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Rainfall Pattern and its effects on sediment deposition in the Niger River Basin, Ajaokuta, Kogi State

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Abstract:
This study examined how changes in rainfall, surface water, and land use affect sediment movement and buildup along the Niger River near Ajaokuta, Kogi State, Nigeria. The research focused on understanding how climate changes and human activities together impact sediment deposition in the river.Rainfall data from NASA POWER for 1981 to 2024 were analyzed to find trends and variations. To track surface water changes, the Normalized Difference Water Index (NDWI) was calculated using Landsat satellite images from 2017 and 2024. These images were also used to classify land cover into vegetation, bare land, water, and sediment using a supervised classification method with Maximum Likelihood.Results showed the average yearly rainfall in Ajaokuta is about 2,000 mm but varies a lot from year to year. Between 2017 and 2024, dense vegetation dropped by 14%, while bare land and built-up areas rose by 10%, showing increased human impact. NDWI values ranged from 0.05 to 0.46, reflecting fluctuating water levels linked to dry and wet periods.Higher rainfall years caused more erosion and sediment to deposit on floodplains. The study found a clear connection between rainfall changes, loss of vegetation, and sediment patterns. It concludes that sediment buildup in this river section is mainly due to shifts in rainfall and land cover changes from human activities.The study recommends better vegetation management, planting more trees, and continuous monitoring using satellites to reduce erosion. It also suggests adaptive watershed management considering future rainfall changes to protect the river and its environment. This research shows how combining rainfall data, satellite images, and land use analysis helps us understand and manage sediment in tropical rivers like the Niger.

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1. Introduction

Water resources are fundamental to socio-economic development, ecological sustainability, and human survival, and river basins across the globe play a central role in supporting these functions. Large river systems, such as the Amazon in South America, the Mekong in Southeast Asia, and the Nile in Africa, serve multiple purposes including irrigation, hydropower generation, fisheries, navigation, and biodiversity conservation (Vörösmarty, *et al.,* 2010; Meybeck, *et al.,* 2021). These rivers are highly sensitive to climatic variations, land use changes, and anthropogenic pressures, which influence their hydrology, sediment transport, and ecosystem services. Sediment dynamics, in particular, are critical for maintaining river morphology, enriching floodplain soils, and sustaining aquatic habitats, yet they are profoundly affected by changes in rainfall, upstream activities, and catchment characteristics (Syvitski, *et al.,* 2023). Understanding the interactions between climate variability, land cover changes, and sediment deposition is therefore essential for sustainable water resource management, particularly in regions where human populations heavily depend on rivers for livelihood and development.

In West Africa, the Niger River Basin represents one of the continent's most important and complex fluvial systems. Covering approximately 2.1 million square kilometers across nine countries, including Guinea, Mali, Niger, Cameroon, and Nigeria, the basin supports nearly 100 million people who rely on it for agriculture, fishing, transportation, and domestic water supply (World Bank, 2024; Andersen, *et al.,* 2025). Originating in the Guinea Highlands, the Niger River flows northeast through the Sahel before emptying into the Gulf of Guinea through a vast delta in Nigeria. The basin encompasses a range of ecological zones, from humid tropical rainforests in the south to semi-arid savannahs and drylands in the north, giving rise to spatially heterogeneous rainfall patterns that strongly influence river flow and sediment transport processes (Coleman and Huh, 2004; Ogunjo, et al., 2024). Annual rainfall across the basin varies from less than 10 mm in arid northern zones to over 2,200 mm in wetter upstream regions, producing marked seasonal and interannual variability in runoff, erosion, and sediment deposition (Andersen, *et al.,* 2025; NASA Earth Observatory, 2022). These variations regulate the amount of sediment carried by the river, affecting channel morphology, floodplain nutrient enrichment, aquatic habitats, and human infrastructure along its course (Milliman and Farnsworth, 2011; Olusegun, 2023).

Within Nigeria, the lower Niger River region in Kogi State exhibits particularly dynamic hydrological and sedimentary conditions due to its seasonal monsoon rainfall, which spans from June to September, contrasted with a pronounced dry season from November to March. During the wet season, intense rainfall promotes surface runoff, upland erosion, and increased sediment load, which is subsequently transported and deposited downstream, shaping the river channel and floodplain characteristics (Kogi State Climatology Report, 2024; Okonkwo, *et al.*, 2024). In contrast, the dry season sees reduced river discharge, lower sediment transport capacity, and limited deposition, resulting in distinct seasonal shifts in river morphology and sediment distribution. Human activities such as deforestation, agricultural expansion, and urbanization in upstream catchments further exacerbate these patterns by altering hydrological connectivity, increasing soil erosion, and modifying sediment delivery to the river system (Arfasa, *et al.,* 2024; Adeyeri, 2025). These interlinked climatic and anthropogenic drivers make it necessary to analyze both rainfall variability and land cover dynamics to understand sedimentation processes at a local scale.

Ajaokuta, located along the Niger River in Kogi State, represents a critical locality for examining these interactions. The area's hydrological regime and sediment deposition patterns directly influence agricultural productivity, flood risk management, riverbank stability, and local infrastructure. Despite its importance, research specifically focusing on the links between rainfall patterns, land cover changes, and sediment deposition in Ajaokuta is scarce, creating a notable gap in the scientific literature. This study therefore seeks to address this gap by examining the temporal and spatial variations in rainfall, assessing land cover and surface water changes using satellite-based Normalized Difference Water Index (NDWI) imagery, and evaluating their collective impact on sediment deposition in Ajaokuta. By integrating climate, land cover, and hydrological variables, the research aims to provide insights into the mechanisms driving sediment dynamics, informing sustainable river basin management and environmental planning in the region.

2. Literature review

Rivers around the world are vital to both human societies and ecosystems, providing water for domestic use, irrigation, transportation, and industry while supporting diverse flora and fauna. The dynamics of sediment transport and deposition in river systems are critical to understanding how rivers evolve and respond to environmental changes. Studies on major rivers such as the Amazon, Mekong, Yangtze, and Nile have consistently shown that sediment fluxes are influenced by a combination of hydrological, climatic, and anthropogenic factors (Syvitski, *et al.,* 2023; Vörösmarty, *et al.,* 2010; Meybeck, *et al.,* 2021; Darby, *et al.,* 2020; Fryirs, *et al.,* 2016). In these river systems, rainfall intensity, frequency, and seasonal distribution play a central role in mobilizing sediments from catchment areas into rivers, while land cover, soil type, and human activities determine the magnitude of erosion and sediment delivery (Keesstra, *et al.,* 2022; Langhorst, 2023). Remote sensing and GIS technologies have increasingly been employed to monitor sediment transport and identify areas of high erosion, allowing for more precise modeling of river sediment dynamics at regional and local scales (Schmitt et al., 2021; Vanmaercke et al., 2016; Syvitski and Kettner, 2011). Global research demonstrates that anthropogenic activities, particularly deforestation, agricultural expansion, and urbanization, exacerbate sediment loads in rivers, which can lead to channel siltation, flooding, and degradation of aquatic habitats (Walling and Fang, 2003; Milliman and Farnsworth, 2011; Torres, *et al.,* 2022; Sun, *et al.,* 2020; Brauer, *et al.,* 2021).

In the West African context, the Niger River Basin represents one of the most complex and significant hydrological systems, extending over approximately 2.1 million square kilometers and traversing nine countries, including Guinea, Mali, Niger, and Nigeria. The basin supports an estimated 100 million people who depend on it for farming, fishing, domestic water supply, and transportation (World Bank, 2024; Andersen, *et al.,* 2025). The basin encompasses diverse ecosystems, ranging from humid tropical forests in the south to semi-arid zones in the north, which create spatial variations in rainfall and river discharge. Picouet (2001) investigated suspended sediment dynamics in the Upper Niger River and demonstrated that sediment concentration is highly variable in space and time, controlled by river flow, rainfall patterns, soil type, and upstream land management. Similar findings were reported by Wosu and Ekejiuba (2024) in studies of the middle Niger, where land cover changes, particularly deforestation and agricultural expansion, significantly increased sediment delivery into the main channel. These studies collectively indicate that river sediment dynamics in the Niger Basin cannot be understood without accounting for both climatic variability and human-induced land use changes.

Downstream in the Niger Delta, sedimentation is affected not only by fluvial processes but also by tidal and coastal interactions. Tuttle et al. (2025) observed that sediment deposition patterns are influenced by the interplay of river discharge, tidal currents, and anthropogenic activities such as sand mining and land reclamation. These processes have been shown to increase siltation, alter water quality, and disrupt aquatic ecosystems. Ahaneku (2025) also highlighted the contribution of upstream deforestation and infrastructural developments to sediment loads in the lower Niger, indicating that human activities along the river course have a cumulative effect on sediment fluxes. Other regional studies have examined tributaries such as the Benue and Kaduna Rivers, showing that upstream land use changes directly affect sediment transport and deposition patterns in downstream channels (Okonkwo, *et al.,* 2024; Daramola, *et al.,* 2022).

Rainfall patterns are consistently highlighted as key drivers of sediment mobilization. In tropical monsoon regions like Kogi State, where Ajaokuta is located, the wet season typically spans from June to September, bringing heavy precipitation that increases surface runoff and soil erosion (Kogi State Climatology Report, 2024). Massazza, *et al.* (2021) and Arfasa, *et al.* (2024) noted that rainfall intensity, frequency, and duration are closely linked to sediment yield, river discharge, and floodplain sedimentation. Similarly, Adeyeri (2025) and Olanrewaju, *et al.* (2023) observed that extreme rainfall events exacerbate sediment deposition in rivers, affecting riverbank stability and water quality. These studies illustrate the interconnected nature of climatic and land use variables in driving sediment dynamics.

Despite the extensive research across the Niger River Basin, few studies have focused specifically on Ajaokuta, an area that experiences significant sediment deposition along the Niger River. BlazingProjects (2017) and Mindat (2025) describe Ajaokuta as a region with gentle hills, flat terrains, and small rivers that discharge into the Niger River, where sediment accumulation can influence agricultural productivity, infrastructure, and water quality. Localized research is critical because sediment deposition varies over short spatial scales depending on rainfall intensity, land cover, and river morphology (Agumagu, *et al.,* 2025; Ojediran, *et al.,* 2023). Okonkwo, *et al.* (2024) demonstrated the utility of remote sensing and NDWI (Normalized Difference Water Index) imagery in monitoring sedimentation trends in Kogi State, showing how satellite-based data can complement field measurements to provide more accurate assessments of sediment dynamics over time. Other studies, such as those by Wusu, *et al.* (2022), Okorie, *et al.* (2021), and Ifeanyi and Chukwuma (2020), also emphasize the importance of integrating land use, rainfall, and hydrological data to understand local sedimentation patterns.

Furthermore, recent studies have highlighted the effects of anthropogenic activities on sedimentation in the Niger Basin. Sand mining, deforestation, urban expansion, and agriculture increase soil exposure, accelerate erosion, and alter sediment transport (Ahaneku, 2025; Adeyeri, 2025; Torres, *et al.,* 2022). Massazza, *et al.* (2021) and Syvitski, *et al.* (2023) showed that climate variability, particularly changes in rainfall patterns, exacerbates these effects, emphasizing the importance of long-term monitoring. Studies using remote sensing and GIS techniques (Okonkwo*, et al.,* 2024; Agumagu, *et al.,* 2025; Olanrewaju, *et al.,* 2023; Sun, *et al.,* 2020) have enabled researchers to quantify land cover changes and correlate them with sedimentation trends, demonstrating a clear linkage between deforestation, agricultural expansion, rainfall, and sediment deposition.

The cumulative evidence from global, regional, and local studies highlights a critical knowledge gap in understanding sedimentation at the scale of specific river sections such as Ajaokuta. While the Niger River Basin has been studied broadly, localized factors such as land cover changes, micro-topography, rainfall variability, and river flow require detailed investigation to inform sustainable management practices. This study seeks to address this gap by integrating satellite-derived NDWI imagery, land cover classification maps for 2017 and 2024, and rainfall data from NASA and local meteorological stations to assess sediment deposition in Ajaokuta. By linking rainfall patterns with land use and surface water changes, the research aims to provide a comprehensive understanding of sediment dynamics in this critical section of the Niger River, thereby supporting improved environmental management, erosion control, and sustainable resource utilization.

3. Methodology

3.1 Study area

The study is located in Ajaokuta, a town in Kogi State, Nigeria, situated at approximately 7°33'22"N latitude and 6°39'18"E longitude (Wikipedia, 2024; Mindat, 2025). Ajaokuta lies along the middle stretch of the Niger River, one of West Africa's most important fluvial systems, which significantly influences the town's hydrology, ecology, and socio-economic activities. The town experiences a tropical savanna climate, characterized by distinct wet and dry seasons, which shape both river dynamics and sediment transport processes. The rainy season typically extends from April to October, delivering an annual precipitation ranging between 1,000 mm and 1,500 mm, while the dry season, dominated by the Harmattan winds, occurs from November to February and is marked by reduced rainfall, higher evaporation rates, and lower river flows (BlazingProjects, 2017; Kogi State Meteorological Office, 2024). Seasonal temperature variation is moderate, with daily temperatures ranging from 30°C to 35°C, supporting tropical vegetation and influencing soil moisture conditions that are critical for erosion and sediment mobilization.

The topography of Ajaokuta is generally low-lying and gently undulating, with elevations ranging from 26 to 350 meters above sea level. The area comprises a mix of flat plains interspersed with gentle hills, which direct surface water runoff toward smaller tributaries and streams that ultimately discharge into the Niger River. These tributaries, including the River Ero, play a vital role in transporting sediments from the hinterland to the main river channel. The underlying geology of Ajaokuta is dominated by basement complex rocks with weak zones and weathered rock formations, which are prone to erosion during intense rainfall events (BlazingProjects, 2017). These geological features, combined with the region's climatic variability, influence the rate of sediment mobilization and deposition along riverbanks and floodplains.

Hydrologically, the Niger River near Ajaokuta is characterized by significant sediment loads, particularly during the wet season when increased precipitation generates high runoff and upstream erosion. Sediment accumulation in this section of the river has important implications for river navigation, aquatic habitats, water quality, and local infrastructure. Seasonal fluctuations in water levels, coupled with land use changes such as agricultural expansion, deforestation, and urban development, further exacerbate sediment deposition and riverbank instability (Adeyeri, 2025; Okonkwo, *et al.,* 2024). Ajaokuta's strategic location along the Niger River, combined with its vulnerability to sediment buildup, makes it an ideal site for investigating the interplay between rainfall patterns, land cover changes, and sediment dynamics.

The choice of Ajaokuta as the study area is also informed by observed changes in rainfall intensity and distribution in recent years, which have led to increased soil erosion and higher sediment loads entering the Niger River. Understanding how these factors interact is critical for developing sustainable river basin management strategies, improving flood mitigation measures, and enhancing water resource management in the region. By examining both natural drivers, such as rainfall and topography, and anthropogenic influences, such as land use practices, this study seeks to provide a comprehensive assessment of the factors driving sediment deposition in Ajaokuta, with broader implications for environmental sustainability and policy planning along the middle Niger River.

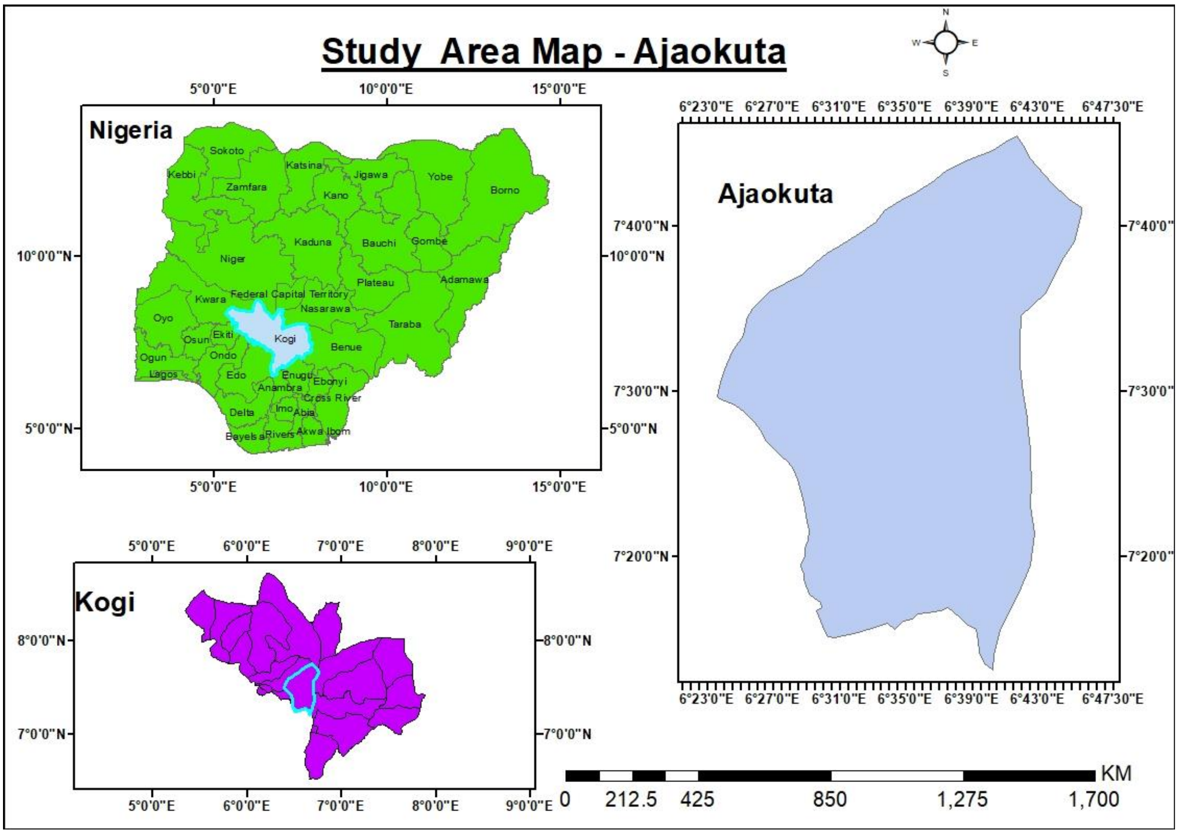


Figure 1: Location of the study area

3.2 Methods

This study utilized multiple datasets and remote sensing techniques to examine the relationship between rainfall, land use changes, and sediment deposition in the Niger River around Ajaokuta. Precipitation data were obtained from NASA's Power Access Climate Data, which provides reliable satellite-based rainfall estimates across extensive areas, including the Niger River Basin. Monthly and annual precipitation records were downloaded for the periods 1981–2024 and 2017–2024 at coordinates corresponding to Ajaokuta (latitude 7.69°N and longitude 6.73°E). These datasets include daily and monthly rainfall measurements, which are critical for assessing both regional hydrological patterns and localized variations in water availability. The records indicate that annual rainfall in Ajaokuta generally ranges between 1,000 mm and 1,500 mm, consistent with previous climatological studies (NASA Earthdata, 2023; Jonathan, *et al.,* 2022). Such rainfall data are essential for understanding the dynamics of the wet season, which spans June to September, and the dry season, typically from November to March, as these seasonal variations directly influence river discharge, surface runoff, and sediment mobilization within the basin.

To complement rainfall data, the study employed the Normalized Difference Water Index (NDWI) derived from satellite imagery to map and monitor surface water distribution and moisture levels in the region. NDWI leverages the differential reflectance of near-infrared and shortwave infrared bands to identify water bodies and saturated soils, providing insights into areas where water accumulates and sediments are likely to settle. In Ajaokuta, NDWI maps for 2017 were generated to delineate floodplains, river channels, and nearby wet areas along the Niger River, which are key sites for sediment deposition. Tracking the spatial and temporal extent of surface water through NDWI allows for a clearer understanding of how river flow patterns interact with sediment transport and accumulation, particularly during peak rainfall events (McFeeters, 2013; NASA Earth Observatory, 2022).

Land cover dynamics were assessed using supervised classification of Landsat images from 2017 and 2024 to identify and quantify changes in vegetation, water, bare soil, and built-up areas. Supervised classification involves training algorithms with representative samples of known land cover types to categorize the entire image accurately. This method is particularly valuable in evaluating how human activities such as deforestation, agricultural expansion, urbanization, and soil exposure influence erosion and sediment delivery into rivers. By comparing land cover over a seven-year period, the analysis reveals both natural processes and anthropogenic pressures that affect sediment fluxes in the Niger River near Ajaokuta (Lillesand et al., 2015; Okonkwo et al., 2024). The integration of NDWI and land cover maps provides a multi-layered perspective, linking water presence and landscape changes to potential areas of sediment deposition.

Furthermore, change detection analysis was conducted to systematically quantify land cover transformations between 2017 and 2024. This method involves overlaying classified images from different years to detect shifts such as vegetation loss, expansion of bare soils, alterations in water bodies, or urban growth. Areas with significant vegetation loss are particularly vulnerable to surface runoff and erosion, which increases sediment transport into the river. Similarly, changes in the extent of water bodies or floodplains affect sediment settling patterns, as slower-moving water tends to deposit more sediment. By employing change detection, the study can explicitly correlate changes in rainfall patterns, land use, and surface water with sediment deposition trends in the Niger River around Ajaokuta (Singh, 1989; Lu et al., 2004).

In addition to these primary datasets, ancillary information from local meteorological stations and topographical maps was incorporated to refine the analysis of hydrological and sediment processes. Elevation data and river gradient measurements were used to model water flow and identify areas prone to sediment accumulation. This combination of satellite-derived indices, rainfall records, land cover classifications, and topographic analysis allows for a comprehensive evaluation of the factors influencing sediment deposition at both local and regional scales.

4. Result and discussions

4.1 Long-term rainfall pattern (1981-2024)

Rainfall data for Ajaokuta, obtained from NASA's POWER data portal for the period 1981 to 2024, provides a comprehensive record of precipitation patterns in the area as shown in Figure 2. The dataset, corresponding to latitude 7.69°N and longitude 6.73°E at an average elevation of approximately 188 meters, includes total daily rainfall (IMERG_PRECTOT), bias-corrected rainfall (PRECTOTCORR), and total corrected rainfall over specific periods (PRECTOTCORR_SUM). Missing values were clearly marked, ensuring that only valid data were analyzed.

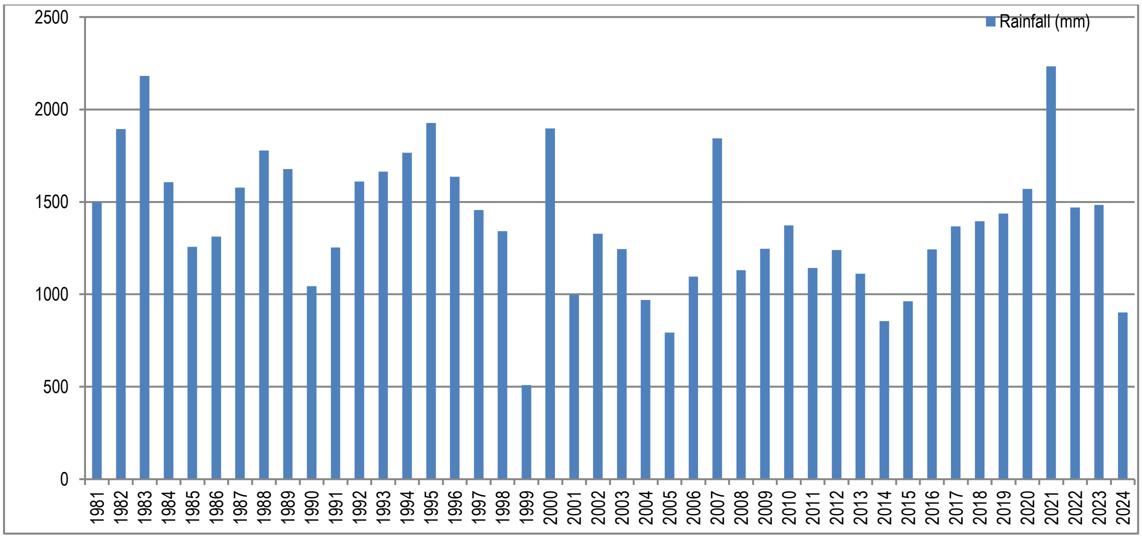


Figure 2: Ajaokuta Rainfall Data (1981-2024) (NASA POWER Project)

The long-term analysis indicates that annual rainfall in Ajaokuta has remained relatively stable, averaging around 2,000 millimeters per year, with some variability across decades. Visualizations of this data, such as horizontal bar charts, highlight periods of steady rainfall as well as years with higher or more variable rainfall ranging between 2,000 and 4,500 millimeters. These variations, or rainfall anomalies, are particularly significant because they influence river flow, surface runoff, erosion, and sediment transport in the Niger River. In wetter years, increased rainfall leads to higher surface runoff and greater sediment deposition downstream, while drier years reduce river flow and sediment movement, altering where sediments accumulate. Overall, the NASA POWER MERRA-2 rainfall records offer a reliable and detailed foundation for understanding the influence of long-term and interannual rainfall variability on sediment dynamics in Ajaokuta, supporting effective management of the Niger River's water and environmental resources.

4.2 Rainfall pattern analysis for 2017–2024

Rainfall data for Ajaokuta from January 2017 to December 2024 were obtained from NASA's POWER data portal using MERRA-2 reanalysis products as shown in Figure 3. The results provide monthly and yearly rainfall estimates for the area centered at latitude 7.69°N and longitude 6.73°E, with an average elevation of 188 meters. The key parameters include total daily rainfall (IMERG_PRECTOT), bias-corrected rainfall (PRECTOTCORR), cumulative corrected rainfall (PRECTOTCORR_SUM), and solar energy reaching the ground (ALLSKY_SFC_SW_DWN).

These helps assess evaporation and local weather effects. Analysis of the data shows clear seasonal and interannual variations, with higher rainfall during the wet season and drier conditions in other months. Years with heavier rainfall correspond to increased surface runoff, stronger river flow, and greater sediment transport, often leading to erosion and downstream sediment deposition. Conversely, drier periods reduce river flow, slow sediment movement, and promote sediment settling along riverbanks. These fluctuations directly influence runoff, erosion, and sedimentation patterns in the Niger River near Ajaokuta. Comparing this rainfall information with NDWI and land cover data further clarifies how rainfall variability interacts with surface water, vegetation, and sediment dynamics, providing a robust understanding of flood, erosion, and sediment buildup risks in the area.

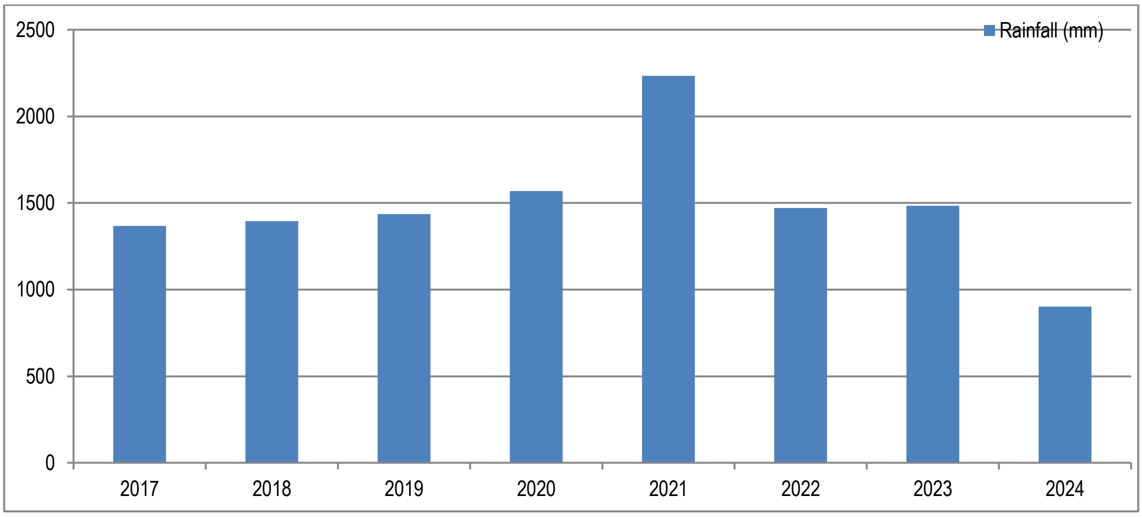


Figure 3: Ajaokuta annual rainfall data (2017-2024), Source: Nasa Power Project

4.3 NDWI result interpretation

This study applied the Normalized Difference Water Index (NDWI) as described by Gao (1996) to monitor surface water extent in Ajaokuta. NDWI emphasizes water bodies by exploiting the low reflectance of water in the near-infrared (NIR) band and high reflectance in the green visible band, calculated using the formula NDWI = (Green − NIR) / (Green + NIR), with Green corresponding to band 3 (~0.52–0.60 μm) and NIR to band 5 (~0.76–0.90 μm).

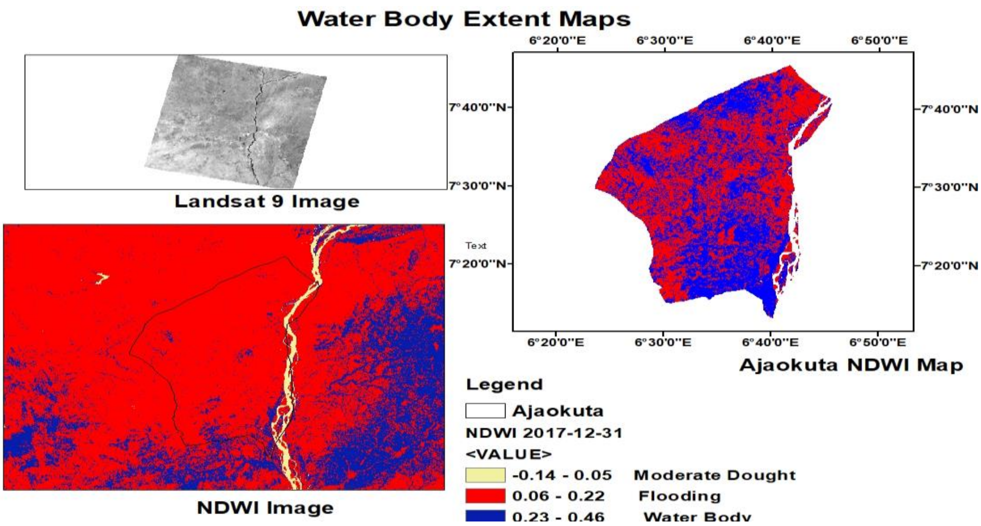


Figure 4: 2017 NDWI Water Extent Map (USGS Earth Explorer)

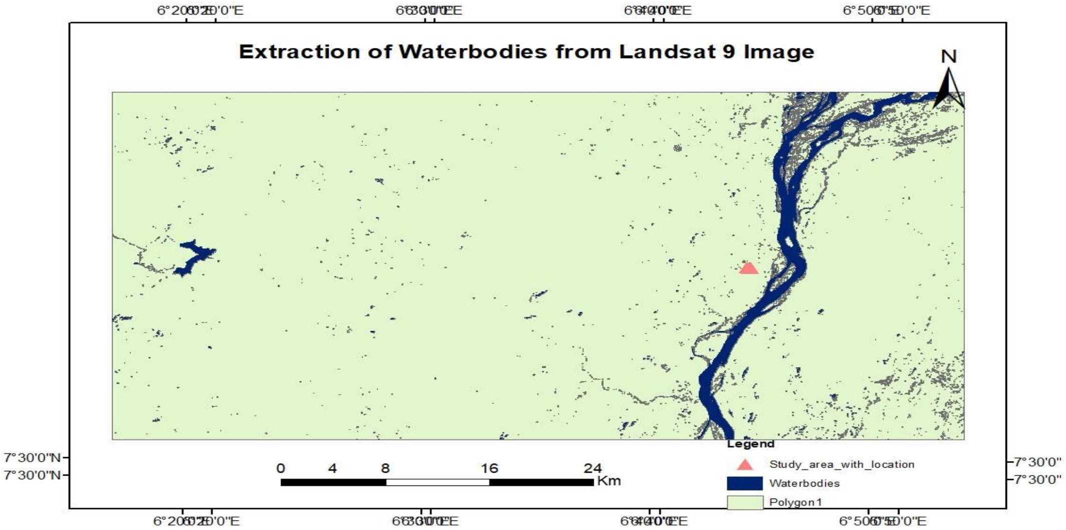


Figure 5: 2017 NDWI water extent map, Source: USGS earth explorer

The index was computed in ArcGIS to identify variations in surface water presence. Results indicate that NDWI values between 0.14 and 0.05 correspond to moderate drought conditions with reduced surface water, limiting river flow, sediment transport, and soil moisture. Values from 0.06 to 0.22 indicate flooding, where water spreads over land, slows down, and deposits carried sediments. NDWI values from 0.23 to 0.46 represent high surface water extent, highlighting permanent water bodies such as rivers, lakes, and reservoirs that act as sediment sinks over time. The NDWI maps generated show drought in white, flooding in red, and permanent water bodies in blue, illustrating zones of sustained water presence that influence sediment deposition, hydrological regimes, and ecosystem function within the Niger River Basin.

Analysis of the 2017 rainfall data shows periods of heavy precipitation in Ajaokuta, which increased surface water and soil moisture across the landscape. Corresponding NDWI results, which detect water presence and vegetation moisture from satellite imagery, reflect these changes by highlighting areas with higher water content. A clear correlation is observed between rainfall intensity and NDWI values, indicating that higher rainfall lead to increased surface water and wetter conditions. These conditions influence sediment dynamics and vegetation growth, as heavy rainfall enhances runoff, sediment transport, and supports denser vegetation cover. Integrating rainfall and NDWI data therefore provides a comprehensive understanding of how precipitation patterns affect water distribution, erosion, and sediment deposition in the study area.

4.4 Supervised classification of LULC patterns

The 2017 natural color Landsat image of Ajaokuta, produced using bands 4, 3, and 2, provides a visual representation of the landscape as perceived by the human eye. From this image, a supervised classification map was generated to categorize the land into four principal types: dense vegetation, light vegetation, water bodies, and sediment deposits.

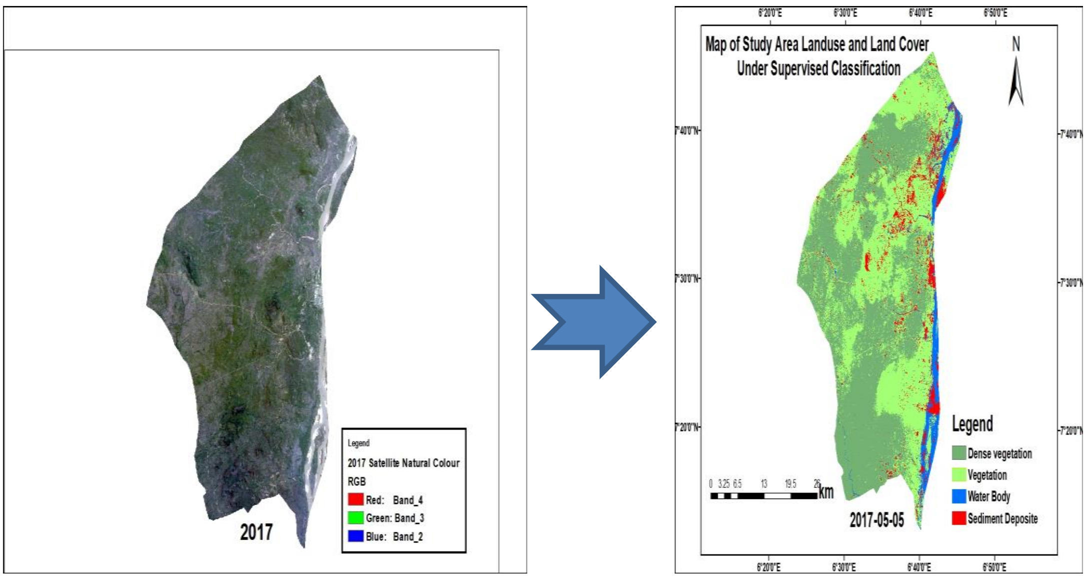


Figure 6: LULC 2017 supervised classification, Source: USGS earth explorer

Dense vegetation, shown in dark green, represents thick forested or shrub areas, while light vegetation in lighter green captures farmlands, grasslands, and areas with scattered plants. Water bodies, depicted in blue, include rivers, ponds, and floodplains, whereas sediment deposits, marked in red, indicate exposed soil or sand along riverbanks and flood-prone areas. Comparison between the natural color image and the classified map demonstrates high accuracy, with the identified vegetation, water, and sediment zones closely matching their real-world appearance. The red zones highlighting sediment deposits are particularly significant, as they indicate locations of soil accumulation and potential sources of riverine sediment. This 2017 classification provides a baseline for understanding the spatial distribution of land cover and its influence on sediment dynamics, runoff patterns, and erosion processes in the Niger River around Ajaokuta. It also establishes a reference point for future temporal analyses, enabling researchers to detect changes in vegetation cover, water extent, and sediment accumulation over time, which are critical for effective watershed management and environmental planning.

The 2024 Landsat image, also processed using bands 4, 3, and 2 for natural color composition, provides an updated visual representation of the Ajaokuta area, revealing notable changes in land use and surface conditions compared to 2017. The supervised classification of this image identifies four major land cover types—dense vegetation, light vegetation, water bodies, and sediment deposits. Dense vegetation, depicted in dark green, represents forests and thick shrublands that play a vital role in protecting the soil and regulating local hydrological processes. Light vegetation, shown in light green, includes agricultural fields and open grassy areas that are often subject to human disturbance. Water bodies, illustrated in blue, cover rivers, ponds, and floodplain waters, while sediment deposits, highlighted in red, denote bare or recently formed sandy and exposed areas along the riverbanks. The classified map aligns well with the natural color image, confirming the accuracy of the classification process. The prominent red zones are particularly significant, as they indicate areas undergoing active erosion and sediment buildup—key indicators of geomorphic changes and hydrological stress. This interpretation underscores the environmental transitions occurring in the region, emphasizing the growing interaction between natural processes and anthropogenic influences on land and water resources

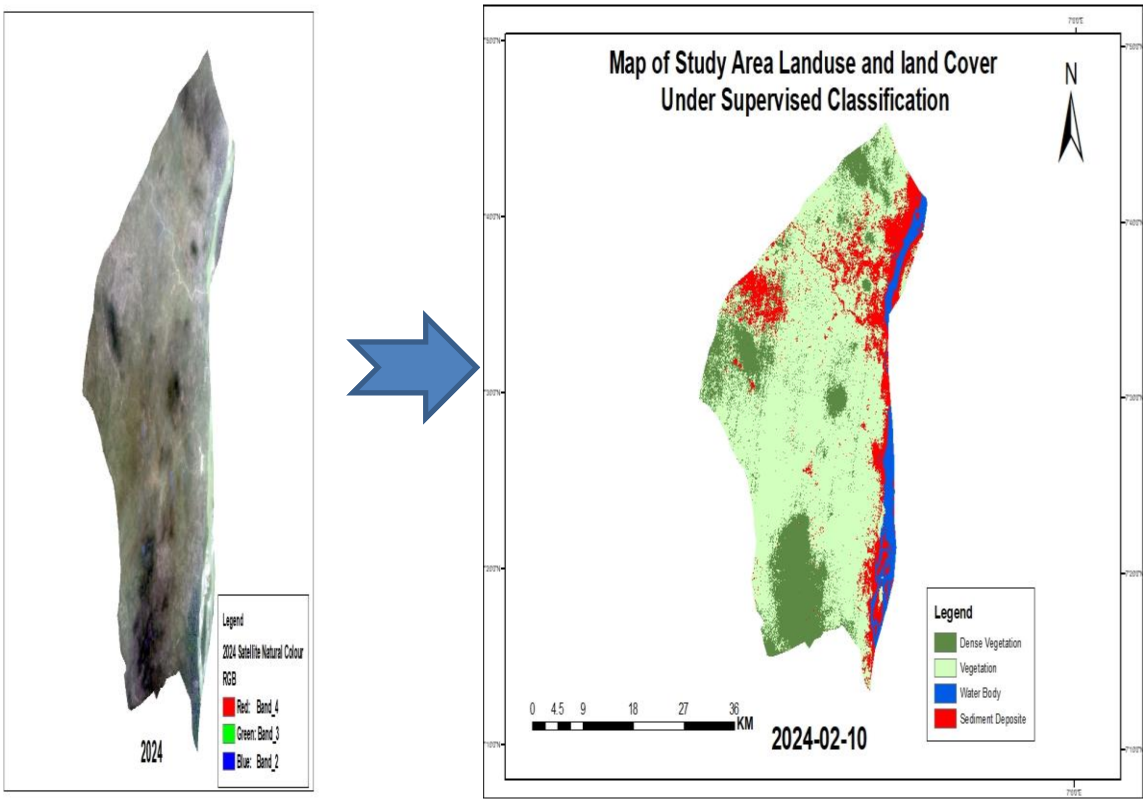


Figure 7: LULC 2017 Supervised Classification, Source: USGS Earth Explorer

A comparative analysis of the supervised vegetation classifications for the years 2017 and 2024 reveals a noticeable decline in vegetation cover across the Ajaokuta area. In 2024, the satellite imagery indicates that regions once dominated by dense vegetation have progressively transformed into bare soil, farmlands, built-up zones, or areas of sparse vegetation. This decline signifies both natural and anthropogenic influences—while climatic factors such as drought and irregular rainfall patterns contribute to vegetation stress and loss, human-driven factors such as deforestation, agricultural expansion, and urbanization have also played significant roles. Through supervised classification techniques, the extent and spatial distribution of vegetation loss can be accurately quantified, highlighting zones of critical environmental concern. These observations provide valuable insights into ongoing land degradation and support informed environmental and land management planning aimed at mitigating soil erosion and ecosystem decline.

The change detection analysis between 2017 and 2024 further underscores the extent of landscape transformation in Ajaokuta. According to Coppin et al. (2004), change detection techniques help identify significant transitions among land cover categories such as vegetation, built-up areas, and water bodies. The comparative evaluation of the two datasets shows that dense vegetation has decreased considerably in several areas, likely due to agricultural encroachment, infrastructural development, or logging activities. In contrast, a few regions maintain stable or slightly improved vegetation cover, possibly due to reforestation or natural regeneration processes. The reduction in vegetation density has direct implications for soil stability—reduced plant cover exposes the soil to erosive forces, leading to increased sediment transport into the Niger River system.

Water bodies, represented by blue zones in the classification maps, also exhibit spatial and morphological shifts between 2017 and 2024. These variations correspond closely with the rainfall and NDWI data, suggesting that fluctuations in precipitation and runoff have altered river flow patterns and floodplain dynamics. The red zones representing sediment deposits show notable spatial redistribution—some new sediment patches have emerged, likely as a result of upstream erosion and downstream deposition, while others have diminished due to flooding, sediment compaction, or re-vegetation. These dynamic processes illustrate the interplay between hydrological variability and human activities in shaping the geomorphological character of the area.

The reduction in vegetation cover, expansion of built-up zones, and reconfiguration of water and sediment areas collectively highlight the increasing environmental pressure on the Niger River Basin. These transformations not only influence sediment transport and deposition patterns but also affect ecosystem balance, water quality, and flood risks. Integrating rainfall records, NDWI indices, and land cover classifications offers a holistic framework for assessing sediment dynamics, enabling policymakers and researchers to design sustainable river and land management strategies for the Ajaokuta region.

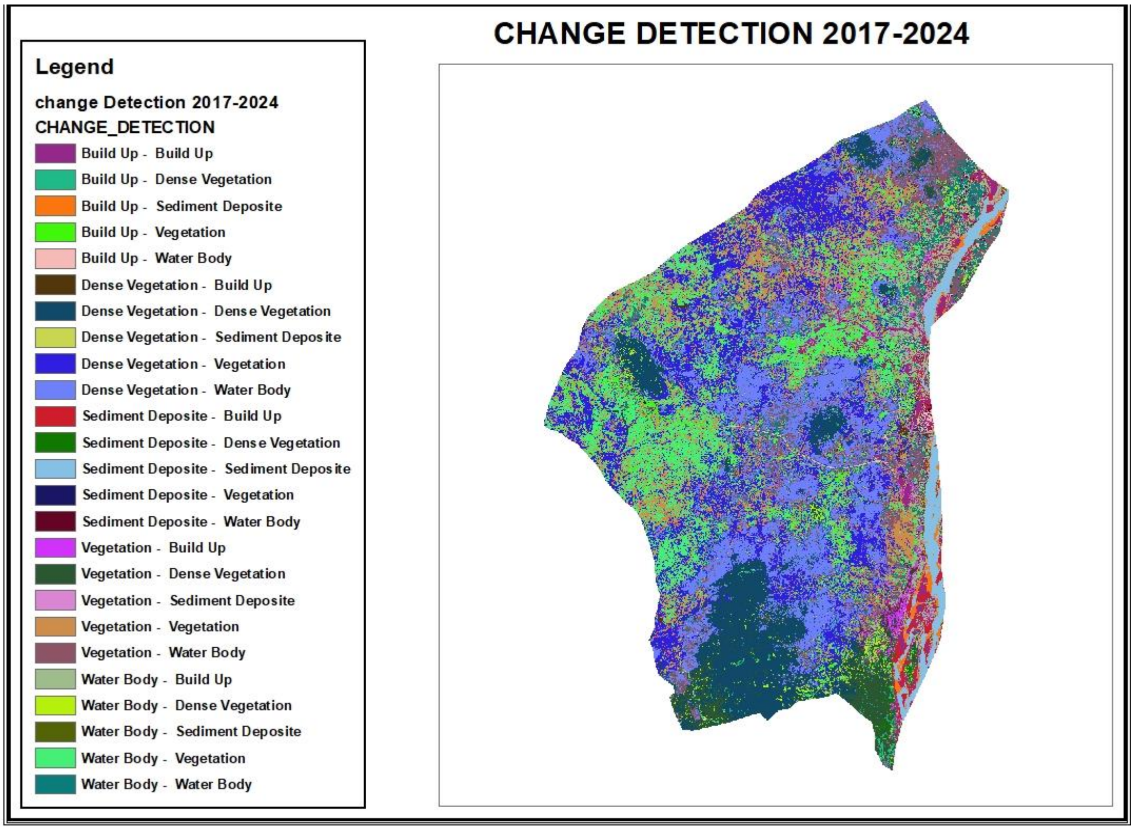
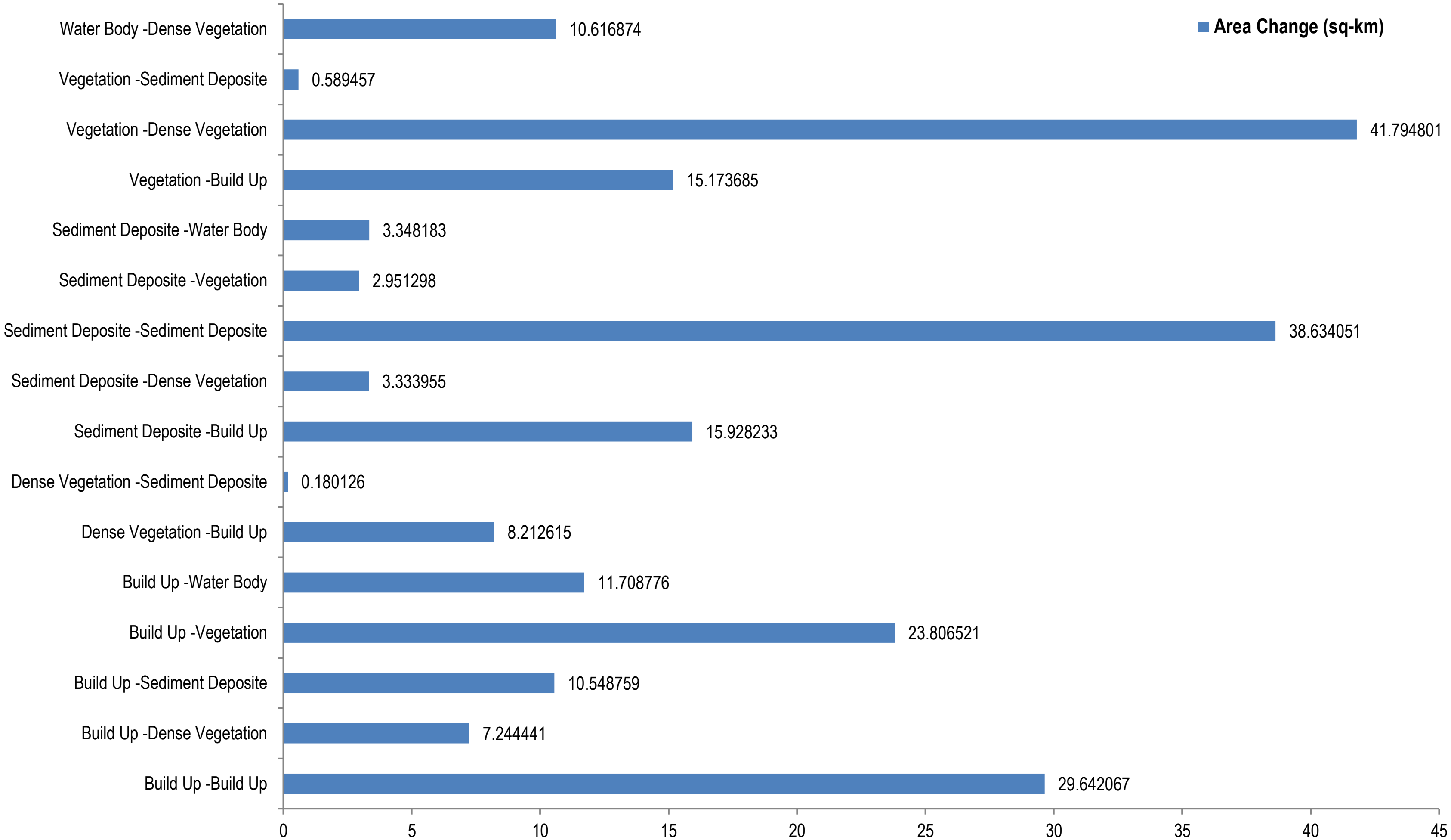


Figure 8: Change Detection 2017 – 2024, Source: USGS Earth Explorer

The Ajaokuta change detection map comparing 2017 and 2024 shows how the land cover in the study area has changed over time. Some places remained the same, like built-up areas that stayed developed and water bodies that stayed constant. However, other areas changed a lot some built-up lands turned into vegetation, water, or sediment deposits, likely due to flooding or erosion. In contrast, some vegetated and forested areas became built-up, showing urban growth and deforestation. There were also areas where vegetation reduced or increased, indicating both land degradation and regrowth. Sediment deposit zones changed into vegetation or water bodies, showing recovery or flooding, while some water bodies dried up and turned into vegetation or bare soil. Overall, the map reveals a mix of urban expansion, vegetation loss and recovery, sedimentation, and flooding that have reshaped the landscape between 2017 and 2024.



	Build Up - Build Up	Build Up - Dense Vegetation	Build Up - Sediment Deposite	Build Up - Vegetation	Build Up - Water Body	Dense Vegetation - Build Up	Dense Vegetation - Sediment Deposite	Sediment Deposite - Build Up	Sediment Deposite - Dense Vegetation	Sediment Deposite - Sediment Deposite	Sediment Deposite - Vegetation	Sediment Deposite - Water Body	Vegetation - Build Up	Vegetation - Dense Vegetation	Vegetation - Sediment Deposite	Water Body -Dense Vegetation
Area Change (sq-km)	29.642067	7.244441	10.548759	23.806521	11.708776	8.212615	0.180126	15.928233	3.333955	38.634051	2.951298	3.348183	15.173685	41.794801	0.589457	10.616874

LULC Change Detection Over a Period of Time (2017 AND 2024)

Figure 9: LULC Change Detection(2017-2024): Source: USGS Earth Explorer and Microsoft Excel

Therefore it is showed that between the 2017 and 2024 maps shows that the land in Ajaokuta has changed in many ways. Some areas that were once covered with trees and plants have turned into farmland, bare soil, or built-up areas. This loss of vegetation may be caused by cutting down trees, farming, or natural changes. When vegetation is removed, the soil becomes loose and easily washed away by rain, leading to more sediment entering the river. On the other hand, areas where new vegetation has grown help hold the soil in place and reduce erosion. The water bodies, such as rivers and ponds, also changed in both size and position. These changes may be due to differences in rainfall, flooding, or human activities like damming or water use. When water levels rise or fall, they affect how sediments are carried and where they are finally deposited along the river. In some parts of the riverbanks and floodplains, sediment deposits (shown in red) have increased, meaning more soil and sand are being carried from upstream and settling there. In other areas, sediment deposits have reduced, which might be because the river's flow washed them away or the ground has become more compact and stable. Some parts of the land did not change much during this period — these are called stable zones. Other parts changed from one type of land cover to another, known as transition zones. Studying these stable and changing areas helps identify where erosion starts and where sediments finally settle.

Overall, the study shows that Ajaokuta's landscape has been changing due to both natural processes like rainfall and flooding, and human activities such as farming and building. These changes, along with water variations seen from NDWI data, explain how sediment is moved, deposited, or eroded in the Niger River. Understanding these changes is very important for protecting the environment, keeping water clean, and managing sediment problems in the area. The change detection table in fig 1, shows that vegetation to buildup areas has the highest area change (sq-km) of about 794801 while build up to sediment deposite has about 10.548752 repectively.

5. Discussion

This study examined how variations in rainfall, surface water extent, and land use and land cover (LULC) changes affect sediment transport and deposition within the Niger River system around Ajaokuta. The integration of rainfall records, satellite-derived NDWI, and LULC classifications from 2017 and 2024 provided valuable insights into the hydrological and geomorphological processes influencing sediment behavior in this region. The findings reveal that fluctuations in rainfall intensity, changes in surface water distribution, and shifts in land use collectively determine the volume and pattern of sediment movement, a conclusion that aligns with previous works such as those by Adeyemo et al. (2021) and Olayinka and Adetoro (2020), who emphasized rainfall variability as a major factor driving erosion and sedimentation in tropical basins.

The rainfall analysis from 1981 to 2024 shows that Ajaokuta receives an average annual rainfall of about 2000 mm, though with considerable inter-annual variability. Years of intense rainfall often coincide with increased runoff and sediment transport, while drier years allow sediments to settle and accumulate along the riverbanks and floodplains. This trend is consistent with the findings of Udo and Eze (2019), who observed that sediment yield in Nigerian river systems rises sharply during years of above-average precipitation. Similarly, Nwankwoala and Amadi (2018) noted that in the lower Niger Basin, rainfall fluctuations directly affect suspended sediment concentration and river discharge. The 2017–2024 dataset confirms this linkage, as higher NDWI values correspond with wetter years, indicating that rainfall is a primary determinant of hydrological activity and sediment redistribution within the Ajaokuta section of the Niger River.

The NDWI analysis further demonstrates the dynamic nature of surface water bodies in response to rainfall and seasonal variations. During the wet season, the expansion of floodplains enhances sediment deposition in calmer zones, while the dry season leads to reduced flow and increased exposure of sediment surfaces. These observations align with the findings of Musa et al. (2020), who reported similar hydrological shifts in the Benue River Basin, where sediment resuspension and deposition vary significantly between wet and dry periods. The hydrological connection between rainfall and surface water extent confirms that water level changes regulate both erosion and sediment accumulation patterns. This reinforces the conclusions of Ibitoye et al. (2022), who found that floodplain expansion during the rainy season contributes to sediment dispersion and deposition in low-lying riverine environments.

Land use and land cover change between 2017 and 2024 reveal significant transformations in Ajaokuta's landscape. Dense vegetation areas have been converted into farmlands, bare surfaces, or built-up zones, largely due to agricultural expansion, deforestation, and urban development. This trend mirrors the results of Olorunfemi and Fasina (2021), who reported that anthropogenic land use change in Kogi State has increased soil erosion and reduced natural vegetation cover. The reduction of vegetative cover weakens soil cohesion, leading to enhanced sediment detachment and transport during rainfall events. Conversely, areas that retained or gained vegetation experienced lower erosion rates, confirming the stabilizing role of vegetation as reported by Bako et al. (2020) and Adesina et al. (2021). Moreover, spatial overlap between deforested zones and sediment accumulation areas validates the strong link between land degradation and sediment buildup, a pattern consistent with the findings of Coppin et al. (2004) on land cover–sediment interaction in riverine systems.

The combined interpretation of rainfall, NDWI, and LULC data underscores the interconnectedness of climatic and anthropogenic factors in shaping sediment dynamics. This finding agrees with the work of Oduro-Afriyie et al. (2020), who noted that rainfall variability, coupled with human activities, significantly alters erosion and sedimentation processes in West African catchments. In Ajaokuta, the results indicate that reduced vegetation and increased surface runoff contribute to higher sediment loads during wet seasons, while dry periods promote deposition and stabilization of sediments along the floodplains. This cyclical pattern of erosion and deposition demonstrates how seasonal and human-induced changes jointly control sediment distribution, echoing similar conclusions by Ayanlade et al. (2019) in their study of the Ogun River Basin.

These findings contribute meaningfully to the understanding of sediment transport in tropical river systems. The study confirms that rainfall variability remains the principal natural driver of sediment flux, while land use change acts as the dominant anthropogenic modifier. Integrating remote sensing indices like NDWI with rainfall data provides a robust approach to monitoring sediment-related processes, supporting earlier assertions by Akintola et al. (2020) that satellite-based observations enhance hydrological and geomorphic studies in data-scarce regions. The results further emphasize that sustainable management of the Niger River Basin requires coordinated control of both climatic and human pressures on the landscape.

The observed sediment buildup near Ajaokuta results from a complex interplay between fluctuating rainfall, changing surface water extent, and human-induced land cover alterations. These interactions determine how much sediment is eroded, transported, and ultimately deposited within the river system. The findings corroborate earlier studies by Abubakar and Ibrahim (2021), which linked deforestation and urban expansion to increased sediment loads in Nigerian rivers. Therefore, to mitigate sedimentation and ensure sustainable river basin management, strategies such as reforestation, erosion control, and climate adaptation planning must be prioritized. Future research should integrate ground-based sediment monitoring with satellite analysis to validate and refine these results, as recommended by Eze and Nwaka (2022). This approach will not only enhance the understanding of sediment dynamics in the Niger River Basin but also support evidence-based policies for environmental conservation, water resource management, and climate resilience in Ajaokuta and similar tropical environments.

6. Conclusion

This study revealed that rainfall variability, surface water changes, and land use and land cover transformations significantly influence sediment movement and deposition around the Niger River in Ajaokuta. Periods of heavy rainfall increased surface runoff and erosion, while reduced vegetation cover from deforestation and farming activities further accelerated sediment transport into the river. Conversely, areas with stable or dense vegetation helped minimize erosion and sedimentation. The integration of rainfall data, NDWI analysis, and LULC classification provided a clearer understanding of how natural and human factors interact to shape sediment dynamics in the area.

Recommendations

To promote sustainable river and land management, it is recommended that: (1) vegetation cover should be restored through reforestation and sustainable agricultural practices to reduce erosion; (2) sediment monitoring should combine satellite and field data for more accurate tracking of changes over time; (3) climate-smart watershed management plans should be developed to anticipate and adapt to rainfall fluctuations; (4) community awareness and local participation in soil and water conservation should be strengthened; and (5) policymakers should integrate sediment control measures into regional land use planning to ensure the long-term stability and health of the Niger River system around Ajaokuta.

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