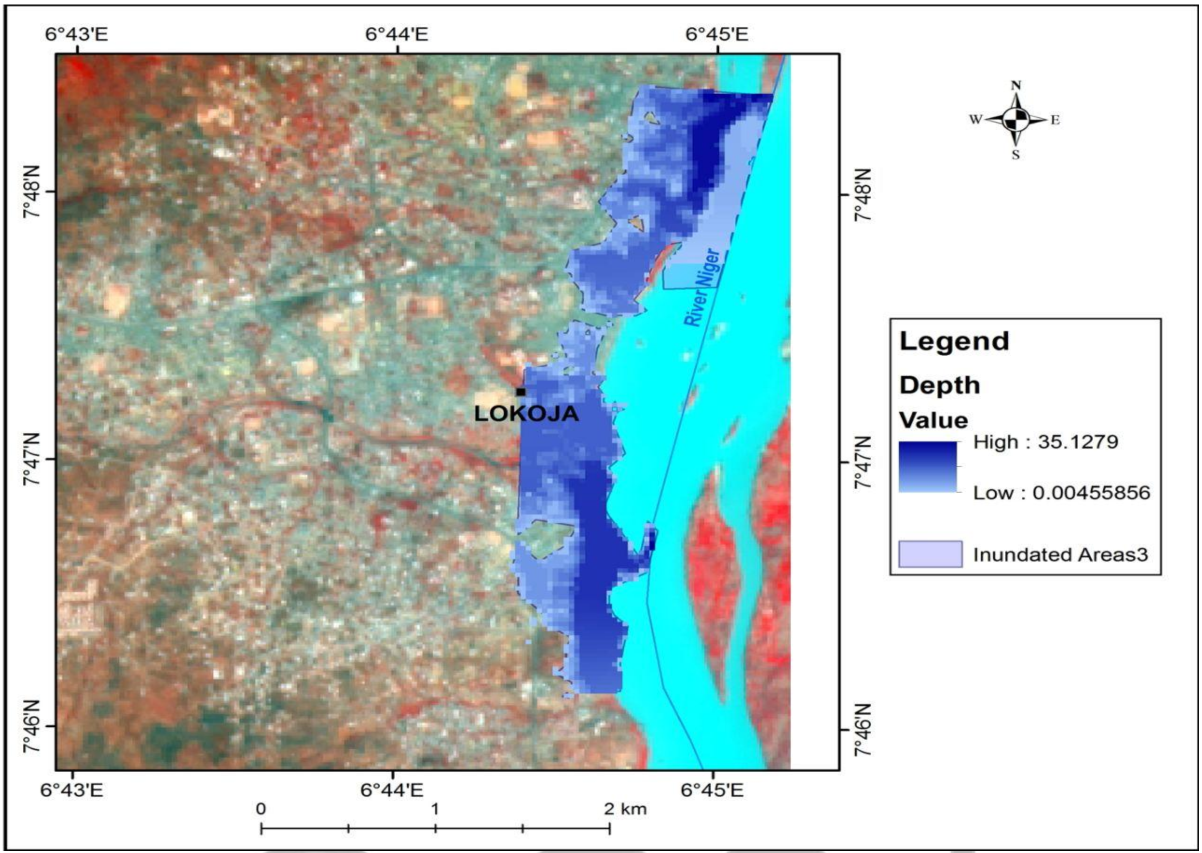

Figure 6: Depth of the flood waters from HEC RAS simulation of Lokoja

Validation of HEC-RAS Output by the Observed Data

The simulated output was validated by comparing the simulation output with the observed data of 2015 flood event from the National Waterways Authority (NIWA) Lokoja. NIWA observed that the inundation depth of River Niger as at the time of the flood event was 37m. The inundation depth level obtained through HEC-RAS simulation of the flooded month was 35m. The difference in the estimation (which is less by 2m) of the inundation depth level by HEC-RAS simulation could be attributed to the usage of Land use and Digital Elevation Model (DEM) data in the model. As the results yielded by the HEC-RAS model were very close to the observed data of 2015 flood, the model can be scientifically believed as valid to perform assessment of flood event for the study area. The model results indicated that most of the areas inundated in Lokoja were along the flood plain which is true with the observed data.

Assessment of Flood Extent in the Study Area

The infrastructure failure of any area is estimated from the potential vulnerability of its critical facilities in the face of a hazard. Hospitals, schools, waste water treatment and potable water plants, hazardous plants, transportation utilities such as airport, railroad, and bus stations are identified as critical facilities by (Odeh, 2002). Potential impact on these key facilities, which play a critical role in the functioning of the state capital, can paralyze the functionality of the area. The assessment is conducted by overlaying the street map and facilities of the study area on the extent and depth of inundation (HEC-RAS simulation results) occurred during the flood of 2015. The information analysed helps to determine or prioritize the mitigation measures that can make the area more disaster-resistant. The results presented in figure 7 shows that the study area is extremely exposed to flooding risk.as shown in Figure 7 On the issue of flooding, it becomes obvious in this study that newly developed areas along the Niger River are flood prone as indicated in the Figure below. Also it is clear that new development activities are growing along the river banks that are threat to flooding. The incidence of floods in the study area is caused by a combination of natural and human induced activities along the floodplains. Lokoja happens to be the confluence of the two largest rivers in Nigeria; Rivers Niger and Benue. The size and importance of these rivers coupled with increasingly growing human activities. The results indicated that the developed methodology was efficient in modelling and visualizing the spatial extent of different month’s scenarios and in determining flooded areas at risk. It was found that changes in water elevations of the River Niger made the downstream areas more at risk.

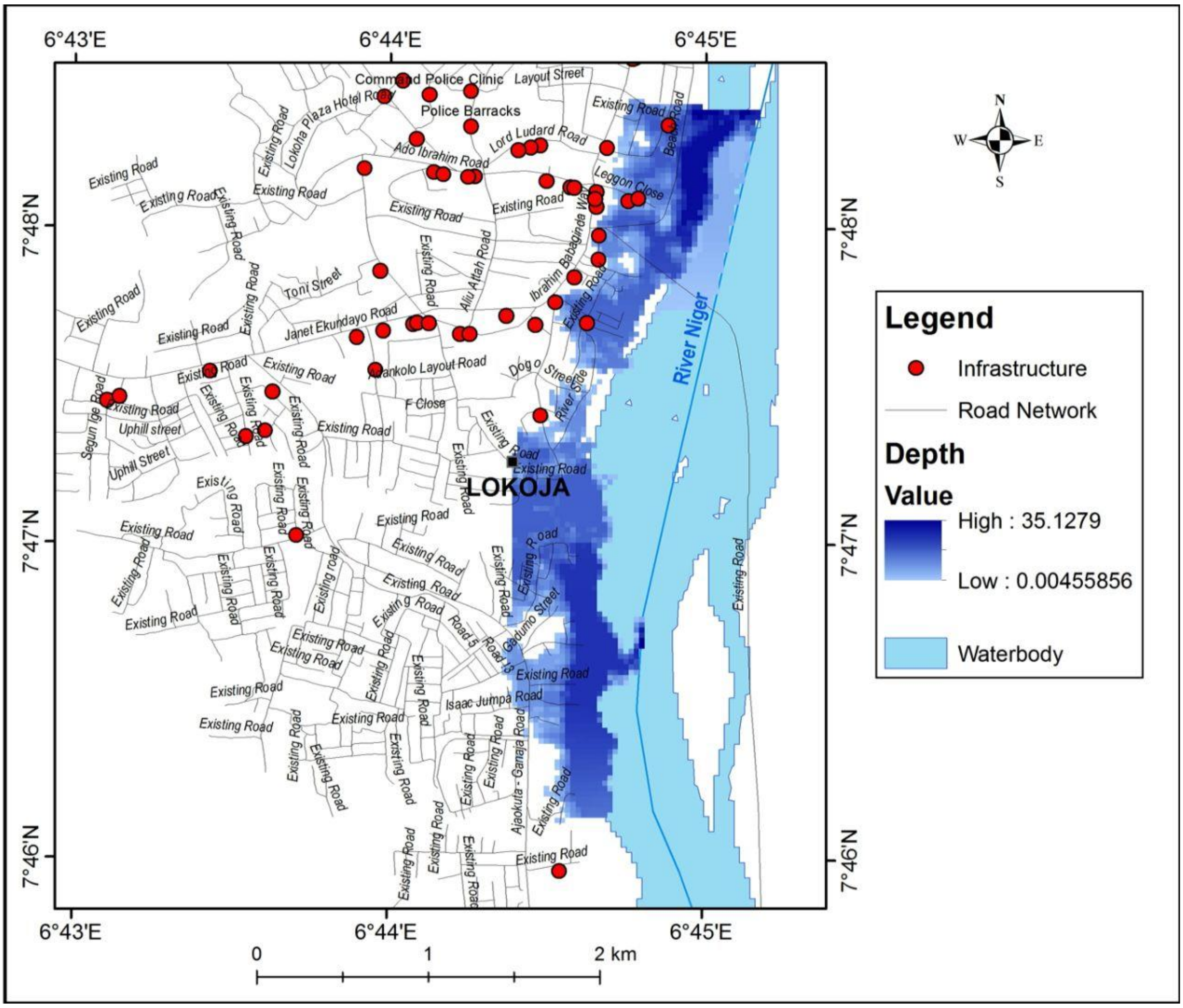

Figure 7: The Key Facilities of the Study Area Overlaid on the Inundation depth.

Conclusion

This research focused on integrating GIS tools to Hydraulic analysis. These tools could reasonably separate high hazard from low-hazard areas in the floodplain to minimize future flood losses this study presents a systematic approach in identifying flood hazard and subsequently in assessing the inundation of the area by the integration of hydrological models with GIS. The combination of Arc GIS and HEC-RAS 1-D flood simulation model indicate

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the capability of simulating flood events and spatially depicting the degree of exposure of the area towards a hazard event in terms of inundation extent and depth of water levels. The model can be said to have generated reliable quantified output. This hybrid approach provides quantified information on the water level depths and facilitates to access the data at any point of interest, the visualization and the quantification of the flood risks, as facilitated by this approach, can generate invaluable information and assist the decision making authorities to make informed choices towards mitigating the catastrophic effects of flooding disaster.
The assessment from the 2015 flood event simulated by HEC-RAS model reveals the intensity of risk Lokoja was exposed to. The exposure of the area to a higher magnitude flood event is amplified with higher number of critical facilities getting affected by flood waters The catastrophic effects of flooding disaster can be mitigated by integrating scientifically reliable information obtained from a risk assessment studies developed using this hybrid approach. The study highlights the need for flood control and mitigation strategies in the low areas.

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