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Research Article

Assessing Nature-Based Flood Mitigation Measures at the General Area of the Confluence of Rivers Benue and Niger in Kogi State, Nigeria

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Abstract

Flooding in the confluence area of Rivers Benue and Niger remains a major environ-mental and socio-economic challenge which disrupts livelihoods, damages infrastructures and increase vulnerabilities in affected communities. The existing flood management in Nigeria relies on conventional engineering solutions, with limited to no consideration of Nature-Based Solutions (NBS). While NBS have been explored in other regions, their applicability to this area remains under-researched. This study assessed the potential of Nature-Based Solutions (NBS) for mitigating flood risks in this region through the integration of Geographic Information Systems (GIS), Remote Sensing (RS), and hydrological modeling. Landsat imagery (2012-2023), Digital Elevation Models (DEM), soil, and climate datasets were utilized alongside HEC-HMS and HEC-RAS models, and Google Earth Engine (GEE) for flood extent analysis. Results showed peak flood coverage in 2018 (172.68 km²), followed by a decline to 99.12 km² in 2023. Flooding trends were attributed to increased rainfall variability, land-use changes, and inadequate drainage infrastructure. A suitability analysis for NBS implementation identified areas appropriate for wetland restoration, afforestation, and sustainable drainage systems. The study highlights the potential of integrated NBS and engineered measures in enhancing long-term flood resilience.

Keywords

Flood Mitigation, Nature-Based Solutions, Geographic Information Systems, Remote Sensing, River Niger, River Benue, Kogi

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1. Introduction

Floods, as natural disasters, pose significant threats to human lives, infrastructure, and the environment, causing widespread devastation and disruption to communities across the globe [1]. Over the past decades, the frequency and intensity of floods have increased, posing a significant challenge to the objectives of Sustainable Development Goal 13, which aim to take urgent action to combat climate change and its impacts, highlighting the crucial need for enhanced sustainable development and climate resilience efforts [2]. According to the World Health Organization [3], floods have affected more than 2 billion people worldwide between 1998 to 2017. Nigeria, home to approximately 224 million people according to the latest United Nations Population Funds data [4], is well-acquainted with the challenges presented by flooding. With its complex network of rivers, deltas, and coastal regions, the country is susceptible to various types of flooding, including riverine, urban, and coastal flooding [5]. The im-pacts of floods in Nigeria are far-reaching, disrupting livelihoods, damaging infra-structure, compromising food security and aggravates public health concerns.

In Nigeria, where recurrent floods pose ongoing challenges, the general area of the confluence of River Benue and Niger in Kogi State stands out as one of the nation's most vulnerable regions, grappling with the profound impacts of these calamitous events. The confluence area, situated at the intersection of two major rivers, exhibits unique hydrological characteristics that make it susceptible to frequent and severe flooding [6]. Consequently, the communities residing in this region face significant challenges in coping with the adverse consequences of these inundations.

While engineering interventions have, in the past, favored flood management, there is a growing recognition of the role that Nature-Based Solutions can play in enhancing resilience, especially in vulnerable regions like the confluence area. Tradi-tion-ally, flood management strategies rely on structural engineering solutions, such as building dams, levees, drainage channels and embankments, to protect vulnerable areas from floodwaters [7]. While these measures have provided some degree of protection, they often come with substantial drawbacks.

Nature-Based Solutions (NBS) strategies offer an innovative and eco-friendly alternative to conventional flood management strategies by capitalizing on nature's inherent resilience and capacity to mitigate flood hazards [8]. NBS encompass a diverse range of interventions that aim to work harmoniously with natural processes and eco-systems, rather than against them.

Despite increasing interest in Nature-Based Solutions globally, their application within the Nigerian flood management context remains underexplored. This study addresses this research gap by focusing on the confluence region of Rivers Benue and Niger. The primary objectives are to (i) identify the flooded areas within the general confluence area (ii.) analyze temporal trends and patterns of flooding incidents (iii) assess the socio-economic activities affected by recurrent flooding (iv) delineate potential areas suitable for the implementation of NBS and (v) determine suitable NBS approach.

2. Materials and Methods

2.1. Study Area

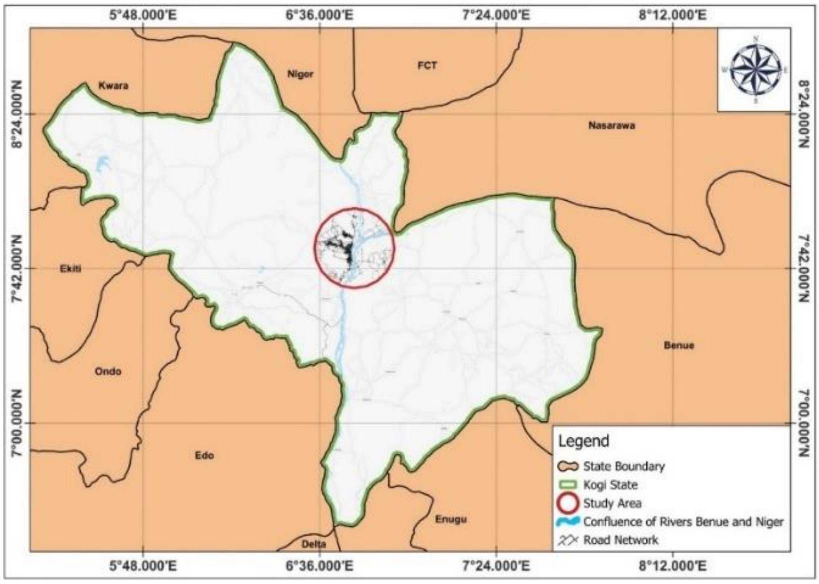

Figure 1. The Study Area in Kogi State.

The study area is part of the confluence region denoting where rivers Benue and Nigeria coincide and is located in Kogi state, Nigeria at latitude 7˚39'0"N to 7˚55'12"N and longitude 6˚35'24"E to 7˚02'24"E (Figure 1), with a total land area of 308.6 km^2. It is situated at an altitude between 45-125 metres above sea level towards the north-south and the foot of the Patti Ridge [9]. The vital highways to at least five of the country's six geopolitical zones cross at Lokoja, which is also located around 160 km south of the Federal Capital Territory, Abuja [10]. The area comprises major Local Government Areas (LGA) in the state: Kogi, Bassa, Lokoja, Okehi, Adavi and Ajaokuta Local Government Areas of Kogi State.

2.2. Data Sources

Field Observations: The primary objectives of the field observations were to validate and complement remote sensing data by gathering on-the-ground information regarding land use, land cover changes, and flood extent. Also, to assess the state of existing infrastructure, such as flood protection measures, embankments, and drainage systems.

Observations included land cover and land use assessments, identification of natural features, and documentation of infrastructure and land use changes. Data was collected using Global Positioning System handheld device. Collected data was then cross-referenced with remote sensing imagery to ensure accuracy and consistency. Data from field observations, integrated with remote sensing and GIS data, created a comprehensive dataset for subsequent analysis. This integrated approach enabled a holistic understanding of the study area's dynamics.

Satellite Imagery: The primary source of satellite imagery for this study includes publicly available LandSat datasets from the USGS Earth Resources Observation and Science Center (EROS). The Landsat satellite imageries of 2012, 2015, 2018 and 2023 data were sourced from USGS. This comprehensive timespan ensures coverage of pertinent flood events within the study area. Table 1 gives detailed information about the satellite imageries and their date of acquisition.

Table 1. *Details of Selected Imageries.*

Satellite (Sensor)	Path/Row	Date of Acquisition	Source	Cloud Cover	Composite
Landsat 7 (ETM+)	189/55	December 25, 2012	USGS	0.00	5, 4, 3
Landsat 8 (OLI/TIRS)	189/55	December 26, 2015	USGS	3.12	6, 5, 4
Landsat 8 (OLI/TIRS)	189/55	February 1, 2018	USGS	1.42	6, 5, 4
Landsat 9 (OLI/TIRS)	189/55	February 7, 2023	USGS	2.26	6, 5, 4

Digital Elevation Model (DEM): The data was obtained from the Shuttle Radar Topographic Mission with precise knowledge of the study area's topography. The spatial resolution of the DEM data is uniformly set at 30 meters, ensuring sufficient detail for hydrological modelling and terrain analysis.

Land Use Land Cover Data: The data was classified from the acquired Landsat satellite imageries. The dataset employed a hierarchical classification scheme encompassing various land cover categories, including built up, bare land, water bodies, and vegetation.

Soil Data: Soil data was obtained from SoilGrids, a digital soil mapping based on global compilation of soil profile data and environmental layers with expertise in soil characterization.

Hydrological Data: The Hydrological data, river networks, was obtained from the Geo-Referenced Infrastructure and Demographic Data for Development (GRID3). The dataset includes critical attributes such as river widths, river depths, flow direction and other hydraulic parameters.

Infrastructure Data: This data was sourced from GRID3, capturing information about roads, utilities, and other critical infrastructure.

Climate Data: This data was acquired from ClimateEngine and The Nigerian Meteorological Agency.

2.3. Method of Data Collection and Analysis

2.3.1. Method of Physical/Socio-economic Data Collection

A Stratified Random Sampling approach was adopted to select specific observation points for field data collection within the study area. The wards of the study area served as the sample frame and settlements within each ward were considered the sample layer. From the reconnaissance survey and data gotten from GRID^3, 72 settlements were established. The sample frame for this study consists of the wards within the study area. The settlements were designated as the sample layer. The sample size for the study was calculated and determined based on the Taro formula [11] and the ArcGIS sampling design tool [12] for determination of the sample size.

The ArcGIS sampling design tool provided a systematic and objective approach to random sampling within each ward.

2.3.2. Field Observations

The field observations leveraged the sample size generated from the stratified random sampling method to not only address the study's primary objectives but also to provide essential reference points for the validation of land use and land cover analysis. The systematic selection of 61 settlements, determined through the stratified random sampling process, ensures a representative coverage of the study area. Table 2 shows how the settlements were selected from the various wards in the study area.

Table 2. Selected sample settlements for the study.

S/N	Local Government Area	Ward	Settlements	Sample Settlements
1	Bassa	Kpata	19	$\frac{19}{72} \times 61 = 16$
		Mzum	7	$\frac{7}{72} \times 61 = 6$
2	Kogi	Irenodo Riverine	16	$\frac{16}{72} \times 61 = 13$
		Akpasu	6	$\frac{6}{72} \times 61 = 5$
3	Lokoja	Lokoja A	3	$\frac{3}{72} \times 61 = 3$
		Lokoja B	2	$\frac{2}{72} \times 61 = 2$
		Lokoja C	1	$\frac{1}{72} \times 61 = 1$
		Lokoja D	1	$\frac{1}{72} \times 61 = 1$
		Lokoja E	4	$\frac{4}{72} \times 61 = 3$
		Oworo	3	$\frac{3}{72} \times 61 = 3$
4	Ajaokuta	Geregu	10	$\frac{10}{72} \times 61 = 8$
			72	61

2.3.3. Satellite Imagery Processing and Analysis

The processing and analysis of this data entailed the following key steps:

i. Image Pre-processing: Pre-processing included activities such as atmospheric correction and cloud removal to ensure data quality.
ii. Image Classification: Remote sensing techniques included supervised classification to classify land cover types, delineate flood extents and monitor land cover changes over time.
iii. Time-Series Analysis: Time-series analysis of satellite imagery facilitated the examination of long-term trends and the identification of recurring flood events.

2.3.4. Hydrological Modelling

The following outlines the key steps in this process:

i. Data Preparation: Hydrological data, including river discharge, streamflow, and rainfall records, were processed and formatted for input into the models.
ii. HEC-HMS Modelling: The Hydrologic Engineering Center-Hydrologic Modelling System (HEC-HMS) was utilized to simulate rainfall-runoff processes, facilitating the comprehension of river flow and precipitation runoff within the watershed.
iii. HEC-RAS Modelling: The Hydrologic Engineering Center-River Analysis System (HEC-RAS) models' hydraulic behaviour and flood inundation in river systems, providing information into flood extents and depths.

2.3.5. Analysis

The GIS-based analysis encompassed:

i. Identification of the flooded areas: This involved identifying the flooded areas within the general confluence area, a comprehensive methodology integrating image classification and hydrological modelling was employed. Initially, high-resolution satellite imagery from four specific years—2012, 2015, 2018, and 2023—captured by Landsat 7, 8, and 9 were obtained. This imagery was processed using image classification techniques to distinguish flooded areas from non-flooded ones. Additionally, a Digital Elevation Model (DEM) was utilized to assess terrain characteristics, aiding in identifying low-lying regions prone to flooding. Hydrological data was incorporated into the analysis to understand the dynamics of water movement in the area. Climate data provided weather patterns and potential contributing factors to flooding events. The integrated dataset was then imported into ArcGIS for spatial analysis. Furthermore, hydrological modelling tools, HEC-RAS and HEC-HMS was employed to simulate and analyze the flow of water in the confluence area. The results obtained from these analyses contributed to a detailed understanding of the flooded areas.

ii. Analysis of flooding incidents: This section focused on analyzing the temporal trends and patterns of flooding incidents from 2012 to 2023. Google Earth Engine (GEE) wase used to process satellite imagery for the selected years: 2012, 2015, 2018, and 2023 employing a standardized flood detection workflow that utilizes spectral water indices and threshold-based classification. The Modified Normalized Difference Water Index (MNDWI) was applied to identify surface water features, with a threshold value of 0.3 used to delineate flooded areas. Pre-processing steps included cloud masking and atmospheric correction to enhance data reliability. Flood extents were extracted for the selected years and results were validated against field observations and high-resolution satellite images. This approach provided a consistent framework for comparing temporal trends in flood extent across the study area, using imagery with a spatial resolution of 30 meters.

iii. Assessment of socio-economic activities: The primary data source for this objective was the information collected through systematic field surveys. A comprehensive checklist had been designed to guide the field observations. Settlement-specific data was collected, including information on flood control structures, drainage systems, public infrastructure, and the primary economic activities of the residents.

iv. Determination of areas suitable for NBS: The primary datasets for this analysis include land use/land cover data, soil data, topographical data and hydrological data. These datasets were collected and integrated to develop an understanding of the environmental conditions in the study area. In ArcGIS, a suitability analysis was conducted, considering factors such as land cover types, soil characteristics, topography, hydrological conditions, and climatic factors. Weightage were assigned to each criteria based on its relevance to NBS implementation. In this regard, the standardized maps of the selected criteria were combined using the raster calculator tool in ArcGIS. The determined weights were multiplied by the respective weight to generate the final target area index ranging from 1 to 5. The equation as entered in the raster calculator tool is displayed below.

$$\text{Target Area Index} = (\text{Land cover} * w3) + (\text{Distance to Drainage Network} * w3) + (\text{Soil texture} * w5) + (\text{Elevation} * w2) + (\text{slope} * w1) \quad (1)$$

Where w is the determined weight of the criteria.

v. Suitable NBS approach: Various NBS options were identified based on their applicability to the study area's environmental and socio-economic context. These options include green infrastructure, reforestation, wetland restoration, and other nature-based interventions. A target area structure was developed to break down the decision criteria facilitating a structured assessment. Expert opinions were incorporated in the identification process to ensure a robust evaluation when indicating the most suitable approach for the study area.

3. Results

3.1. Identification of Flooded Areas

HEC-HMS was employed to conduct a comprehensive spatial analysis of the basin. This included DEM pre-processing and the delineation of streams and subbasins. The DEM pre-processing involved correcting elevation data to ensure accuracy in the representation of the terrain. Subsequently, the stream and sub-basin delineation identified the natural flow paths and divided the basin into smaller, manageable units for detailed analysis.

In the HEC-RAS model, the basin is conceptually represented as a network of interconnected sub-basins, each linked by channel pathways. This conceptual model, DEM of the study area and the hydrologic elements, is presented in Figures 2 and 3 respectively, where the spatial arrangement and the hydrological connectivity of the sub-basins are illustrated. The model was developed from the HEC-HMS environment.

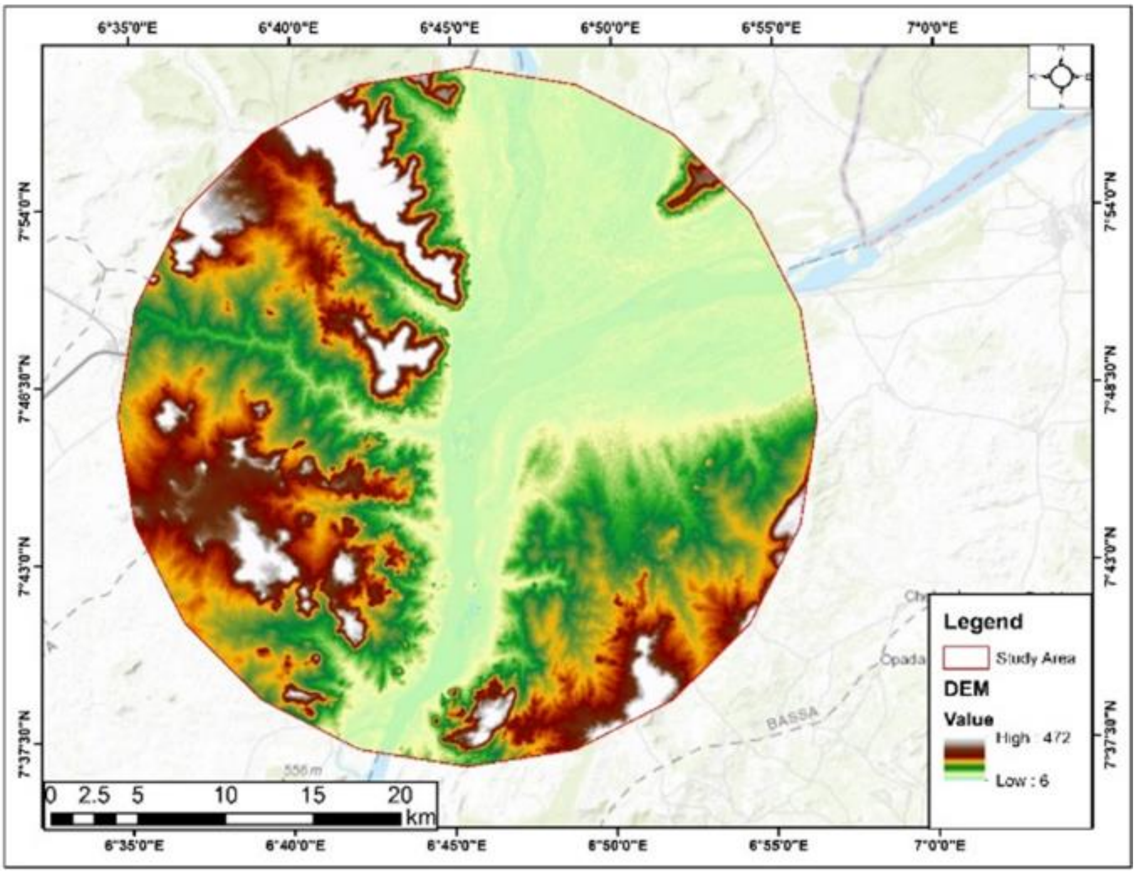

Figure 2. DEM of the Study Area.

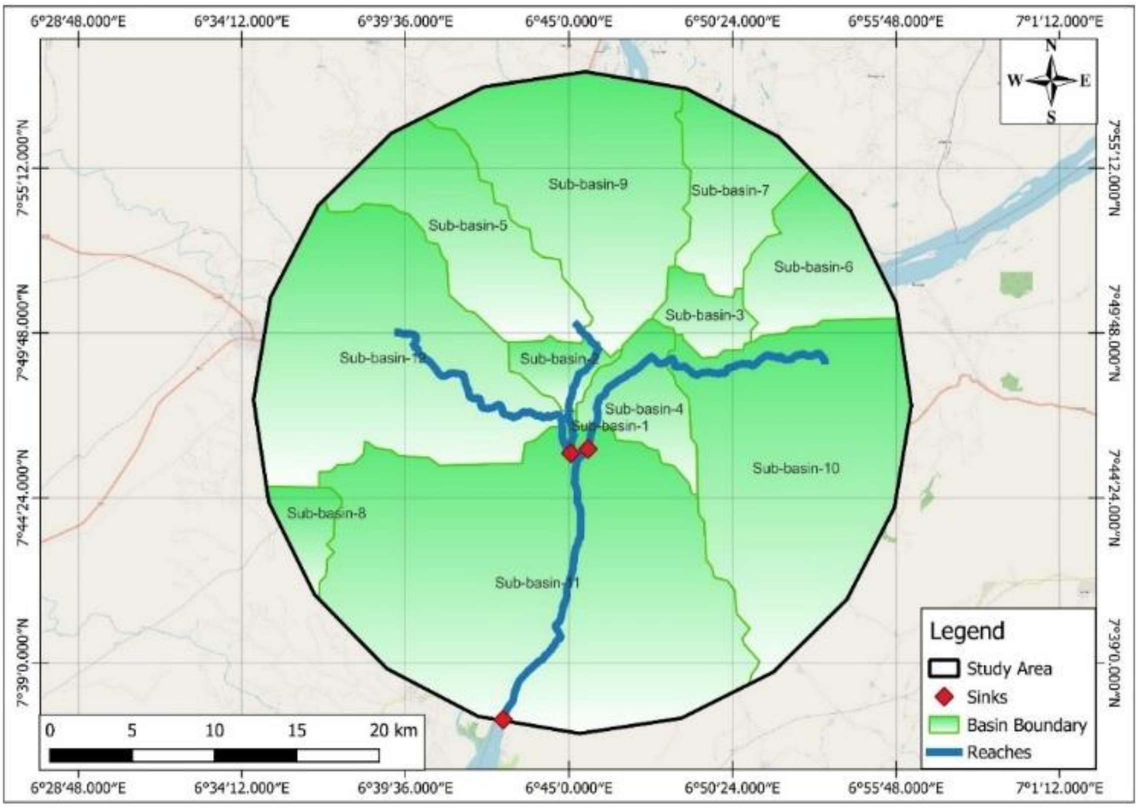

Figure 3. Hydrologic Elements in the HEC-HMS Model.

Land cover data, which significantly influences runoff and infiltration rates, were also prepared and integrated into the model as input data. This preparation involved classifying the land cover types and their respective hydrological properties. The spatial distribution of different land cover types, such as waterbody, vegetation, builtup and bareland, was mapped and is presented in Figures 4, 5, 6 and 7. These figures provide a detailed visualization of the land cover variations across the basin.

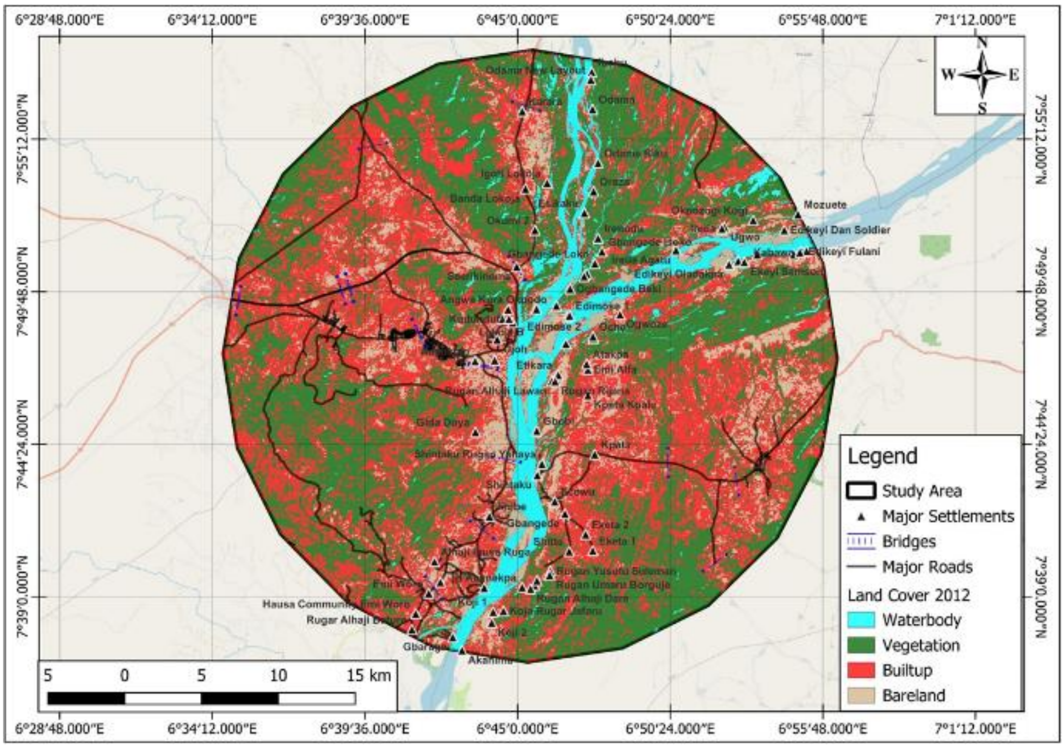

Figure 4. Land Use/ Land Cover (2012).

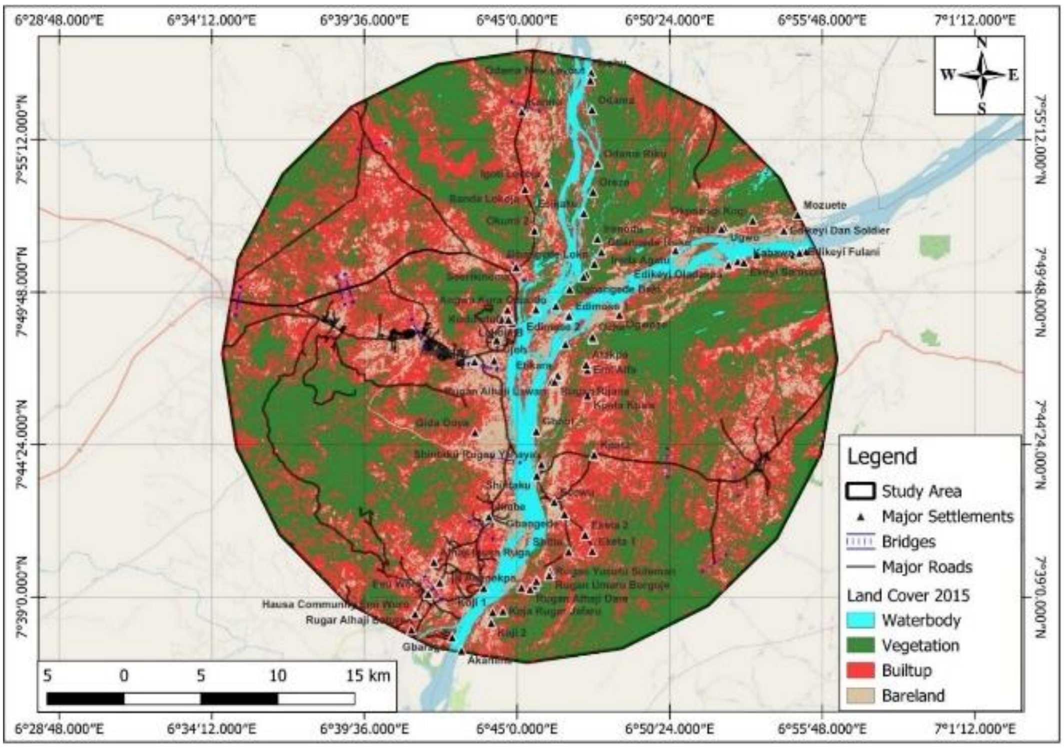

Figure 5. Land Use/ Land Cover (2015).

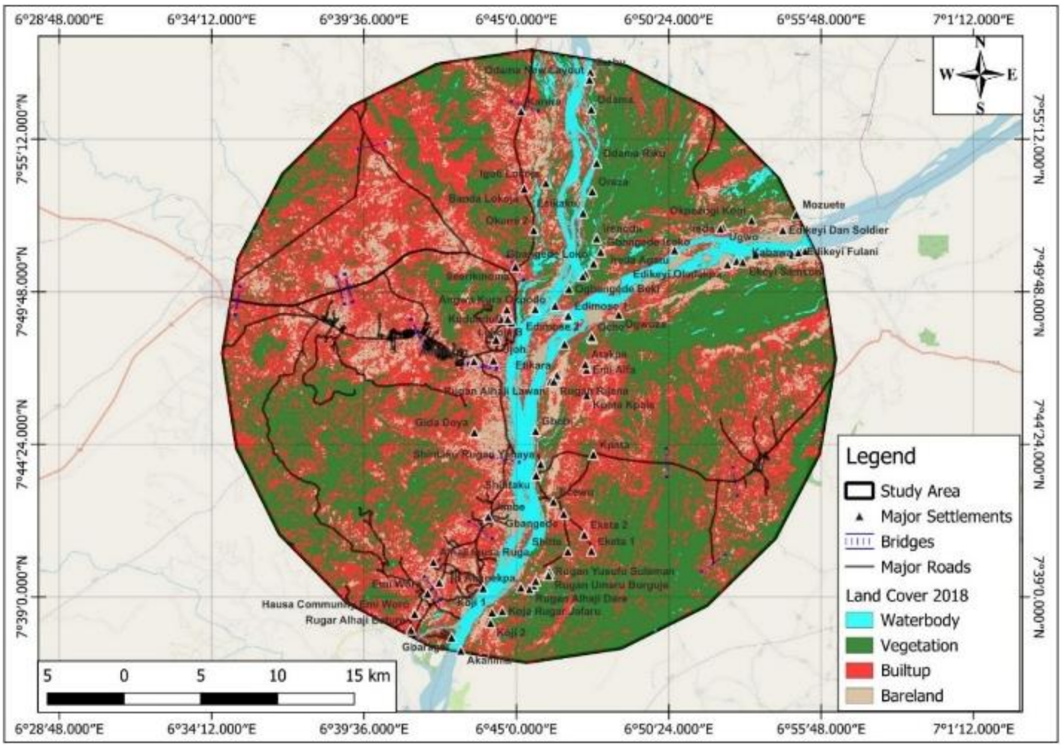

Figure 6. Land Use/ Land Cover (2018).

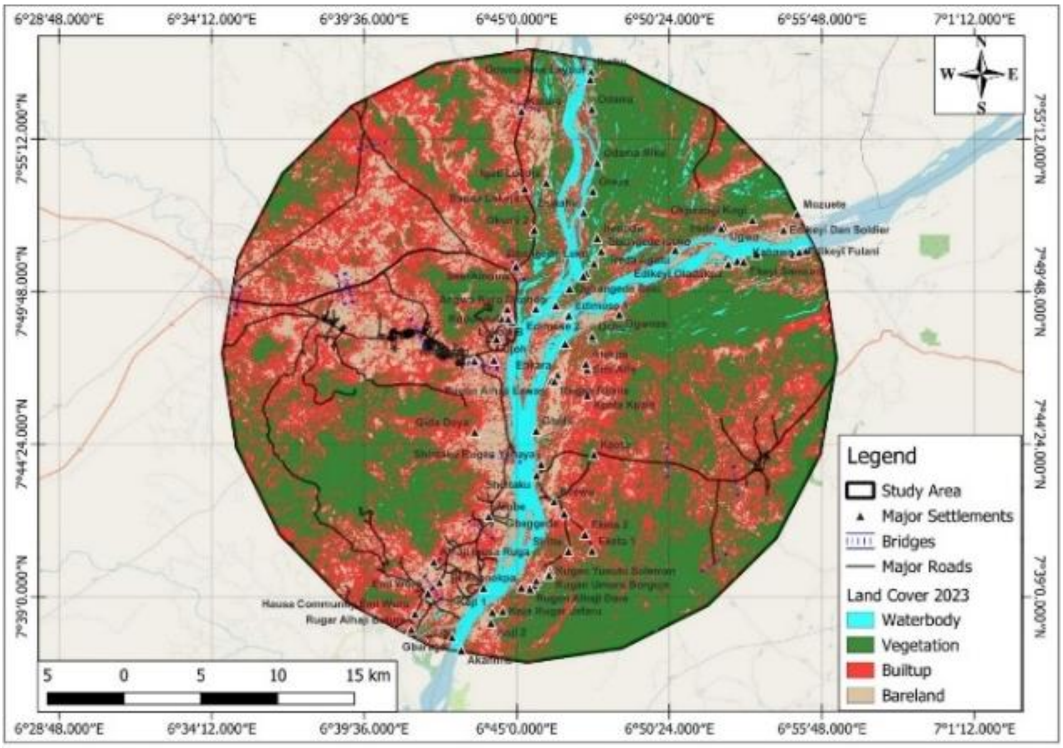

Figure 7. Land Use/ Land Cover (2023).

HEC-HMS was used to simulate the precipitation-runoff processes in the study area. This model helped in understanding how rainfall translates into river discharge, providing insights into the potential volume of water entering the river system during different rainfall events. This is presented in Figure 8. HEC-RAS was employed to simulate the hydraulics of water flow within the river channels. Reaches were delineated using the GIS tool in HEC-HMS.

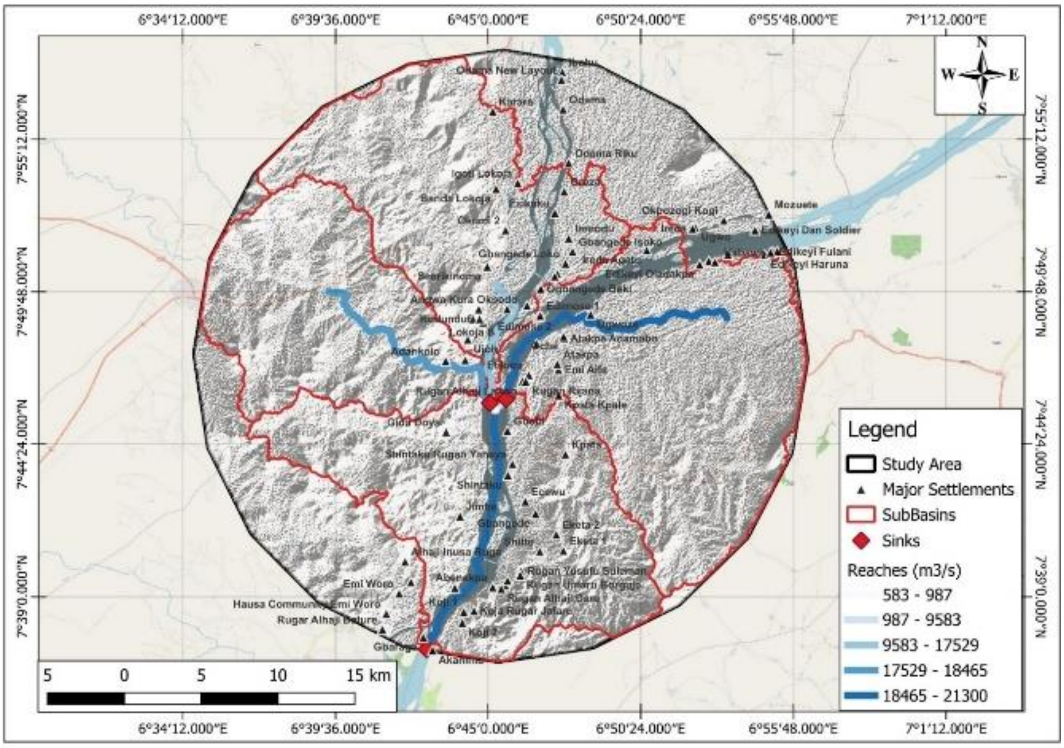

Figure 8. HEC-HMS Model Setup.

The reaches as shown in the legend of Figure 8, represent specific ranges of hydrological measurements within the river system.

Each reach connects different sub-basins. When rainfall occurs, water collects in various sub-basins and then flows into the reaches. The width of a reach on the map represents the speed of the water flow. The steps involved in HEC-RAS modelling included Creating Geometry, Defining Flow Boundaries and Running Simulations. The output of these steps is shown in Figure 9.

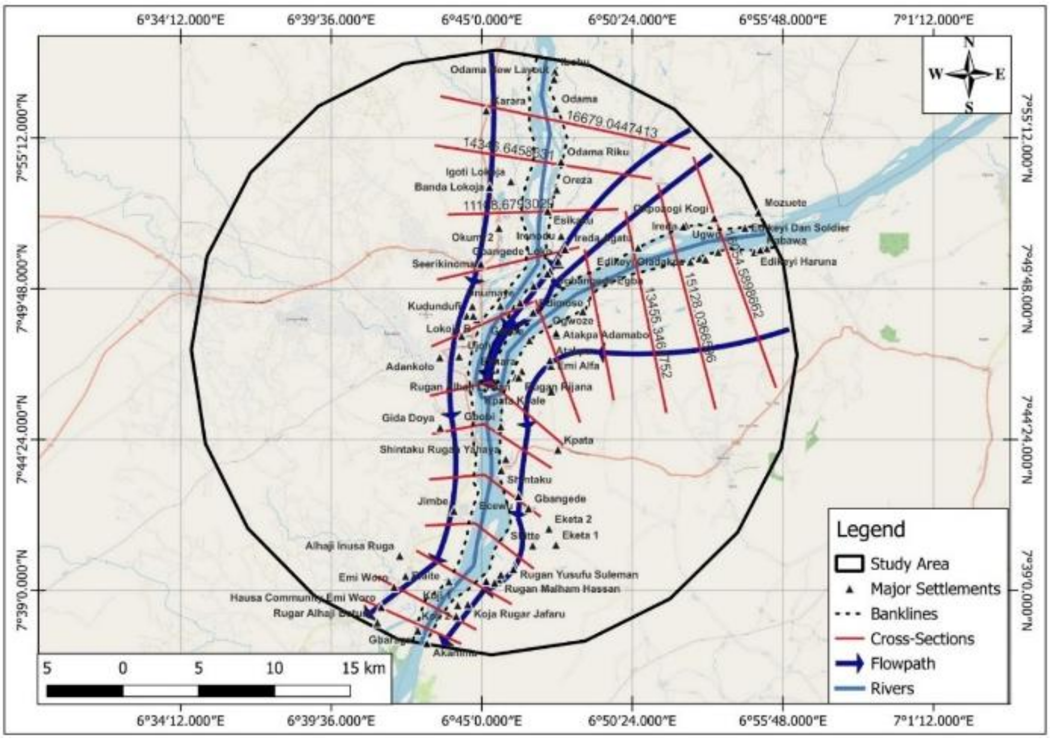

Figure 9. Geometric Representation Setup.

The Curve Number (CN) grid maps were generated using the land cover data. Calculated curve numbers are used to model surface runoff of the area. The spatial distributions of calculated curve number (Figure 10) are mapped for each pixel in the raster data format.

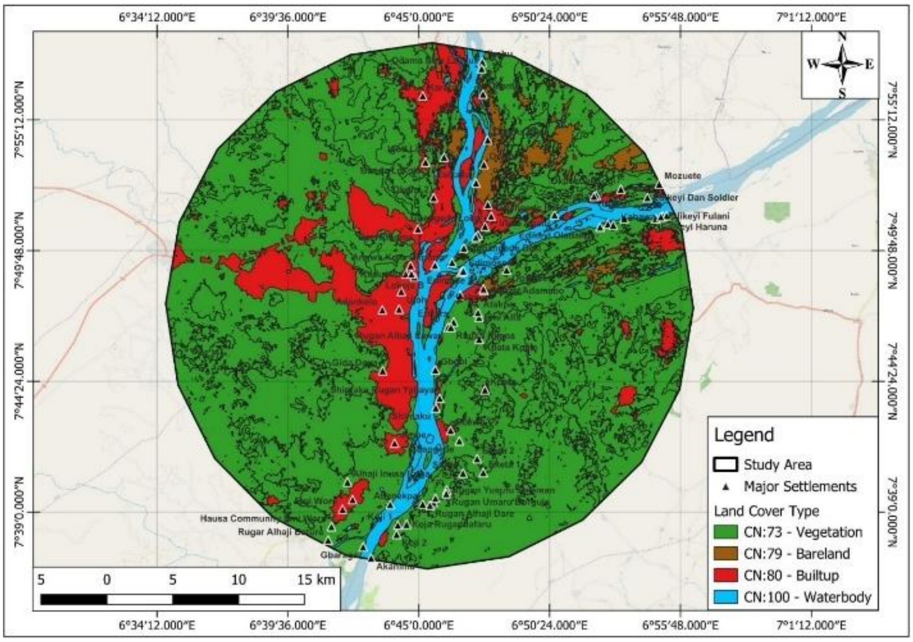

Figure 10*. Curve Number Land Cover Map.*

3.2. Spatial Distribution of Flooded Areas

Using the results from HEC-RAS and HEC-HMS, a flood map was generated to illustrate the spatial distribution of flooded areas. Figure 11 provides a visual representation of the extent of flooding under a modelled flood scenario, identifying critical areas prone to inundation.

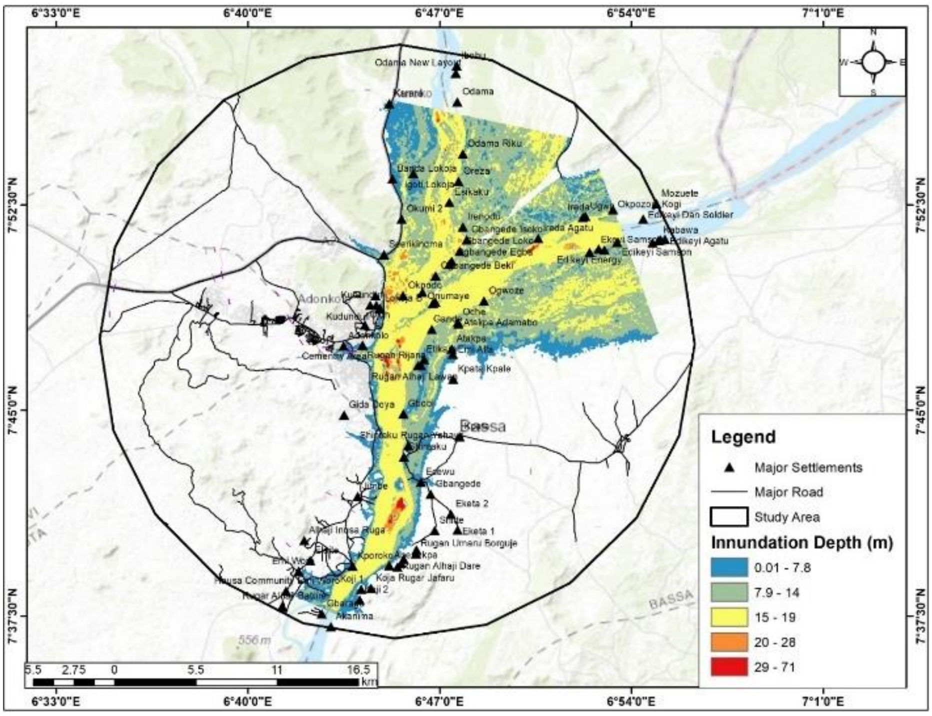

Figure 11*. Flood Inundation Map of the Study Area.*

To provide a comprehensive understanding of the flood scenario, the inundation depths were categorized into five ranges: 0.001 - 7.8 meters, 7.9 - 14 meters, 15 - 19 meters, 20 - 28 meters, and greater than 29 meters. To further quantify the effects of the flood, the areas covered by each depth of inundation were calculated.

Table 3. Areas Covered by the Different Inundation Depths.

Inundation Depth (meters)	Area (square kilometres)	Percentage (%)
0.001 - 7.8	51.40377	16.65
7.9 - 14	130.8301	42.39
15 - 19	120.8332	39.15
20 - 28	4.781401	1.55
29 - 71	0.795442	0.26
	308.643913	100

3.3. Analysing Temporal Trend and Pattern of Flooding Incidents

This objective focused on analysing the temporal trends and patterns of flooding incidents in the general confluence area of Rivers Benue and Niger in 2012, 2015, 2018 and 2023 using Google Earth Engine (GEE). Figure 12 shows the results of the distribution of flooded areas and the extent of the flooded area, measured in square kilometres.

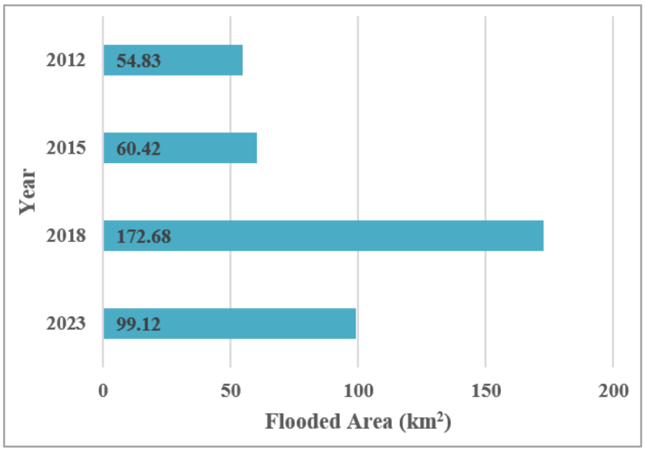

Figure 12. Total flooded areas by year (2012-2023).

Figures 13, 14, 15 and 16 show the flooded areas by the years 2012, 2015, 2018 and 2023 respectively.

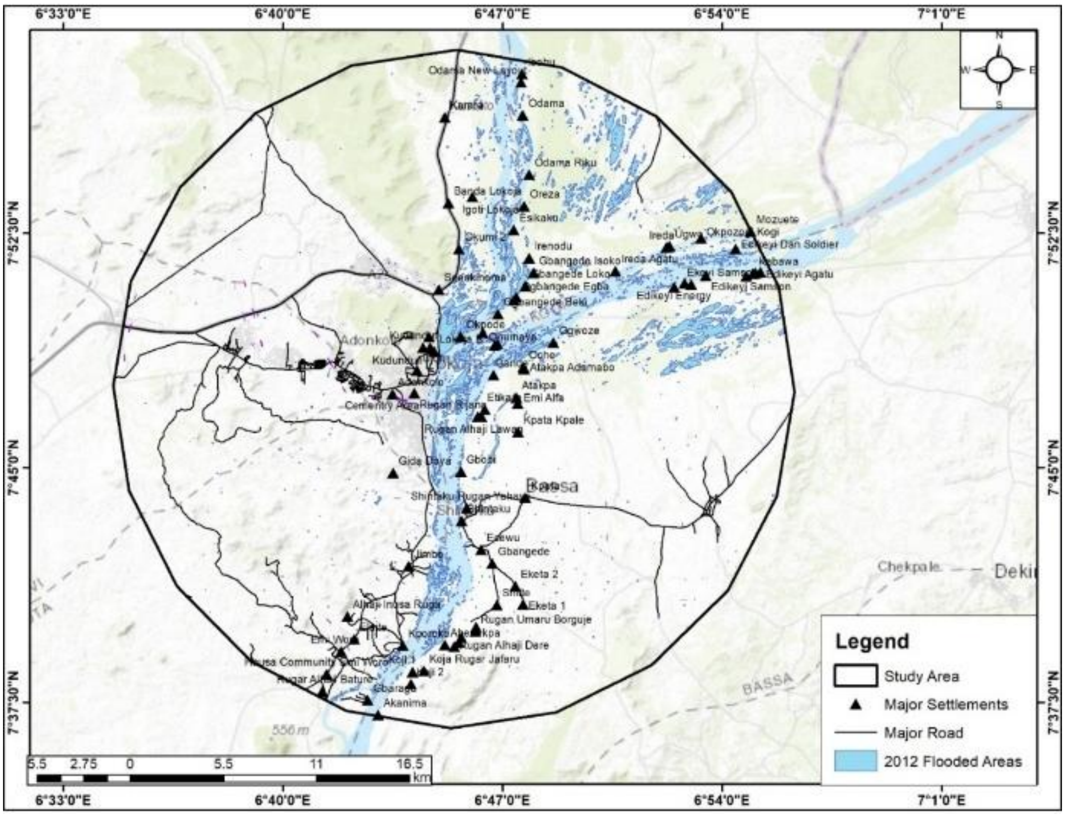

Figure 13. 2012 Flooded Areas.

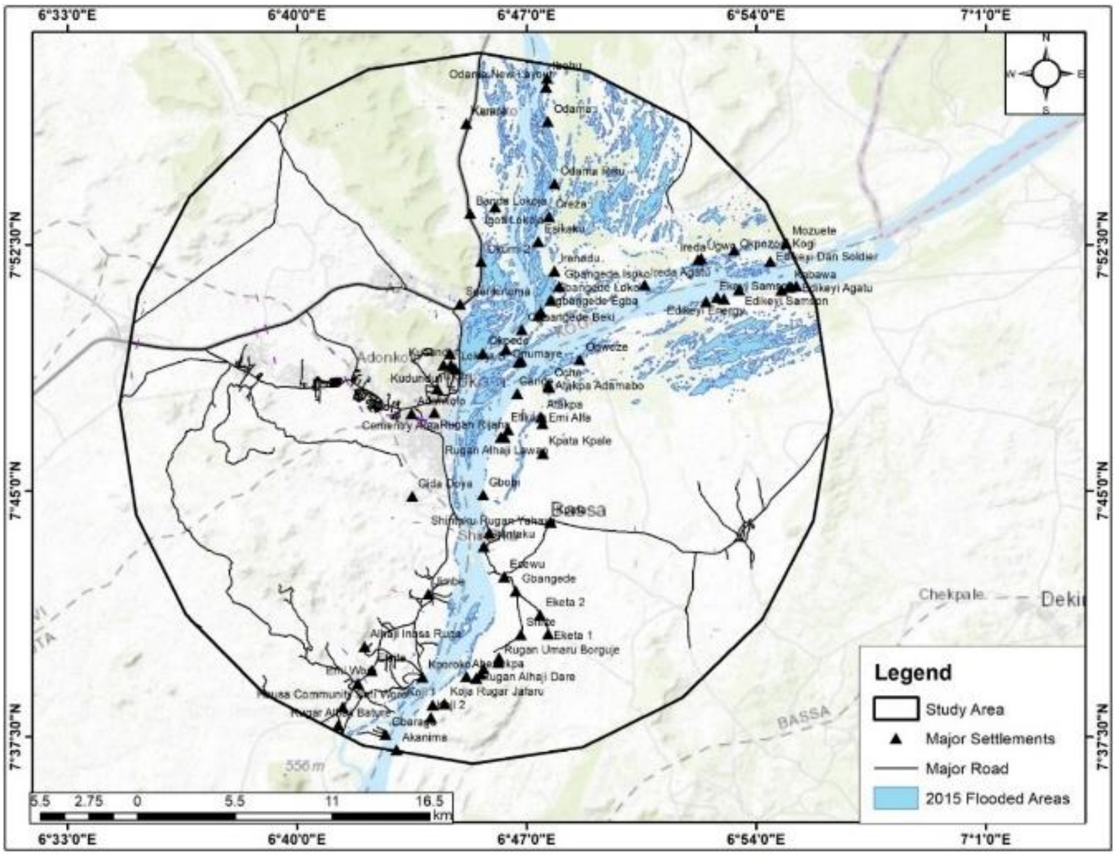

Figure 14. 2015 Flooded Areas.

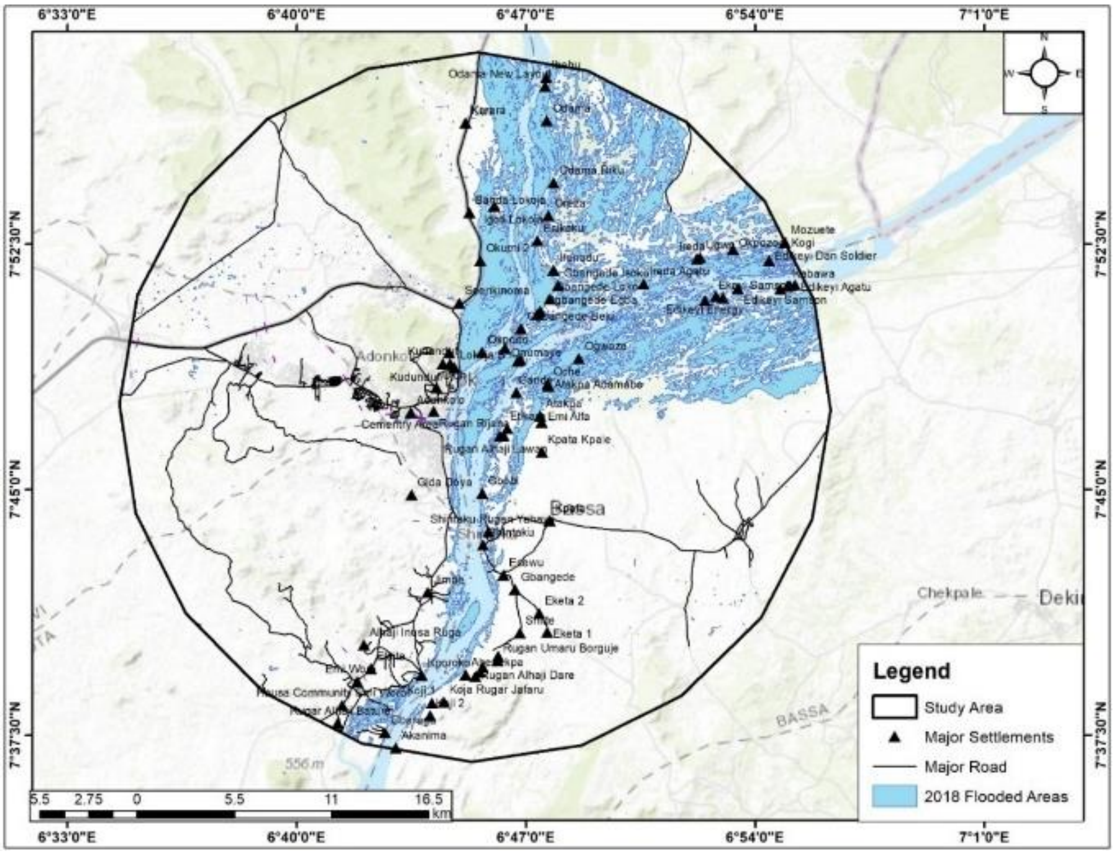

Figure 15. 2018 Flooded Areas.

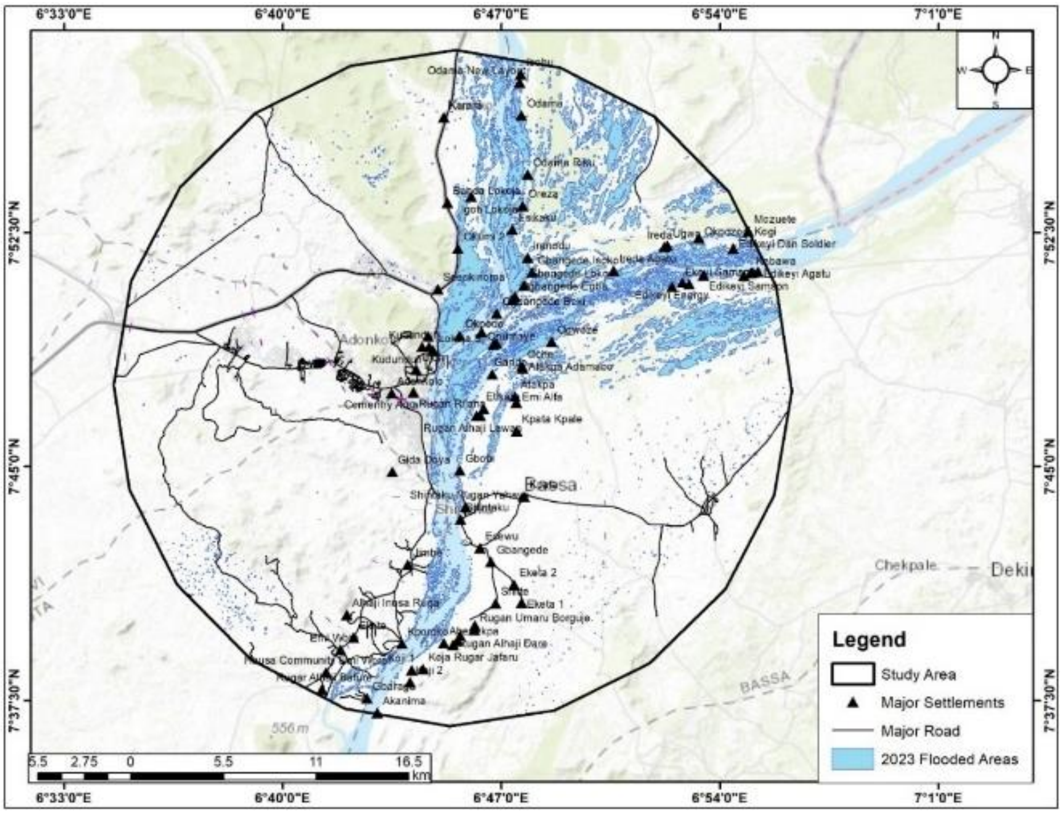

Figure 16. 2023 Flooded Areas.

3.4. Assessing the Socio-Economic Activities Influencing Recurrent Flooding

To assess the socio-economic effects of recurrent flooding, field surveys were conducted across various settlements. These surveys captured data on land use, primary economic activities, infrastructure, and the effects of flooding on livelihoods. The collected data were analysed and presented through various charts to visualize the socio-economic landscape of the region. Due to security concerns, some settlements could not be visited.

Distribution of Settlements by Primary Economic Activity

The distribution of primary economic activities across settlements indicates the economic diversity in the region. Most settlements rely on agriculture, with farming and fishing being predominant. Some areas have mixed residential and commercial activities, especially those closer to the settlements as shown in Figure 17.

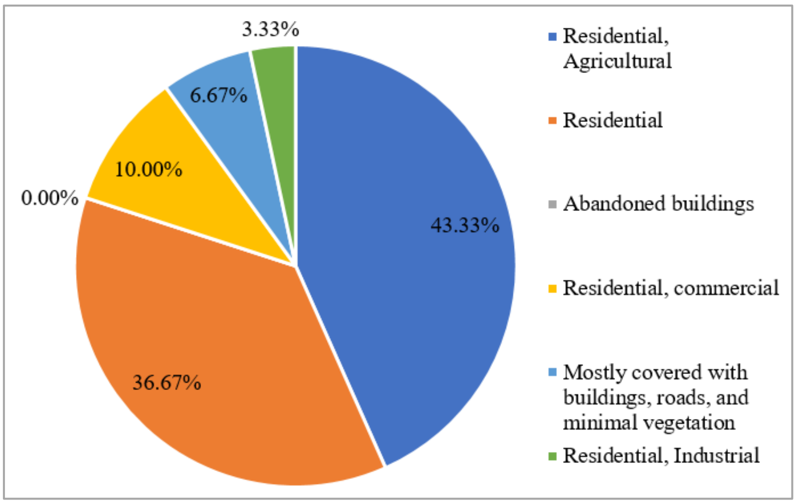

Figure 17. Distribution of Settlements by Land Use Type.

Effects of Flooding on Livelihoods

Flooding severely affects livelihoods by damaging crops, disrupting market access and causing temporary or permanent displacement. Figure 18 visualizes the various effects of flooding on the surveyed settlements.

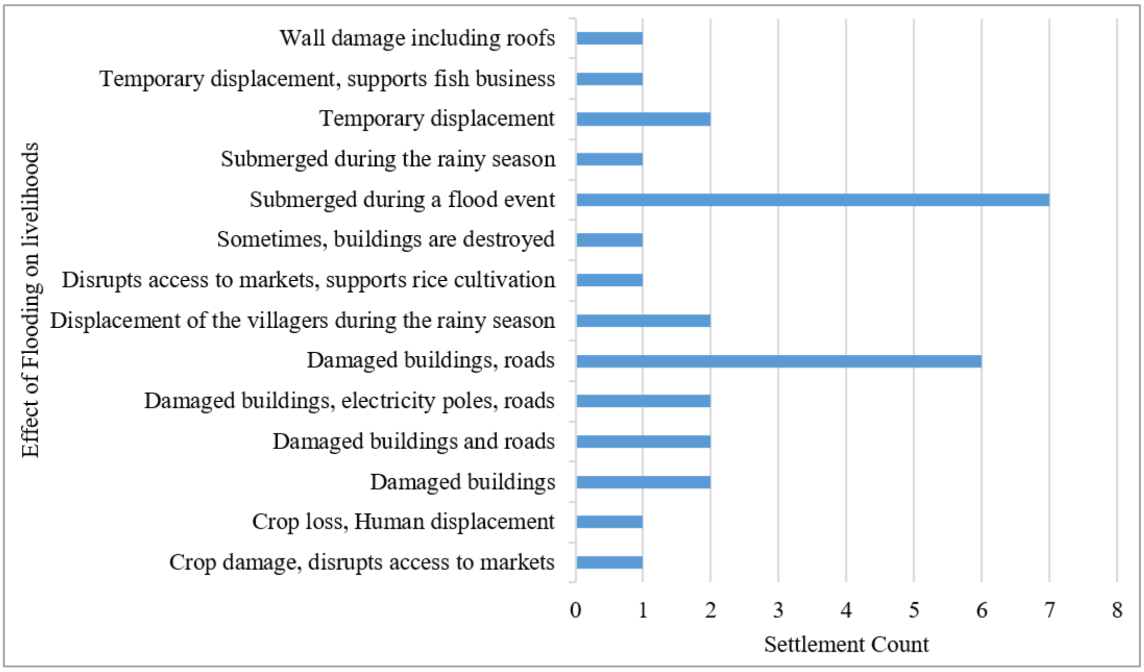

Figure 18. *Effects of Flooding on Livelihoods*

Condition of Drainage Systems

The effectiveness of drainage systems is important in managing floodwaters and the condition of the drainage systems is shown in the chart displayed in Figure 19. The survey assessed the condition of drainage systems in the settlements, identifying whether they were open, clogged, or non-existent.

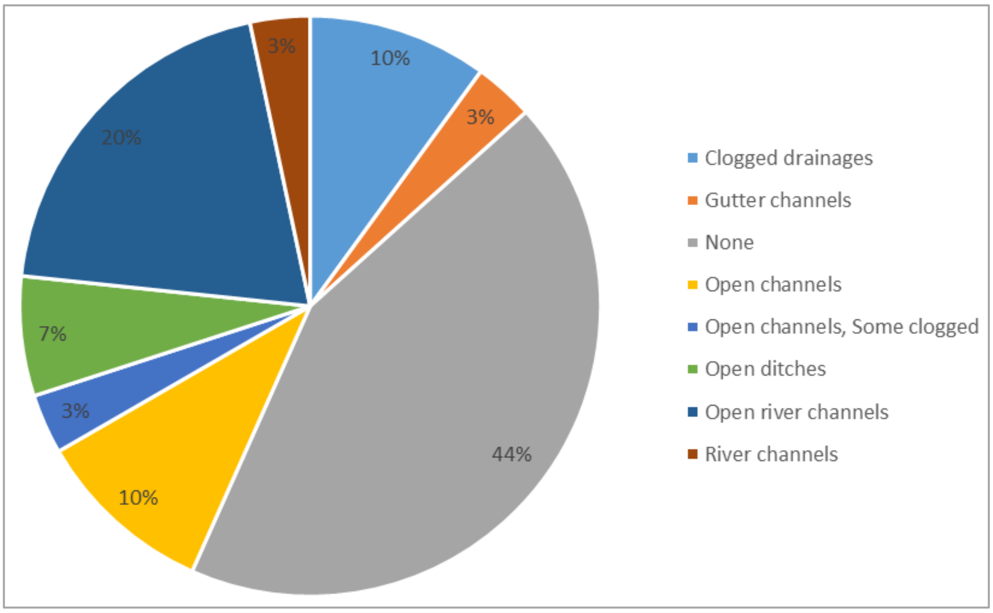

Figure 19. *Condition of Drainage Systems.*

3.5. Delineating Potential Areas Suitable for the Implementation of NBS

3.5.1. Standardization of Criteria

The criteria used in identifying target areas for NBS implementation were based on the spatial elements and factors that are subject to surface runoffs and inundation. With this, criteria or factors mentioned in the existing literature on surface runoffs and inundation were used. These studies basically focus on the physical and meteorological characteristics that cause changes in runoff and inundation. Considering these studies, five criteria were used. These five criteria included the elevation (DEM), slope, land use land cover, distance to rivers and soil texture.

Classified criteria values for NBS target areas on flood management, reflecting the professional opinions of flood management experts, are shown in Table 4. The five selected criteria were used in calculating the target area index for the NBS implementation. The results were further categorised into five classes, namely target area type 1, target area type 2, target area type 3, target area type 4 and target area type 5.

Table 4. *Classified criteria values for NBS target areas on flood management professional's opinion.*

ID	Number of Thematic layers	Classes	Weight	Rating
1	Slope	0 - 3°	31	5
		4 - 7°		4
		8 - 14°		3
		15 - 22°		2
		23 - 55°		1
2	Elevation	-38 - 76m	25	5
		76 - 136m		4
		136 - 204m		3
		204 - 300m		2
		300 - 531m		1
3	land use and land cover	Waterbody	19	3
		Vegetation		1
		Built-up		4
		Bareland		2
4	Distance to Rivers	0 - 3752m	19	5
		3752 - 8030m		4
		8030 - 12758m		3
		12759 - 19137m		2
5	Soil texture	Clayey soil	6	5
		Gravelly clay soil		4
		Loamy Soil		2

3.5.2. Determining the Most Suitable NBS Approach

Applying different NBS measures for different locations in the study area was also in line with a study [13] which also point out that different flood management measures are required for different locations in a city. Figures 20 and 21 illustrates target area types and the identification and implementation of Nature-Based Solutions (NBS) within the study area respectively. It highlights various target areas categorized by types of NBS.

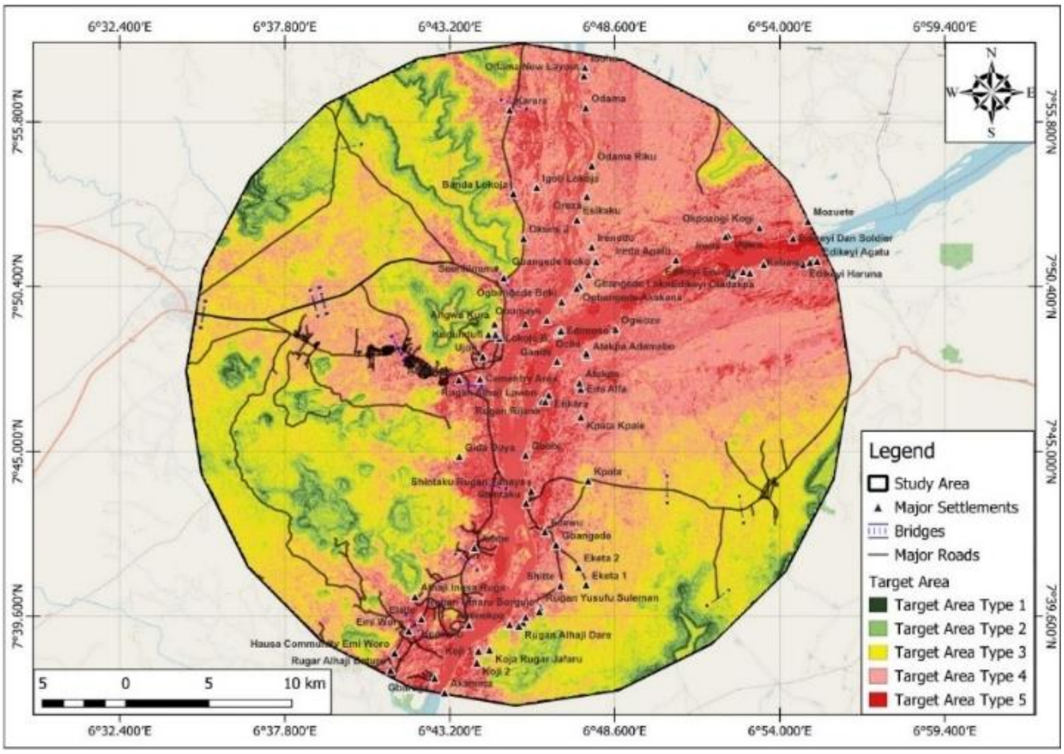

Figure 20. NBS Target Areas.

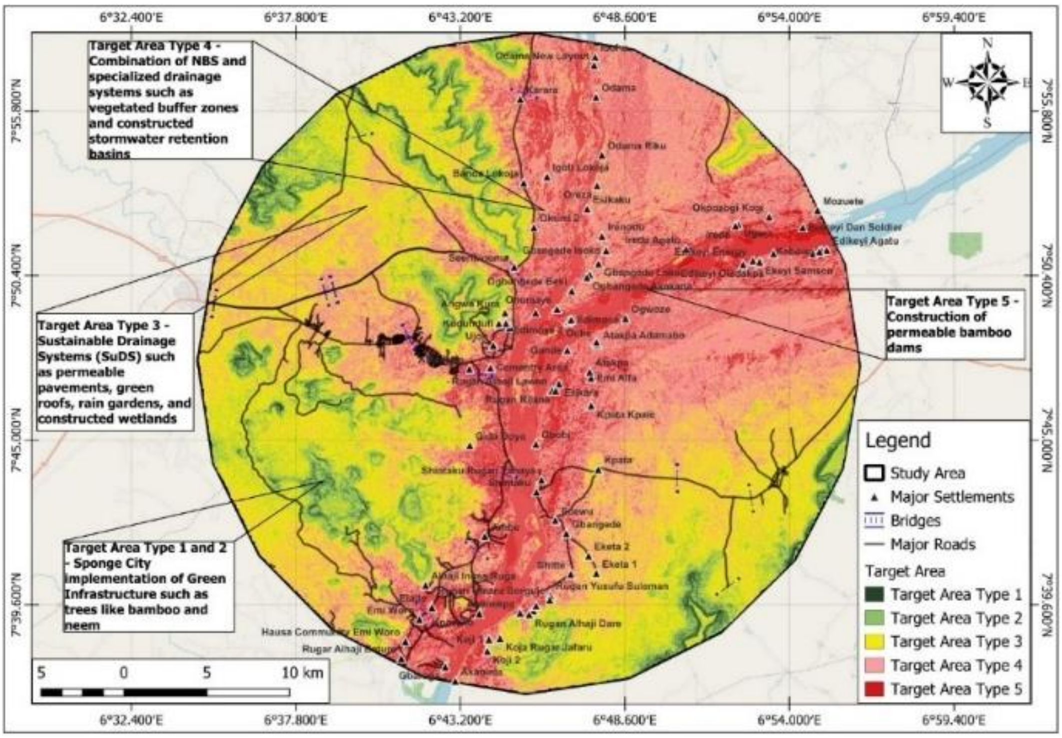

Figure 21. Identification of Appropriate NBS.

4. Discussion

The severe inundation depths identified (Figure 11), particularly in areas near the riverbanks, indicate high susceptibility to flooding, aligning with the findings of [14] who also noted significant flooding events in Lokoja. Their findings emphasize the importance of integrating GIS and hydrological models to enhance flood forecasting accuracy and emergency preparedness strategies, aligning closely with the methodology and outcomes of this study. Additionally, the identification of inundation depths underscores the urgency of implementing sustainable flood management practices and infrastructure improvements to protect lives and property The detailed visualization of inundation depths facilitates the precise identification of high-risk areas, thereby enhancing targeted flood mitigation strategies and emergency response plans. For instance [15] highlight the significance of accurate flood mapping in bolstering community resilience and infrastructure planning, which aligns well with the findings of this study. Additionally, understanding the spatial distribution of flood depths can inform the construction of flood defences in the most vulnerable zones, thereby potentially mitigating future flood impacts. A study [16] suggest that past flood inundation maps in Lokoja have been overestimated, indicating that the actual effects may vary, potentially challenging the results presented in this map.

The year 2012 saw a relatively low flooded area of 54.83 km², which slightly increased to 60.42 km² in 2015. A notable spike occurred in 2018, with the flooded area dramatically rising to 172.68 km², suggesting a period of intensified flooding possibly due to increased rainfall or other hydrological changes. By 2023, the flooded area had decreased to 99.12 km², indicating a reduction from the 2018 peak but still higher than the earlier years of 2012 and 2015. The significant spike in flooding in 2018 aligns with the report from the National Emergency Management Agency [17], highlighting the heavy rains as the cause of the severe floods, disrupting the livelihoods, populations, and damage to infrastructures. The reduction in the flooded area observed in 2023, compared to the peak in 2018, indicates potential improvements in flood management and early warning systems. The government intervention on raised walls around the perimeter of parts of the rivers may have contributed to mitigating the adverse effects of floods in this region. This alignment with the 2023 data suggests that ongoing efforts in flood preparedness and response strategies may be yielding beneficial outcomes. Contrarily, some studies argue that observed reductions in flooding may not solely be attributed to improved management but could also be due to natural hydrological variability, thereby necessitating continuous and rigorous scientific investigation [18].

Several studies align with the surveyed results on the settlements. A study [19] examined the perceived effects of flooding on lives and properties in Lokoja. They found that flooding causes damage to household properties, vehicles, buildings, and farmlands, and even results in fatalities. This aligns with the findings that residential areas suffer significant damage and displacement. Additionally, research on the 2022 flooding in Lokoja revealed that business activities were severely affected, further emphasizing the economic toll of recurrent flooding [20]. While most studies support the findings, there are some nuances and additional perspectives. Some studies suggest that the level of preparedness among residents can mitigate the adverse effects of flooding. Another study assessing flood vulnerability in Lokoja highlighted that while certain areas are highly vulnerable to flooding, others have moderate to low vulnerability [21]. This suggests that the effect of flooding is not uniform across all areas, and targeted interventions could be more effective in mitigating flood risks.

In Target Area Type 1 and 2, this area could benefit from Green Infrastructure like urban green spaces that absorb rainwater and reduce runoff. This comes from a study [22] on the potentials for sponge city implementation in Sub-Saharan Africa, where cities like Hawassa (Ethiopia), Beira (Mozambique), Kigali (Rwanda), Ouagadougou (Burkina Faso), and Cotonou (Benin) are examined in detail to enhance flood resilience. The Sponge City concept is a holistic water management approach designed to mitigate flooding, enhance water quality, and improve resilience by integrating green infrastructure with traditional drainage systems.

For Target Area Type 3, this area is Suitable for Sustainable Drainage Systems (SuDS) and offers an alternative approach to conventional drainage practices in line with the ideals of sustainable development. This is in line with the study [23] on modelling and assessment of sustainable urban drainage systems in dense precarious settlements subject to flash floods. In the context of the study area, SuDS can be designed to slow down the flow of water, allowing more time for the rivers to carry away floodwaters and reducing flood risks. The implementation of SuDS in this area could include features such as permeable pavements, green roofs, rain gardens, and constructed wetlands.

For Target Area Type 4, these zones are ideal for the combination of NBS and specialized drainage systems due to the heavy human activity in this area [24]. Establishing vegetated buffer zones along the river banks can help filter pollutants and reduce erosion. These zones can also slow down runoff, allowing more water to infiltrate the soil.

For Target Area Type 5, this represents areas for construction of permeable bamboo dams to reduce the speed of water flow and encourage infiltration. Drawing on the successful case study of bamboo check dams in Spain [25], which demonstrated their effectiveness in controlling soil erosion and managing water flow, similar bamboo dams can be constructed in the study area. The use of locally available bamboo would not only be cost-effective but also environmentally sustainable, enhancing the region's flood resilience by allowing more water to percolate into the ground, thereby reducing surface runoff and mitigating flood risks.

5. Conclusions

The study concludes that Nature-Based Solutions offer a viable and sustainable approach to flood mitigation in the confluence area of Rivers Benue and Niger. Unlike conventional engineering-based solutions, which often require significant financial investment and continuous maintenance, NBS work with natural processes to enhance flood resilience while providing additional environmental benefits such as improved water quality, biodiversity conservation, and climate regulation.

The application of GIS and RS allowed for a detailed spatial analysis, which demonstrated the feasibility of implementing NBS in strategic locations. The findings suggest that integrating NBS with existing flood management approaches can enhance the region's ability to cope with recurrent flooding. However, the success of NBS depends on several factors, including policy support, financial investment, technical expertise, and active community involvement.

However, the effectiveness of NBS depends on enabling conditions, including institutional support, adequate funding, technical expertise, and community involvement. Strengthening governance frameworks, aligning land-use planning with flood risk data, and embedding NBS into national adaptation strategies are essential next steps. Future research should focus on long-term monitoring of implemented solutions and the development of context-specific guidelines to inform policy and large-scale adoption.

Abbreviations

LULC	Land Use Land Cover
USGS	United States Geological Survey
SuDS	Suitable for Sustainable Drainage Systems

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Conflicts of Interest

The authors declare no conflicts of interest.

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