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Research article

GEOSPATIAL ASSESSMENT OF THE IMPACT OF LAND USE/LAND COVER DYNAMICS ON FLOODING IN MEME RIVER WATERSHED, LOKOJA, NIGERIA.

Johnson N.G[1*], Nnachi.I N[2], Achegbulu E. O[2] and John-Nwagwu, H.O[2]
[1]Department of Geographic Information Science, African Regional Institute for Geospatial Information Science and Technology, Ile-Ife, Osun state, Nigeria
[2]Department of Geography, Federal University, Lokoja, Kogi State, Nigeria
[*]Corresponding Author's E-mail: ngozi.johnson@afrigist.org

ABSTRACT

Land Use and Land Cover (LULC) changes is seen as one of the factors that influence hydrological processes, often intensifying flood occurrences, particularly in rapidly urbanizing tropical watersheds. This study examined the Impact of Land Use/Land Cover Dynamics on Flooding in Meme River Watershed, Lokoja, Nigeria. An integrated approach combining multi-temporal remote sensing, Geographic Information Systems (GIS), and the Height Above Nearest Drainage (HAND) model was adopted. Multi-temporal Landsat imagery (1991, 2001, 2011, 2021, and 2024) was processed and classified in ArcGIS, while the HAND model was implemented in Google Earth Engine using the MERIT Digital Elevation Model (DEM) to delineate flood-prone areas. The accuracy of the LULC classifications was assessed using confusion matrix statistics and the Kappa coefficient. The findings revealed significant land use and land cover (LULC) transformations between 1991 and 2024. Built-up areas increased from 5.01 km² to 51.93 km², while farmland expanded from 14.73 km² to 399.77 km². Conversely, sparse vegetation declined markedly from 783.42 km² to 386.14 km², and dense vegetation decreased from 40.88 km² to 9.35 km². These landscape changes suggest a potential increase in flood susceptibility, given that the expansion of built-up areas and loss of vegetation are widely recognized as factors that can reduce infiltration and enhance surface runoff. The HAND-based flood susceptibility analysis revealed that 89.46 km² (10.54%) of the study area falls within the very high flood susceptibility zone, while 81.64 km² (9.62%), 132.14 km² (15.92%), and 542.45 km² (63.92%) are classified as high, moderate, and low susceptibility zones, respectively. Overall, approximately 20% of the study area is located within the high and very high flood susceptibility zones, which are predominantly concentrated along river corridors and low-lying floodplains. The results shows that the combined effects of rapid land use change and inadequate flood management are intensifying the exposure of communities, infrastructure, and livelihoods to flood hazards. Therefore, this study recommends enforcement of building laws and regulations particularly within and around natural drainage corridors, strengthening drainage infrastructure and promoting sustainable agricultural practices to reduce flood vulnerability across the watershed.

KEYWORDS

Land Cover Change, Flood Susceptibility, Remote Sensing, HAND Model, Meme Watershed

1.0 INTRODUCTION

Over the past thousand years, approximately 75% of the Earth's surface has undergone significant transformation due to human development, resulting in substantial biodiversity loss, disruption of natural ecosystems, and climate change. Land use change has accounted for a 32% alteration of the global area between 1960 and 2019, encompassing approximately 43 million km² of land (Winkler et al. 2021). Hu et al. (2020a) reported that the transformation of natural landscapes into agricultural land or urban areas induces changes in LULC, consequently resulting in the conversion of soil layers into impervious layers. This alteration leads to a reduction in the soil's water infiltration capacity and groundwater recharge, thereby impacting the hydrological processes within the watershed (Sertel et al. 2019).

Land Use and Land Cover (LULC) changes profoundly influence hydrological processes, often intensifying flood occurrences, particularly in rapidly urbanizing tropical areas (Astuti et al., 2019; Oo & Humphries, 2025; Nazir. et al., 2024; Annan et al., 2025). The conversion of natural lands to impervious surfaces, agricultural lands, or degraded areas significantly alters surface runoff, infiltration capacity, and overall water balance, leading to increased flood frequency and magnitude (Banjara et al., 2024; Lawal et al., 2024; Salaudeen et al., 2022; and Johnson et al., 2022). This phenomenon is a global concern, especially in developing countries were urbanization and population growth drive land modifications.

Flooding stands as one of the most prevalent and destructive environmental hazards globally, with its impacts increasing in recent times due to both natural and anthropogenic factors. In Nigeria, and particularly in Lokoja, Kogi State, flooding has become a recurring issue, leading to significant socio-economic and environmental challenges (Abijith et al, 2025). Studies have shown that LULC changes contribute to the frequency and severity of floods in the region. The Meme River Watershed, located in Lokoja, is particularly susceptible to these dynamics. The area's topography, combined with rapid urban development and inadequate flood infrastructure, exacerbates flood occurrences. The lower section of the Meme River Watershed in Lokoja has experienced notable flood events, which are closely linked to changes in land use and land cover (LULC) patterns; urbanization, deforestation, and agricultural expansion which have transformed natural landscapes, reducing the land's capacity to absorb rainfall and increasing surface runoff. Moreover, the lack of comprehensive land use planning and enforcement further compounds the problem, leaving communities vulnerable to flood hazards.

Recent flood events especially 2012 and 2022, in Lokoja have underscored the urgent need for integrated watershed management approaches that consider the interplay between land use practices and hydrological processes. Understanding the effects of LULC changes on flood occurrence is crucial for developing effective mitigation and adaptation strategies (Balarabe, et al, 2025). This study therefore, has the following objectives; to analyze the spatial and temporal changes in land use and land cover in the lower section of the Meme River watershed for over 30 years, identify and map flood-prone areas in the lower Meme River watershed, examine the relationship between land use/land cover changes and flood occurrence in the lower section of the Meme River watershed and a**ssess** the impact of specific land use types on flood frequency and extent in the study area.

Numerous studies have consistently demonstrated a strong link between LULC alterations and hydrological responses. For instance, research in the Upper-Brantas watershed, East Java, Indonesia, quantified LULC changes between 1995 and 2015 and analyzed their impact on surface runoff using the Soil and Water Assessment Tool (SWAT) model, revealing increased runoff due to landscape transformations (Astuti et al., 2019). Similarly, in the Ouémé River Basin, West Africa, LULC changes influenced water balance components. The study assessed the relationship between LULC changes and changes in water balance using four LULC maps and climate data across three periods within 1998–2016 in the Soil and Water Assessment Tool (SWAT). The model calibration yielded high Nash-Sutcliffe efficiency (NSE) values (≥ 0.82), indicating robust simulation results (Annan et al., 2025). The impact of LULC on hydrological processes is not limited to specific regions; it is a pervasive issue across various basins, including the Hadejia River System in Nigeria, where LULC changes between 1995 and 2015 were linked to altered runoff peak discharges and volumes (Lawal et al., 2024), and the Danjiang River source area in China, where LULC changes significantly affected river runoff (Liu et al., 2024).

In urban environments, the expansion of built-up areas and the reduction of natural vegetation are primary drivers of increased flood risk according to (Idowu & Zhou, 2021; Mukhtar et al., 2020; Mawasha & Britz, 2022). Urbanization leads to higher percentages of impervious surfaces, which minimize water infiltration into the soil and accelerate surface runoff, concentrating water flow and overwhelming drainage systems (Banjara et al., 2024 & Shrestha, 2019). For example, in Lagos State, Nigeria, rapid urbanization and expansion have been associated with incessant flooding, necessitating LULC change assessments for flood hazard mapping (Idowu & Zhou, 2021). In the Kano metropolis, Nigeria, built-up areas increased from 19.7% to 34.4% between 2001 and 2012, with projections indicating a further rise to 54.4% by 2035, directly corresponding to an increase in discharge within the Jakara basin (Mukhtar et al., 2020). Studies using models such as the Hydrologic Engineering Corps-Hydrologic Modelling System (HEC-HMS) have simulated these responses, confirming the heightened flood susceptibility due to urban growth (Mukhtar et al., 2020).

The Meme River Watershed, located within Lokoja Metropolis, Kogi State, Nigeria, is particularly vulnerable to flooding. Lokoja itself is prone to frequent flooding, posing significant threats to human settlements, infrastructure, and economic activities (Nazir, et al., 2024). The confluence of the Niger and Benue Rivers near Lokoja further exacerbates flood risks, as large volumes of water converge, leading to extensive inundation (Nkiruka et al., 2023 and Charles et al., 2024). The spatial patterns of flood inundation in Lokoja have been examined using remote sensing techniques like Maximum Likelihood Classifier algorithms on Landsat images to estimate magnitude and visualize seasonal flood events (Jimoh, 2022). LULC changes in areas like the Ofu River watershed, also in Kogi State, have shown significant increases in built-up areas from 18.931 km² in 2000 to 81.280 km² in 2020, with projections to 112.455 km² by 2030, indicating a clear trend of urbanization that impacts water quality and hydrological regimes (Daniel et al., 2023).

The methodological approaches to studying LULC impacts on flooding often involve the use of hydrological models coupled with remote sensing and Geographic Information Systems (GIS) (Oo & Humphries, 2025, and Rigby et al., 2022). Tools such as the SWAT model are widely employed to assess the effects of LULC changes on streamflow and surface runoff (Astuti et al., 2019; Annan et al., 2025; Umar et al., 2021; Abebe et al., 2022; Leta et al., 2021; Maru et al., 2023; Negash et al., 2022; Mekonnen & Manderso, 2023; Bennour et al., 2023; Bihonegn & Awoke, 2023). For instance, a systematic review of hydrological modeling approaches to assess flood responses under LULC transitions highlights the prevalence of such models over the past two decades (Oo & Humphries, 2025). The SWAT+ model, an advanced version of SWAT, has been developed to improve the assessment process of LULC changes and their hydrological impacts (Rigby et al., 2022). Other models like the Hydrological

Simulation Program FORTRAN (HSPF) have also been used to understand the separate and combined effects of LULC and climate change stressors on river basins (Salaudeen et al., 2022).

The Height Above Nearest Drainage (HAND) model is also a valuable tool for delineating flood-prone areas, as it quantifies terrain-based flood susceptibility independently of complex hydrodynamic simulations. HAND models, derived from digital elevation models (DEMs), effectively map areas prone to inundation based on their elevation relative to the nearest drainage network (Shrestha, 2019). The HAND model normalizes the topography in respect to the drainage network through two sets of procedures on a DEM. First, it runs a sequence of computations to create a hydrologically coherent DEM, define flow paths and delineate the drainage channels (Nobre et al, 2011) The correct definition of the stream network is key to the HAND procedure because the elevations of the drainage channel system are used to calculate the normalized terrain heights. (Jenson and Domingue, 1988; Grimaldi et al., 2007).

Integrating LULC change analysis across decades with HAND enables a spatially explicit assessment of how anthropogenic landscape modifications modulate flood exposure. This approach helps identify vulnerable areas by showing how changes in land cover influence the extent and depth of inundation predicted by the terrain characteristics. Therefore, this work aims to analyse the link between LULC dynamics and flooding in the lower section of the Meme River Watershed, Lokoja, Kogi State, over 30 years through a multi-year (1991, 2001, 2011,2021 and 2024) study. A map matrix- based post-classification method was used to investigate LULC changes to identify the losses or increase in the specified land cover types. Additionally, a flood hazard map was created to evaluate LULC morphology and impacts to the continuous rise of flooding in the State using the HAND model.

2.0 MATERIALS AND METHODS

2.1 The Study Area Description

The Meme River Watershed is located in the southern part of Lokoja, within the Middle Belt region of Nigeria. It lies between latitudes 7°49′N and 8°08′N and longitudes 6°12′E and 6°43′E, covering an area of about 849.64 km² within the lower Niger River Basin. The watershed falls within the Guinea Savannah vegetation zone, characterized by grasslands with scattered trees that support agriculture and grazing. However, increasing urbanization and farming activities have significantly altered the natural vegetation, although riverbanks and valleys still retain denser vegetation that helps reduce erosion and runoff.

The drainage pattern of the watershed is mainly dendritic, reflecting relatively uniform geology and moderate slopes. The Meme River serves as the main drainage channel, receiving water from numerous smaller streams that create a dense network. This high drainage density promotes rapid surface runoff, especially during heavy rainfall, making low-lying areas more prone to flooding (Ezenwaji et al., 2018). Geologically, the region is part of Nigeria’s Basement Complex, with rocks such as granite, gneiss, and schist dominating the western uplands, while the eastern lowlands consist mainly of alluvial deposits near the River Niger. The soils are largely ferruginous tropical types, shallow on slopes but deeper and more fertile in valleys and floodplains.

Administratively, the watershed lies within Lokoja Local Government Area and is inhabited by diverse ethnic groups including Nupe, Bassa, Yoruba, Igala, and Ebira. The area has experienced rapid urban growth due to Lokoja’s role as a state capital and its strategic position near the confluence of the River Niger and River Benue. Major economic activities include farming, trading, civil service, and transportation, also situate in the area is Federal University Lokoja, Adankolo campus and Specialist hospital, Kogi State, among other administrative offices. However, increasing land use changes, unplanned urban expansion, and settlement in flood-prone areas have heightened vulnerability to flooding, making environmental management a critical concern in the watershed (Oyebanji & Salami, 2017).

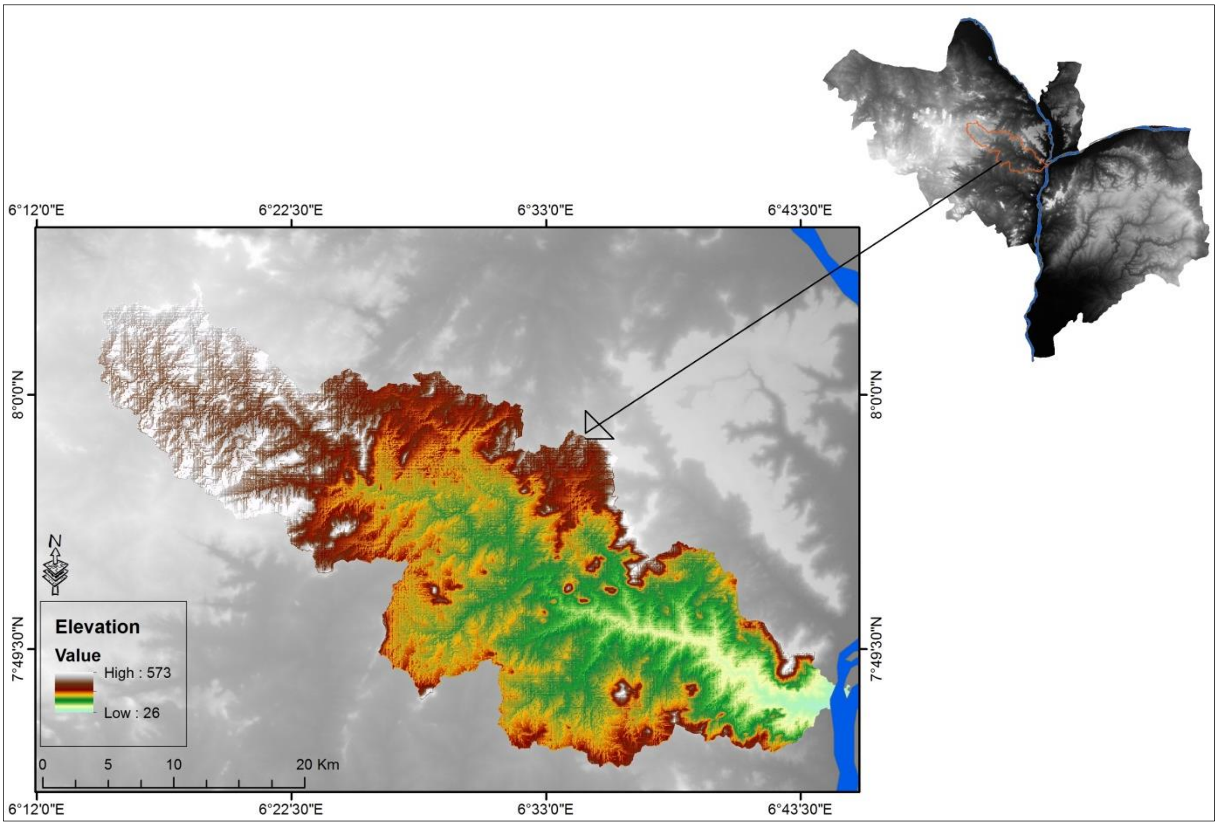


Figure1. Location map of Meme Watershed

2.2 Methodology

2.2.1 Data Acquisition and Processing

The data used in this study includes; 90 m spatial resolution MERIT DEM. MERIT DEM is a high accuracy global DEM at 3 arc second resolution (~90 m at the equator) produced by eliminating major error components from existing DEMs (NASA SRTM3 DEM, JAXA AW3D DEM, Viewfinder Panoramas DEM). MERIT DEM separates absolute bias, stripe noise, speckle noise and tree height bias using multiple satellite datasets and filtering techniques, the imagery was downloaded from https://global-hydrodynamics.github.io web site.

Satellite imageries (Landsat 5(TM), Landsat 7 (ETM+), and Landsat 9 (OLI/TIRS) with different bands downloaded during the dry season (December and January) were acquired from (https://earthexplorer.usgs.gov/) as shown in Table 1. These images were used for LULC change detection in the study area. ArcGIS 10.5 was utilized for satellite image processing and mapping LULC change.

Table1: Data used for the study

Year	Sensor	Acquisition Date	Path/Row	Product Level	Cloud Cover (%)	Preprocessing	Source	SLC-off Handling
1991	Landsat 5 TM	1991-12-08	189/055	L1TP	21.00	TOA Atmospheric Correction (ArcGIS 10.5)	USGS/ EarthExplorer	N/A
2001	Landsat 7 ETM+	2001-01-09	189/055	L1TP	4.00	TOA Atmospheric Correction (ArcGIS 10.5)	USGS/ EarthExplorer	None (pre-SLC failure)
2011	Landsat 7 ETM+	2011-12-07	189/055	L2SP	4.00	TOA Atmospheric Correction (ArcGIS 10.5)	USGS/ EarthExplorer	SLC-off gaps corrected using the Gap Fill tool in ENVI 5.3

Year	Sensor	Acquisition Date	Path/Row	Product Level	Cloud Cover (%)	Preprocessing	Source	SLC-off Handling
2021	Landsat 9 OLI/TIRS	2021-12-18	189/055	L1TP	0.93	TOA Atmospheric Correction (ArcGIS 10.5)	USGS/ EarthExplorer	N/A
2024	Landsat 8 OLI/TIRS	2024-12-18	189/055	L2SP	0.02	TOA Atmospheric Correction (ArcGIS 10.5)	USGS/ EarthExplorer	N/A

Source; Author's Analysis

- Google Earth Pro historical imageries, which provided the advantage of backdated imagery was used for effective validation of land use and land cover information across the different study years.

2.2.2 LULC Change Classification

The study area was classified into six land use/land cover (LULC) categories; water bodies, built-up areas, dense vegetation, shrublands, farmlands, and bare surfaces, using supervised image classification with the Maximum Likelihood algorithm, as presented in Table 2

Table 2: Land Use and Land Cover Classification Scheme

Classes	Description
Built-up	This comprise of urban and rural built-up including homestead area such as residential, commercial, industrial areas, villages, roads network, pavement and man-made structures.
Bare surface	Land of limited ability to support biotic life and in which less than one-third of the area has vegetation cover. These areas typically have less than 4% vegetation cover such as exposed river sand land in-fillings sites, excavation sites, open space and bare soils.
Water bodies	River, lakes and reservoirs
Dense Vegetations	Dense vegetation, Forest lands and deforested area
Shrublands	Grasses and Shrubs
Farmlands	Agricultural Land

Source: Modified from (Jensen, 2005)

2.2.3 Accuracy Assessment

The study adopted the Error Matrix approach to assess the accuracy of the classification, using four parameters; overall accuracy, user's accuracy, producer's accuracy and the Kappa Index of Agreement (KIA). Individual Class Accuracy is calculated by dividing the number of correctly classified pixels in each category by either the total number of pixels in the corresponding column; Producer's accuracy, or row; User's accuracy, as presented in tables 3-7.

Table 3: Accuracy Assessment_1991

ClassValue	Water body	Built-up	Dense vegetation	Shrubland	Farmland	Bare surface	Total	User Accuracy	Kappa
Water body	9	0	0	0	0	0	9	1	0
Built-up	0	6	0	4	0	0	10	0.6	0
Dense vegetation	0	0	7	3	0	0	10	0.7	0
Shrubland	0	0	1	180	0	2	183	1.0	0
Farmland	0	0	2	3	5	0	10	0.5	0
Bare_surface	0	0	0	2	1	7	10	0.7	0
Total	9	6	10	192	6	9	232	0	0
P_Accuracy	1	1	0.7	0.9375	0.8333	0.7778	0	0.9	0

Kappa	0	0	0	0	0	0	0	0	0.7718

Table 4: Accuracy Assessment for 2001

ClassValue	Water body	Built-up	Dense vegetation	Shrubland	Farmland	Bare surface	Total	User Accuracy	Kappa
Water body	10	0	0	0	0	0	10	1	0
Built-up	0	10	0	0	0	0	10	1	0
Dense vegetation	0	0	7	3	0	0	10	0.7	0
Shrubland	0	0	3	182	0	0	185	0.9838	0
Farmland	0	0	0	3	7	0	10	0.7	0
Bare_surface	0	0	0	0	0	10	10	1	0
Total	10	10	10	188	7	10	235	0	0
P_Accuracy	1	1	0.7	0.9681	1	1	0	0.9617	0
Kappa	0	0	0	0	0	0	0	0	0.8937

Table 5: Accuracy Assessment for 2011

Class Value	Water body	Built-up	Dense vegetation	Shrubland	Farmland	Bare surface	Total	User Accuracy	Kappa
Water body	10	0	0	0	0	0	10	1.0000	0
Built-up	0	9	0	0	0	1	10	0.9000	0
Dense vegetation	0	0	7	3	0	0	10	0.7000	0
Shrubland	0	0	5	165	2	0	172	0.9593	0
Farmland	0	0	0	2	18	0	20	0.9000	0
Bare surface	0	0	0	1	1	8	10	0.8000	0
Total	10	9	12	171	21	9	232	0.0000	0
P_Accuracy	1.0000	1.0000	0.5833	0.9649	0.8571	0.8889	0.0000	0.9353	0
Kappa	0	0	0	0	0	0	0	0	0.8525

Table 6: Accuracy Assessment_2021

ClassValue	Water body	Built-up	Dense vegetation	Shrubland	Farmland	Bare surface	Total	User Accuracy	Kappa
Water body	10	0	0	0	0	0	10	1.0000	0
Built-up	0	8	1	0	0	1	10	0.8000	0
Dense vegetation	0	0	8	2	0	0	10	0.8000	0
Shrubland	0	0	0	132	6	0	138	0.9565	0
Farmland	0	0	0	2	44	0	46	0.9565	0
Bare_surface	0	0	0	0	2	8	10	0.8000	0
Total	10	8	9	136	52	9	224	0	0
P_Accuracy	1	1	0.8889	0.9706	0.8462	0.8889	0	0.9375	0
Kappa	0	0	0	0	0	0	0	0	0.8906

Table 7: Accuracy Assessment for 2024

ClassValue	Water body	Built-up	Dense vegetation	Shrubland	Farm land	Bare surface	Total	User Accuracy	Kappa
Water body	9	1	0	0	0	0	10	0.9	0
Built-up	0	8	0	1	2	1	12	0.6667	0
Dense vegetation	0	0	9	1	0	0	10	0.9	0
Shrubland	0	0	0	82	9	0	91	0.901	0
Farmland	0	0	0	9	85	0	94	0.904	0
Bare_surface	0	0	0	0	0	10	10	1	0
Total	9	9	9	93	96	11	227	0	0
Producer_Accuracy	1	0.889	1	0.8817	0.8854	0.9090	0	0.894	0
Kappa	0	0	0	0	0	0	0	0	0.8381

Theoretically, Kappa can be express as

$\check{K}$ = (Observed accuracy − Chance agreement) / (1 − Chance agreement) ……… (1)

Observed accuracy determined by sum of diagonals (points correctly mapped) in the error matrix, while chance agreement determined by sum of product of row and column totals of each class. Kappa coefficient can therefore be statistically expressed as

$\check{K} = (Ŋ\Sigma p - \rho) / (Ŋ^2 - \rho)$ ……………………………. (2)

Where:

Ŋ = Total number of points; p = Sum of correctly classified pixels; ρ = Sum of product row and column totals of each class. The extracted results for overall classification accuracy and Kappa statistics are presented in table 9.

2.2.4 Flood Susceptibility Mapping

Flood susceptibility was assessed using the Height Above Nearest Drainage (HAND) approach implemented in Google Earth Engine (GEE). Instead of generating HAND from a raw digital elevation model (DEM), this study employed the HAND layer available within the MERIT Hydro Version 1.0.1 dataset, which is derived from a hydrologically conditioned DEM. MERIT Hydro removes major elevation errors, sink artifacts, and drainage inconsistencies commonly present in global DEMs, thereby providing reliable terrain information for hydrological analyses. The MERIT Hydro HAND dataset has a native spatial resolution of approximately 90 m (3 arc-seconds). All analyses were conducted at the dataset's native resolution to preserve hydrological consistency.

The HAND raster was clipped to the study area, Projection (WGS 84; EPSG:4326) and used as the primary indicator of flood susceptibility. HAND represents the vertical distance (m) between each terrain cell and its nearest hydrologically connected drainage channel. Lower HAND values indicate terrain located close to river channels and floodplains, whereas higher HAND values represent elevated areas with lower susceptibility to inundation.

The study utilized the hydrologically conditioned MERIT Hydro DEM, which incorporates several preprocessing steps prior to distribution, including: removal of spurious depressions (sink correction); correction of striping and absolute elevation errors; improvement of river connectivity and enforcement of hydrological drainage networks. This approach minimizes uncertainties associated with selecting arbitrary flow accumulation thresholds. The workflow for the HAND model is shown in figure 2.

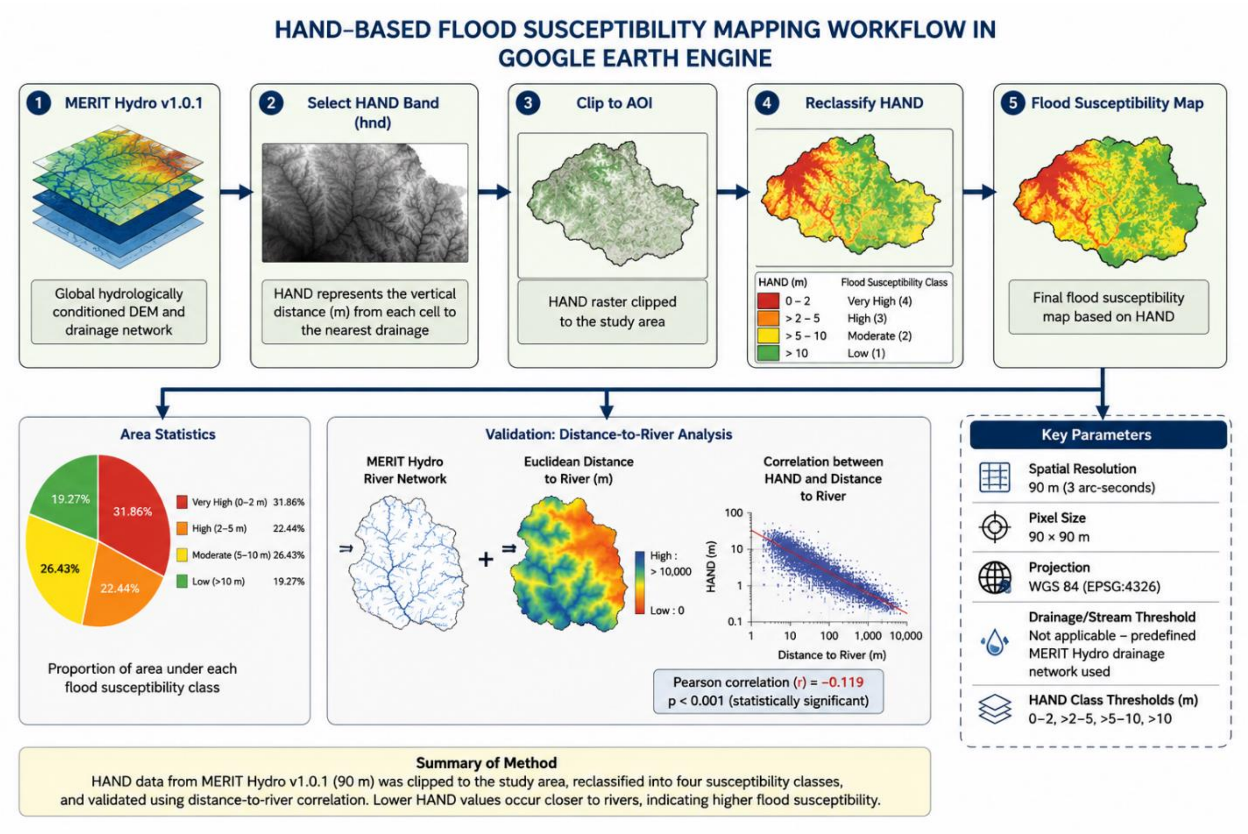
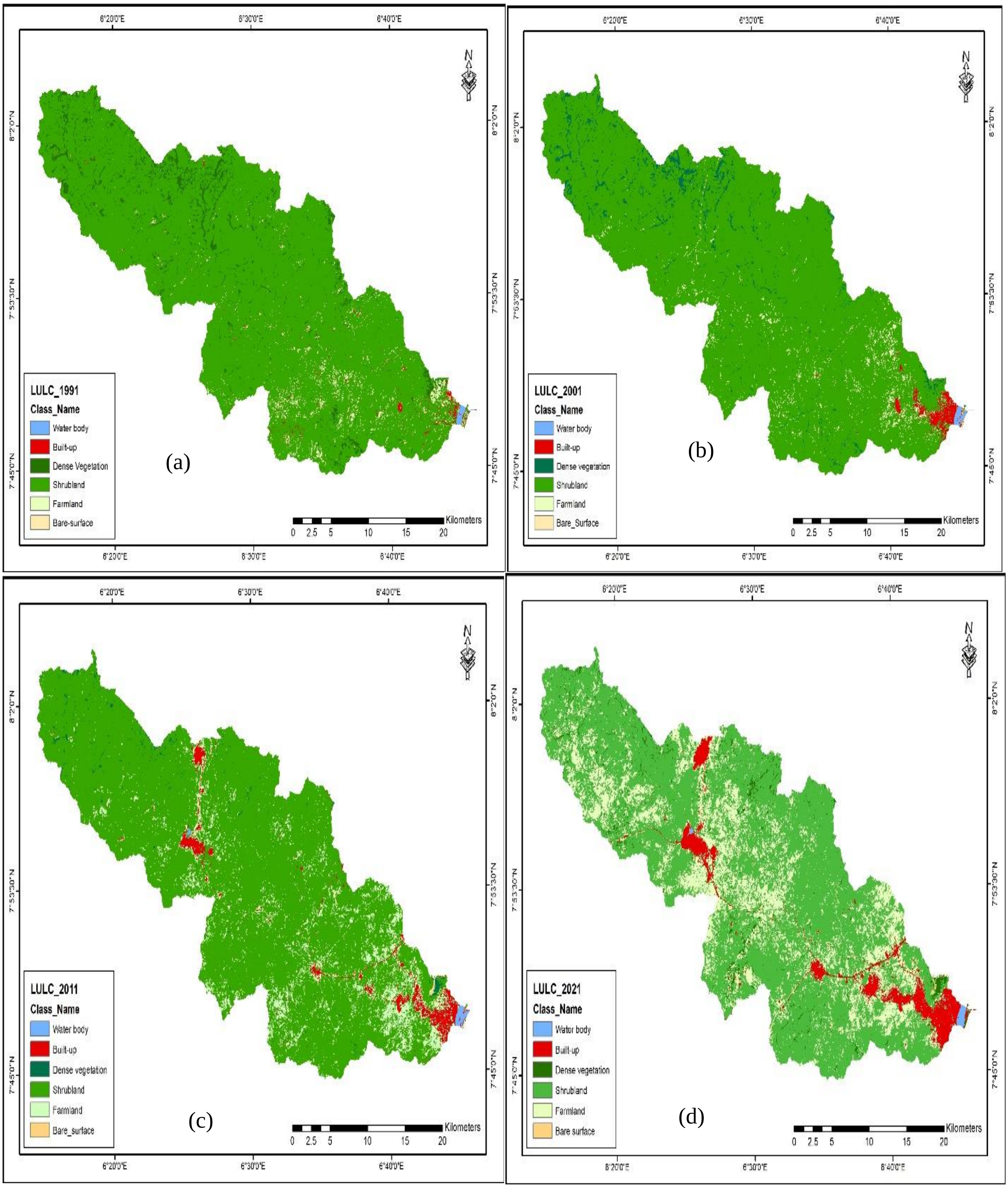


Figure 2. HAND based flood susceptibility workflow in Google Earth Engine

3.0 RESULTS AND DISCUSSIONS

3.1 Drivers of Land Use Change

The results of the Land Use/Land Cover (LULC) change analysis reveal substantial transformations in the study area between 1991 and 2024, with potential relevance to flood occurrence (Figure 3a–e). Over the study period, there has been a pronounced transition from natural vegetation to anthropogenic land uses, particularly built-up areas and farmland. These observed changes indicate increasing landscape modification and coincide with conditions that are widely recognized in the literature as contributing to higher flood susceptibility.


(a)
LULC_1991
Class_Name
Water body
Built-up
Dense Vegetation
Shrubland
Farmland
Bare-surface
Kilometers
(b)
LULC_2001
Class_Name
Water body
Built-up
Dense vegetation
Shrubland
Farmland
Bare_Surface
(c)
LULC_2011
Class_Name
Water body
Built-up
Dense vegetation
Shrubland
Farmland
Bare_surface
(d)
LULC_2021
Class_Name
Water body
Built-up
Dense vegetation
Shrubland
Farmland
Bare surface

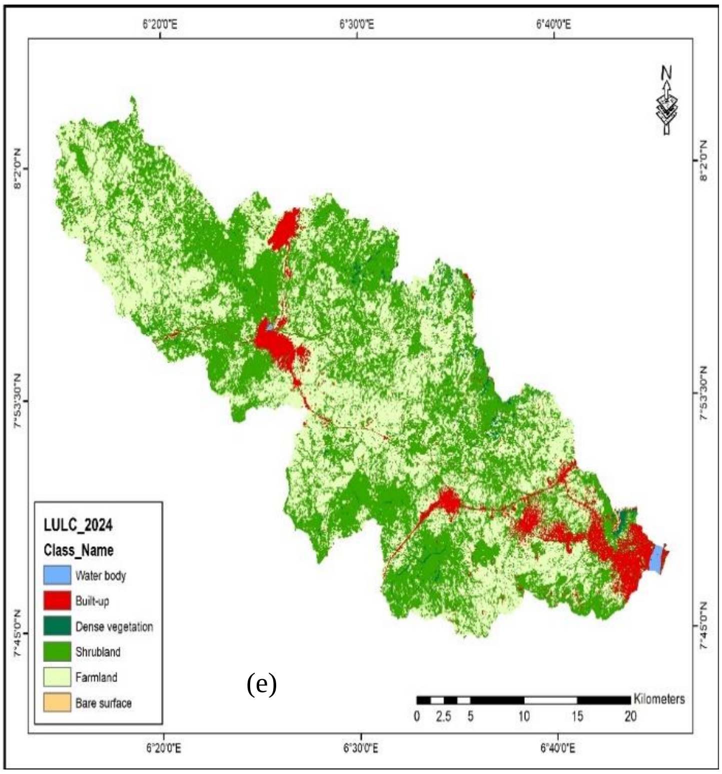


Figure 3. LULC iamges for 1991, 2001, 2011, 2021 and 2024 labelled a-e respectively

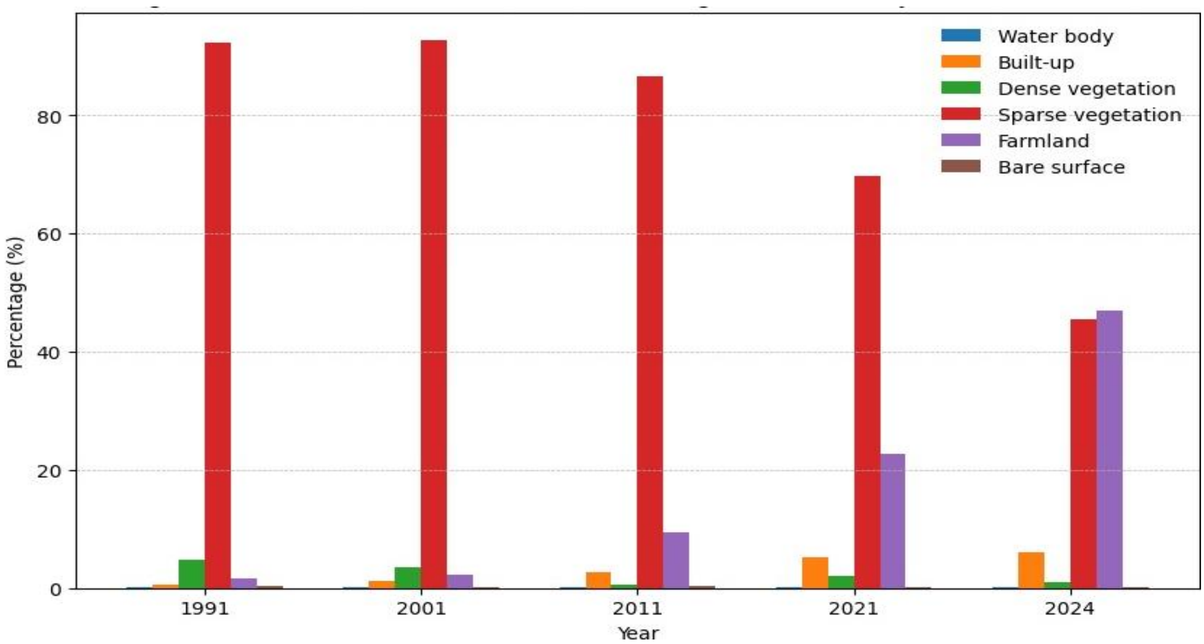


Figure 4 .Results of LULC analysis changes between 1991-2024

Table 8. LULC change statistics for years 1991, 2001, 2011, 2021 and 2024 Respectively

	1991		2001		2011		2021		2024	
Land Cover Classes	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%	Area (km²)	%
Water body	1.385	0.16	1.764	0.21	2.152	0.25	1.893	0.22	1.894	0.22
Built-up	5.005	0.59	10.039	1.18	22.691	2.67	44.204	5.2	51.927	6.11
Dense vegetation	40.877	4.81	29.574	3.48	5.724	0.67	16.687	1.96	9.346	1.1
Sparse vegetation	783.423	92.26	788.579	92.82	736.668	86.69	592.431	69.73	386.137	45.45
Farmland	14.734	1.73	18.663	2.2	80.100	9.43	193.188	22.74	399.772	47.06
Bare surface	3.674	0.43	0.993	0.12	2.433	0.29	1.1566	0.14	0.480	0.06
Total	849.099	100	849.60	100	849.60	100	849.60	100	849.60	100

3.1.1 Built-up Areas

From table 8, one of the most notable trends is the rapid expansion of built-up areas, which increased from 0.59% (5.01 km²) in 1991 to 6.11% (51.93 km²) in 2024, even after the flooding in 2022 which submerged the whole area, one would have taught that development would shift to other areas but reverse was the case. This substantial growth in urban land use is a critical factor influencing flood dynamics because it alters the topography of an area. More so, Built-up surfaces such as roads, rooftops, and pavements are largely impervious, significantly reducing infiltration rates while increasing surface runoff. As a result, rainfall that would naturally infiltrate into the soil is instead rapidly conveyed overland, leading to higher peak discharge and an increased likelihood of urban flooding. Other factors are that most drainages are silted up or the carrying capacity for storm water is too low thereby leading to overflow of water on the land or flash floods. (Johnson et al, 2022).

3.1.2 Farmlands

Similarly, the expansion of farmland represents another major LULC transition, increasing dramatically from 1.73% (14.73 km²) in 1991 to 47.06% (399.77 km²) in 2024. While agricultural land may allow some degree of infiltration, it generally exhibits lower water retention capacity compared to natural vegetation, particularly under intensive cultivation practices. The conversion of vegetated land to farmland often leads to soil compaction, reduced organic matter, and increased susceptibility to erosion. Consequently, this transformation contributes to elevated surface runoff and sediment transport, both of which exacerbate flood conditions, especially during high-intensity rainfall events.

3.1.3 Dense/Sparse Vegetation Cover

In contrast, there has been a marked decline in natural vegetation cover, particularly sparse vegetation, which decreased from 92.26% (783.42 km²) in 1991 to 45.45% (386.14 km²) in 2024. Dense vegetation also declined from 4.81% to 1.1% over the same period. Vegetation plays a vital role in regulating the hydrological cycle through processes such as interception, evapotranspiration, and soil stabilization. Its removal reduces the land’s capacity to absorb and store water, resulting in faster runoff and increased flood peaks. Furthermore, the loss of vegetative cover exposes the soil surface, promoting erosion and sedimentation, which can clog drainage channels and further intensify flooding.

3.1.4 Water bodies

The relatively minor changes observed in water bodies—from 0.16% in 1991 to 0.22% in 2024 suggest that the increased flood occurrence is not primarily driven by the expansion of surface water features. Instead, it is largely attributable to land surface modifications resulting from human activities. This highlights the dominant role of LULC dynamics, rather than climatic or hydrological base conditions alone, in shaping flood risk within the study area. A review of land use and land cover change (LULCC) studies conducted in Lokoja between 2020 and 2024 reveals a strong consensus that rapid urbanisation is the dominant driver of landscape transformation. They consistently report an expansion of built-up areas at the expense of natural vegetation, thereby increasing environmental degradation and flood risk. The study by Popoola et al. (2022)**,** investigated disaster vulnerability associated with the overflow of the Niger River by integrating LULC change analysis with the Normalized Difference Water Index (NDWI). Using Landsat imagery covering 2012–2020, the study found that built-up land increased from 38.40 km² (10.16%) in 2012 to 55.13 km² in 2020**,** while approximately 104.55 km² of undisturbed vegetation was converted to other land uses. The authors concluded that increasing anthropogenic activities, particularly urban expansion and vegetation clearance, have significantly reduced infiltration capacity and exacerbated flood vulnerability in Lokoja. Similarly, Ojo et al. (2023) analysed the spatio-temporal pattern of urban growth in Lokoja using Landsat imagery for 2001, 2011 and 2020. Their findings revealed an accelerated expansion of built-up land from 1,492.35 ha in 2001 to 5,556.27 ha in 2020, representing average urban growth rates of 9.37% (2001–2011) and 10.24% (2011–2020). The study further demonstrated that urban development has been concentrated along major transportation corridors, particularly towards the north-western and south-western sections of the city. The authors projected that future urban expansion would likely continue in the same directions if current development patterns remain unchanged. Collectively, these studies demonstrate a consistent trajectory of increasing urban development and declining vegetation cover across Lokoja, this is also seen from the result of this study (table 8.)

3.2 Accuracy assessment

The reliability of these findings is supported by the accuracy assessment results, which indicate high classification performance across all years. The accuracy assessment was carried out using stratified random sampling techniques by deploying over 200 sample points on the classified images for the different years under study. The classified maps were critically compared with reference data obtained from Google Earth Pro historical imageries, which provided the advantage of backdated imagery for effective validation of land use and land cover information across the different study years. The results revealed that the classified image for the year 2024 produced an overall accuracy of 89.4% with a kappa coefficient of 0.8381, while the classified images for 2021, 2011, 2001, and 1991 recorded overall accuracies of 93.75%, 93.53%, 96.17%, and 90.0% with corresponding kappa coefficients of 0.8906, 0.8525, 0.894118, and 0.7718 respectively. This implies that the classified images showed substantial to near-perfect agreement with the ground reference information obtained from Google Earth Pro based on the kappa coefficient statistical interpretation presented in Table 9.

Table 9: Accuracy Assessment

S/N	Year	Kappa Coefficient (%)	Overall Accuracy (%)	Rating
1	1991	77.18	92	Strong
2	2001	89.37	96	Very Strong
3	2011	85.25	93	Strong
4	2022	89.06	93	Strong
5	2024	83.81	89	Strong

Source; Author's lab work

3.3 Flood Susceptibility Mapping

Figure 5 presents the MERIT Hydro-derived HAND DEM of the Meme Watershed, depicting the drainage-normalized topography of the study area. The HAND representation expresses the relative elevation of the terrain above its nearest drainage channel, with lower values indicating areas that are topographically closer to the drainage network and higher values representing relatively elevated terrain. The resulting HAND surface was subsequently used as the topographic input for the flood susceptibility assessment.

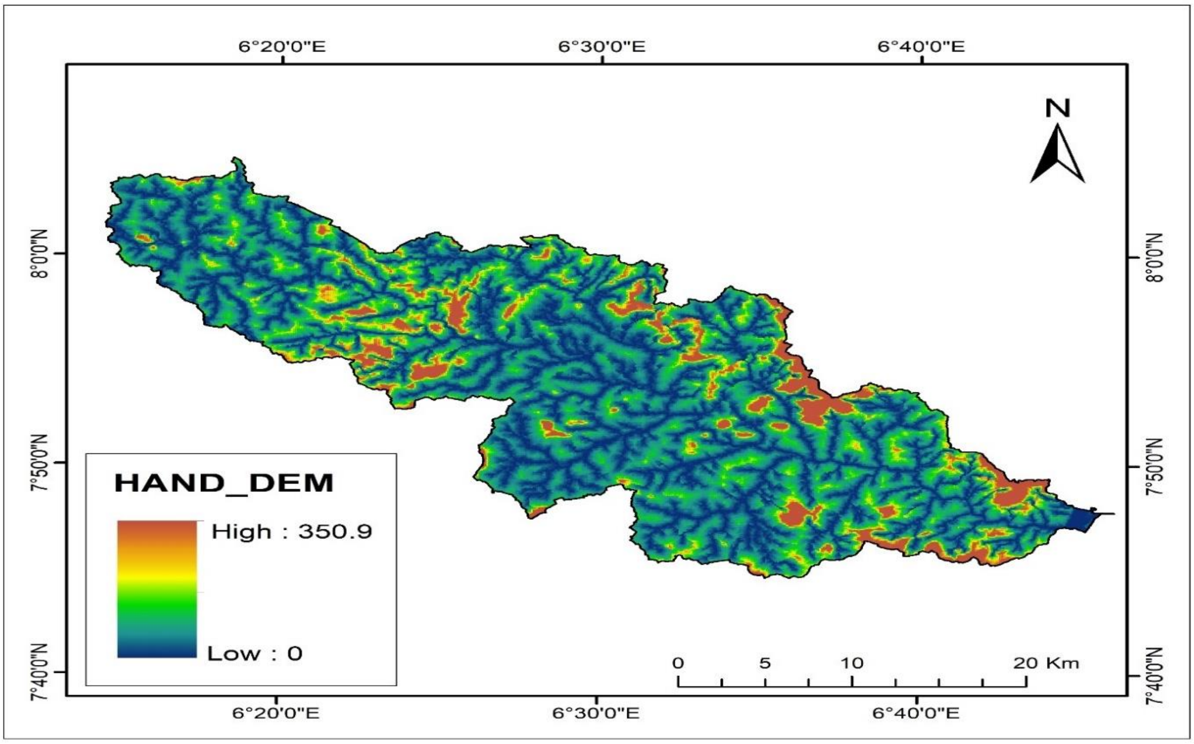


Figure 5. MERIT Hydro HAND DEM color-shaded relief of Meme Watershed showing drainage normalized topography.

HAND values were reclassified into four flood susceptibility classes following commonly adopted thresholds in terrain-based flood susceptibility studies:

HAND (m)	Flood Susceptibility	Class
0–2	Very High	4
>2–5	High	3
>5–10	Moderate	2
>10	Low	1

The HAND-derived flood susceptibility map revealed **distinct spatial patterns (figure 6)**:

- **Very high susceptibility zones (HAND ≤ 2 m)** were concentrated along river corridors and low-lying floodplains, indicating minimal vertical separation from drainage channels.
- **High susceptibility zones (HAND = 2–5 m)** extended laterally from these channels, highlighting areas likely to experience inundation during moderate flood events.
- **Moderate (5–10 m) and low (>10 m) susceptibility zones** were primarily located on elevated terrain and interfluves, reflecting reduced exposure to fluvial flooding.

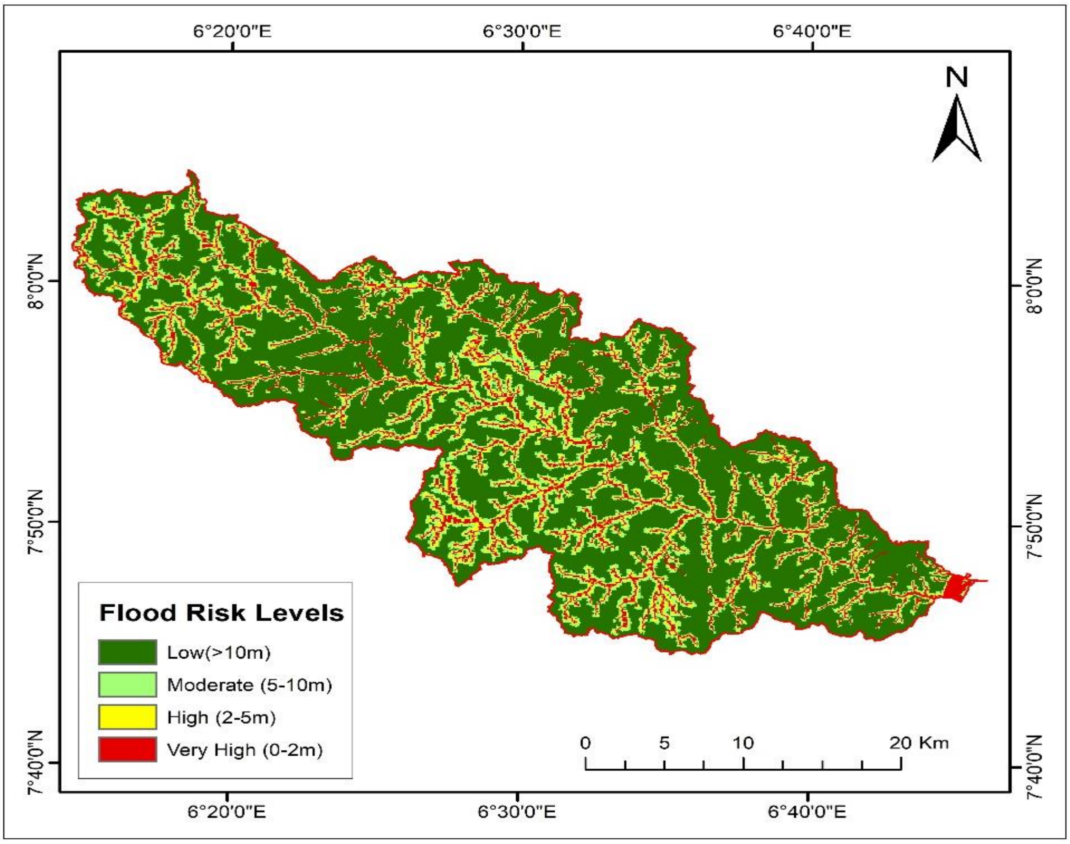


Figure 6. HAND Flood Susceptibility map

3.3.1 Quantitative Area Analysis

The spatial extent of each flood risk class was computed by summing pixel areas and converting to percentages of the total study area. The results are summarized in **Table 10**.

Table 10. Area (%) per Flood Risk Class

Flood Risk Class	HAND Range (m)	Area (Km^2)	Percent (%)
1 (Low)	>10	542.45	63.92
2 (Moderate)	5–10	135.14	15.92
3 (High)	2–5	81.64	9.62
4 (Very High)	0–2	89.46	10.54
Total	—	848.69	100

From the result of the study (table 10), Low-risk areas dominate (64%), while flood-prone zones (high + very high) account for 20% of the study area. This reflects the influence of low-relief terrain and dense drainage networks on flood susceptibility.

3.3.2 Validation Using Distance to River

The HAND-derived flood susceptibility map was independently evaluated using a distance-to-river analysis. First, river pixels were extracted from the MERIT Hydro River network. Subsequently, Euclidean distance from every pixel to the nearest river channel was calculated at the same spatial resolution (90 m). Pearson's correlation coefficient was then computed between HAND values and distance-to-river.

The validation assumes that areas located closer to rivers generally possess lower HAND values and consequently exhibit higher flood susceptibility.

The statistical relationship was quantified using

$$\boldsymbol{r} = \frac{\boldsymbol{CovH,D}}{\boldsymbol{\sigma_H \sigma_D}}$$

Where;

H = HAND values
D = Distance to river.
The analysis produced

- Pearson correlation coefficient (r) = −0.119
- $p < 0.001$

The statistically significant negative relationship indicates that lower HAND values occur preferentially near river channels, thereby supporting the spatial consistency of the HAND-derived flood susceptibility model.

The negative correlation indicates that areas closer to rivers generally have lower HAND values, and thus higher flood susceptibility. Although the correlation is weak, it is statistically significant, reflecting the influence of local terrain variations in addition to river proximity. This independent validation confirms that the HAND-derived flood susceptibility map reliably captures the spatial patterns of relative flood risk along drainage channels.

The HAND-derived analysis demonstrates that topography is the primary control on flood susceptibility. Areas near rivers and low-lying floodplains are more prone to inundation, while elevated interfluves show minimal risk.

The dominance of low-risk areas (~64%) indicates that much of the study area lies above 10 meters relative to the nearest drainage, thereby reducing overall flood exposure, while the concentration of high and very high-risk zones (~20%) along river corridors highlights the strong geomorphological controls on flooding. This spatial pattern is further validated by the statistically significant negative correlation between HAND values and distance-to-river metrics, confirming that areas closer to rivers generally exhibit lower HAND values and consequently higher flood susceptibility. Although this correlation is relatively weak, it remains statistically significant, reflecting the influence of local terrain variations beyond simple river proximity. Together, these independent validations demonstrate that the HAND-derived flood susceptibility map reliably captures essential hydrological patterns and spatial distributions of relative flood risk along drainage channels without requiring detailed hydraulic modeling or event-based data.

3.4. Flood Risk Map

The flood risk area map was generated from a combination of the land use map and HAND flood susceptibility map overlaid using spatial analysis in ArcGIS. The resulting output was classified into four flood risk classes from low to very high (Figure 7). The results of the analysis showed that the high and very-high-risk zone is concentrated on the south-Eastern side of the area and in the area very close to river channels. These areas are the main residential areas according to the land use map classification (Figure 2(a, b, c, d, and e). These areas are mostly characterized by flat elevations and gentle slopes. Most areas of agricultural land and grasslands are also included in the high-risk zone of flooding

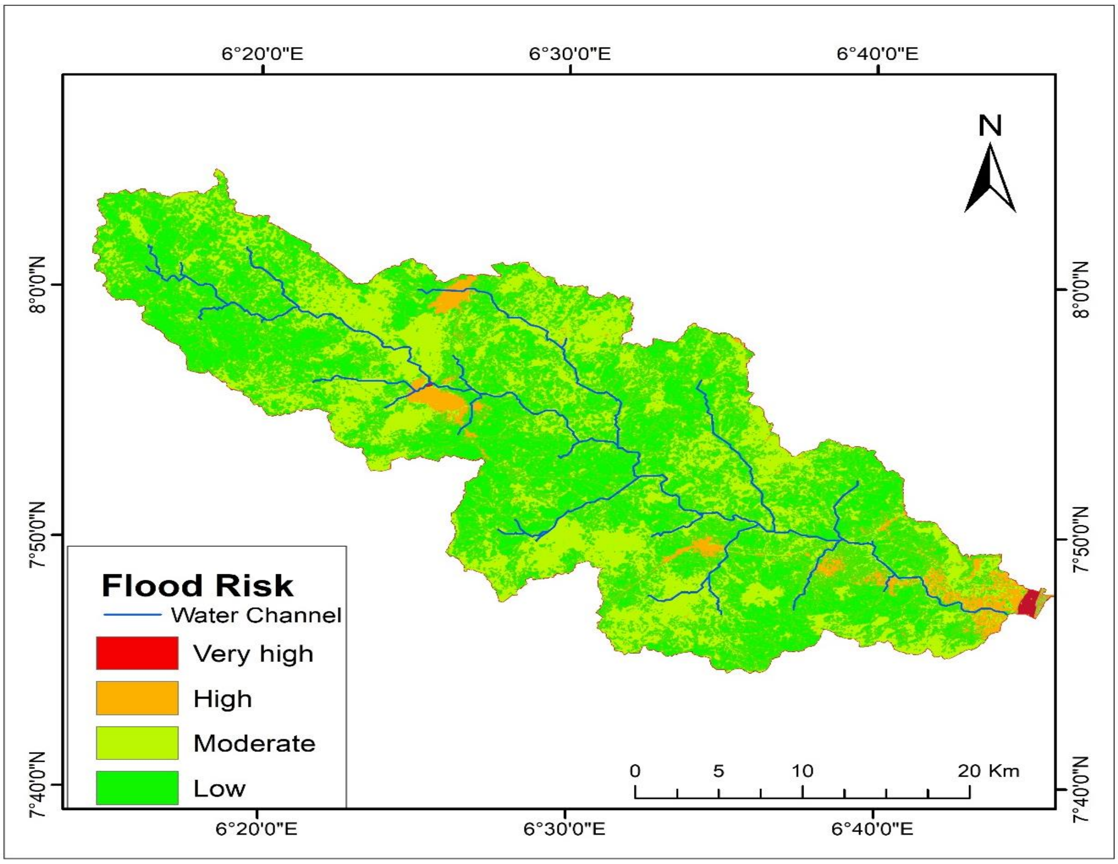


Figure 7. Flood Risk Map

3.5 Implications of LULC Change on Flooding

Figure 8. illustrates temporal changes in major LULC classes, highlighting a substantial decline in sparse vegetation and a corresponding increase in farmland and built-up areas over time. These shifts indicate progressive anthropogenic modification of the landscape, with implications for increased flood occurrence in the study area.

Table 11. Land Use/Land Cover Change in Meme Watershed (1991–2024)

Class	1991 Area (km^2)	2024 Area (km^2)	Change (km^2)	Annual Rate (km^2/yr)
Water Body	1.3853	1.8938	+0.5085	+0.0154
Built-up	5.0053	51.9266	+46.9213	+1.4219
Dense Vegetation	40.8774	9.3455	−31.5319	−0.9555
Sparse Vegetation	783.4226	386.1367	−397.2859	−12.0390
Farmland	14.7336	399.7716	+385.0380	+11.6678
Bare Surface	3.6742	0.4803	−3.1939	−0.0968

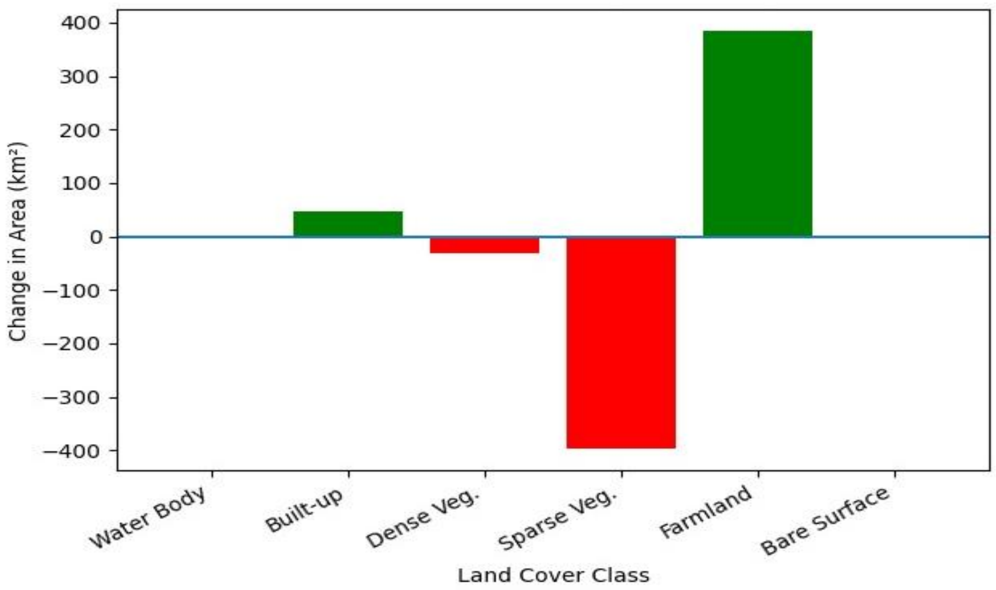


Figure 8. Land Use/Land Cover (LULC) percentage distribution by class from 1991 to 2024.

The study revealed a substantial expansion of agricultural land, with approximately 385 km² converted to farmland during the study period, this has significant implications for regional flood risk especially within the study area. Intensive farming practices including tillage, soil compaction, and the removal of natural vegetation reduce soil permeability and impede water infiltration; consequently, a greater fraction of rainfall is transformed into surface runoff rather than being absorbed subsurface, thereby increasing the probability of flash flooding, river overflow, and heightened landscape-wide flood vulnerability. Furthermore, the study revealed a significant loss of sparse vegetation covering approximately 397 km² (table 11), which normally plays a vital protective role by intercepting rainfall, slowing down surface runoff, and enhancing water infiltration into the soil. As a result of this substantial reduction in vegetative cover, water now moves more rapidly across the landscape, leading to increased runoff velocity and volume, which accelerates erosion processes and elevates the risk of downstream flooding. In addition, dense vegetation decreased by 31.53 km² over the study period, and since forested areas function like natural sponges absorbing and storing significant amounts of water, the loss of this dense vegetation cover substantially reduces the landscape's water storage capacity, allowing more water to reach rivers and streams rapidly. This accelerated water delivery leads to peak discharge spikes, which significantly increase the risk of flooding. Finally, built-up areas increased significantly by 46.92 km² over the study period, and because surfaces such as concrete and asphalt are largely impermeable, almost all rainfall is converted directly into surface runoff rather than infiltrating into the ground. To support the analysis in this study, **N**azir et al. (2024) in their study presented the consequences of these landscape changes by examining the relationship between flood hazards, land use and population distribution in Lokoja. Although the study did not perform LULC classification, it established that continuous urban expansion into floodplains has increased the exposure of residential areas, infrastructure and economic activities to flood hazards. The study emphasised the need for improved land use planning and flood-resilient urban development to reduce disaster risks in the metropolis. Therefore, it is in the right direction to say that this substantial increase in impervious surface area overwhelms existing drainage systems and contributes to heightened risks of urban flooding and waterlogging within the landscape, further compounding the area's overall flood vulnerability. This study also agrees with the findings in the following study (Shrestha et al, 2021, Zhang et al, 2018, Cheng et al, 2022, Scorpio et al, 2018 and de Almeida et al 2018)

4.0 CONCLUSION

This study clearly showed that significant Land Use and Land Cover (LULC) changes have occurred in Meme River Watershed between 1991 and 2024, especially at the lower section, and this has great implications for flood occurrence and environmental sustainability. The results also revealed rapid expansion of built-up areas and farmlands at the expense of natural vegetation cover. Built-up areas increased substantially due to urban growth largely as a result of establishment of the University in the area and infrastructural development, while farmlands expanded extensively as a result of agricultural activities. Conversely, dense and sparse vegetation experienced severe reductions, indicating widespread anthropogenic pressure on the watershed ecosystem. The observed LULC transformations coincide with conditions commonly associated with increased flood susceptibility. The expansion of built-up and cultivated lands at the expense of natural vegetation may have reduced vegetation cover and increased the extent of impervious surfaces, factors that are widely recognized as contributing to greater surface runoff and flood risk. The HAND-based flood susceptibility assessment further indicated that high and very high flood-susceptibility zones are primarily concentrated along river corridors and low-lying floodplains, particularly in areas where human activities and settlement expansion are more pronounced. The accuracy assessment results confirmed the reliability of the classified LULC maps and flood susceptibility analysis, demonstrating that the applied geospatial techniques provide dependable outputs for environmental monitoring and flood risk assessment. The integration of remote sensing, GIS, and HAND modeling proved effective in identifying spatial flood patterns and understanding the hydrological implications of land transformation in the study area. Overall, from the findings there is urgent need for enforcement of watershed management strategies that promote sustainable land-use planning, environmental conservation, and flood mitigation. Measures such as reforestation, preservation of natural vegetation, improved drainage infrastructure, regulation of settlement development in flood-prone areas, and adoption of sustainable agricultural practices are essential for reducing flood vulnerability and enhancing environmental resilience. The study therefore provides a valuable scientific basis for policy formulation, urban planning, and disaster risk reduction efforts within Lokoja and other rapidly urbanizing watersheds in Nigeria.

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Author contributions
Dr. Ngozi Gloria Johnson conceived the study and was responsible for the design and development of the data analysis. Nnach I. Nnachi and Mr. Emmanuel Achegbulu were responsible for data collection and analysis in GEE. Dr. Happy O. John-Nwagwu and Dr. Ngozi Gloria Johnson were responsible for data interpretation and write-up, corrections and proofreading

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No competing financial, professional, or personal interests on this study

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