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RESEARCH ARTICLE

ASSESSMENT OF FLOOD RISK USING CLIMATE DATA AND LAND USE/LAND COVER IN URBAN AREAS OF EDO STATE

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ABSTRACT

Urban flooding in Edo State, Nigeria, has intensified due to rapid urbanization, land use/land cover (LULC) change, and climatic variability. Identifying areas of exposure and vulnerability is critical for planning and risk reduction. This study employed Geographic Information Systems (GIS) and Remote Sensing (RS) to analyze Landsat imagery and classify LULC. Climate data (rainfall and temperature distribution) were integrated to map flood vulnerability across the study area. Flood risk zones were further delineated using spatial analysis of land cover, topography, and climatic factors. Landsat image classification identified five land cover types: built-up areas (14.58%), agricultural land (48.93%), bare ground (5.06%), water bodies (5.35%), and vegetation (26.08%). Results show that anthropogenic activities such as deforestation, agricultural expansion, and infrastructure development significantly alter LULC, heightening flood vulnerability, particularly in agricultural zones. Rainfall distribution showed that areas receiving 2100–2400 mm annually were highly vulnerable, 1600–2000 mm zones moderately vulnerable, and 1300–1500 mm zones low risk. Temperature mapping revealed high-temperature areas occupying 20.63% of the landscape, medium-temperature zones 33.97%, and low-temperature zones 45.40%. Flood risk assessment indicated that 4.78% of the area is at very low risk, 10.20% at low risk, 19.75% at moderate risk, 30.70% at high risk, and the largest share within very high risk. Flood-prone regions in Edo State are strongly influenced by topography, vegetation loss, soil compaction, and precipitation variability. The findings highlight the urgent need for climate-responsive urban policies, sustainable land management, and inclusive adaptation strategies to reduce the increasing threat of urban flooding in the state.

KEYWORDS

Geographic Information Systems (GIS); Remote Sensing (RS); Rainfall and Temperature Distribution; Land use/land cover (LULC) Change

1. Introduction

Flooding is water masses caused by either overflow of water, a river or tide that occurs in normally desert areas. Flooding is considered one of the most common, frequent, and devastating naturally occurring disasters worldwide, posing significant threats in terms of mortality and economic risk. Over the past three decades, floods have affected more than 2.8 billion people globally and caused over 200,000 deaths, as reported by both national and international agencies (Hashizume, 2013; Komolafe et al., 2015; Olanrewaju et al., 2019; Umar and Gray, 2022). Urbanization is a global phenomenon that exerts significant impacts on the environment, affecting land use and land cover, natural resources, and ecological processes. (Seto et al., 2012; Dewangan and Sahu, 2018). Urbanization serves as a major driver of both land use transformation and socio-economic change, influencing multiple layers of the Earth's surface systems and contributing to increased vulnerability to floods and climate change (Yu et al., 2024; Hemmati et al., 2020).

Urbanization and other human activities have significantly altered the structure and function of natural floodplains, particularly in recent decades, reducing their ability to naturally retain and regulate floodwaters (Turner et al., 1990). These changes, coupled with continued reliance on the productive and regulatory functions of floodplains and the presence of fixed human settlements, have increased the exposure of communities to flooding. As a result, there is a greater likelihood that natural hazards will escalate into social disasters. It is stated that flooding with regards to the intensity of natural disasters is reported to have affected the most people as compared any other natural calamity (Green et al., 2000; Brivio et al., 2002; Vlachos, 2010; Centre for Research on the Epidemiology of Disasters [CRED], 2011). There have been 3,119 documented floods around the globe in the last thirty years, which is estimated to have cost over 200,000 lives and has also affected more than 2.8 billion people. In the year 2013, Flood risks are categorised as one of the major natural risks (Ayinde et al., 2013).

According to the UNISDR flood is described as a brief state which is defined by the partial or the total incidence of typically non-water territories with inland water or tide or the atypical and rapid fill up or the draining of surface waters of any origin (UNISDR, 2004). Their occurrence depends on such factors as the precipitation intensity and volume, phase (rain or snow), and river and its drainage basin characteristics such as snow and ice cover, soil moisture content and state (frozen, saturated, wet), wetness, snow/ice melt rate and timing, urbanization, and the presence of dykes, dams, and/or reservoirs. The various weathers impact on flooding: river, flash, urban, sewer, glacial lake outburst and coastal floods (Few et al., 2004). Nonetheless, floods are mainly attributed to

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anthropogenic factors or improper utilization of our natural resources (UNISDR, 2015).

The damage left behind by flood is usually extensive in size, both economical and environmental damage extends to human lives, infrastructure, houses, agricultural grounds; it causes severe suffering to the affected people. Disasters avert sustainable development, food security and economic growth. The losses from natural catastrophes particularly floods are on the rise like the rest of the human suffering deficits and largely impact the less developed countries. They reduce the quality and the developmental capacity of life sustainability (Akolokwu, 2012). Also, the river floods claiming human lives every year are even greater than any other natural disaster. Consequences of natural disasters such as floods may be at the community scale affecting towns and neighbourhoods or at the scale of water catchments and large areas of land in states or countries (Kwak and Kondoh, 2008).

Flood have been reported to have washed away houses estimated at millions of dollars in many countries around the globe (Aljazeera, 2010). More often, flooding is rapidly becoming an ecological challenge in some of the countries with several areas of urban regions submerged annually, especially the Atlantic coastal areas and the shores of adjacent towns and river valleys (Jeb and Aggarwal, 2008). Flooding leading to serious consequences in tropical regions has been caused by heavy rainfall, thunderstorms, hurricanes, snow melt or dam break (Jeb and Aggarwal, 2008). In several nations, flooding has led to land degradation due to lowlands, flooding coasts and river flood plains (Abbas, 2008). Of the disasters that are associated with floods, Nigeria has not been out of this list. Some researchers noted that flooding is not a new phenomenon in Nigeria and, in many instances is devastating (Folorunsho and Awosika, 2001; Adebayo, 2011). The nation claims one of the highest mortality rates in the West African region particularly at the northern region whose large populace and huge stretches of arable land have been submerged (African Research Bulletin, 2010).

1.1 Causes of Flood in Nigeria

Several factors have been identified to influence flooding in Nigeria such are climatology, climate change, social-economic factors, and geophysical parameters, which include; topography, land use and land cover, infrastructures, and river characteristics. These aspects are important to understand in flood risk application, control, and enhancement of mitigation measures and resilience (Fadeyi and Aruofor, 2020). But the following points might be considered as a breakdown of these aspects; Nigeria experiences very heavy, as well as seasonal rainfall whereby during the rainy season, floods prone rivers and also the extensive floods particularly in the urban areas occur. The Niger and Benue rivers normally experience run overs during the rainy season due to the massive flooding (Fadeyi and Aruofor, 2020). Climate change has also led to high temperatures together with the changes in the pattern of precipitation thereby enhancing risks of flood. Extreme weather events and higher rainfall intensity are becoming more common (Aina and Ogunbiyi, 2019).

The topography of Nigeria, including its low-lying coastal areas and the river basins, makes many regions susceptible to flooding. Areas such as Lagos and other coastal cities are particularly vulnerable (Ojo and Olaniyan, 2017). The low elevation areas and flood plains around major rivers, such as the Niger and Benue, are prone to regular flooding due to their proximity to water bodies (Adeyemo and Fagbenie, 2016). The threats posed by flooding are increasing because of the growth of the number of impervious surfaces and the reduction of natural drainage as a result of growing urbanization in the areas like Lagos and Abuja (Adelekan, 2014). Natural flood regulation ability is therefore compromised due to removal of wetlands and forests for agricultural and development activities (Olaoye and Ezeigbo, 2020).

Floods are evaluated and possible forecast made with the assistance of these tools. Geographic Information System and remote sensing are effective technologies for flood hazard mapping, monitoring and risk assessment through the analysis of spatial data and real time data monitoring. According to a study GIS allows combining and comparing a range of spatial data sets, and remote sensing provides up to date musters of current Land Use and Cover Change (LUCC) and hydrological conditions (Ukoje and Mavropoulos, 2019). A GIS application in flood hazard mapping entails the integration of hydrological and hydraulic models, existing flood history, and topographical data, flood-prone areas. These maps are important especially to city planners and the rescue squad. Geographically, GIS may be utilised in vulnerability assessment through the architecture of socio-economic attributes, population, densities and infra structural resistance to gauge the extent to which a given community is vulnerable to the impact of floods. With the purpose of putting a value on the potential outcomes, risk assessment gathers the information about threats and risks. Furthermore, GIS may be useful in land use planning through identifying areas susceptible to floods and should, therefore, not be developed. Anything that helps govern flood such as retention basins, drainage system, levees may be better designed with the help of a GIS (Ologunorisa, 2009).

Places vulnerable to floods may be recognized, flooding intensity may be observed, and the effects of floods may be quantified using information derived from satellite imagery and aerial photography (Munawar et al., 2022; Tettey Tetteh et al., 2024). Remote sensing methods are crucial for applications such as early warning systems for flood detection and real-time monitoring (Munawar et al., 2022; Hakim et al., 2023). Flood prediction models and early warning systems are essential for the timely dissemination of flood alerts and the implementation of response strategies aimed at reducing flood impacts (Hakim et al., 2023; Tettey Tetteh et al., 2024). The aim of early warning systems is to provide near real-time visibility of flood events using hydrological, meteorological, and remote sensing data (Munawar et al., 2022; Hakim et al., 2023). These systems are designed to alert communities and authorized personnel when flooding or other hazardous events are imminent (Munawar et al., 2022; Tettey Tetteh et al., 2024). Geographic Information Systems (GIS) facilitate the integration of data collected from sensors and satellite sources to provide real-time information on flood occurrences (Tettey Tetteh et al., 2024). This data enables early warning systems to communicate potential flood threats to at-risk communities, allowing for timely evacuation and other necessary response actions (Hakim et al., 2023; Tettey Tetteh et al., 2024).

Over time, humans have interacted with land through the utilization of diverse methods and at different stages for their various needs as well as activities. Agricultural and grazing facilities for crop and animals, urban and industrial areas, infrastructures including highways and dams are established through the conversion of natural forests and grasslands (Briassoulis, 2003). Wetlands are developed and transformed for various purposes like agricultural, housing, leisure, business, and other uses. Soil and grounds are cleared to access for both metallics, non-metallics and stones. It gets intensified, marginalised, abandoned or converted to crop, urban and recreational purposes. It does not spare seas either or bodies of water in general.

Land use change is a primary driver of global climate change and significantly affects biodiversity, water and radiation balances, trace gas emissions, and ultimately, temperature across all scales (Riebsame et al., 1994). Land-use alteration is the immediate cause of land-cover transformation. The fundamental driving forces may be attributed to many economic, technical, institutional, cultural, and demographic variables. Humans are increasingly acknowledged as a predominant influence in global environmental change (Moran, 2001; Turner, 2001; Lambin et al., 2001). Alterations in land use are perhaps the most primordial of all anthropogenic environmental effects, and the first to achieve a scale sufficient to merit the designation "globally." Land-cover change, particularly the transformation of wooded regions for other use, has been recognised as a contributing element to climate change. Land cover denotes the physical state of the Earth's surfaces, including flora, trees, grass, constructed structures, paved areas, roads, and other characteristics such as bare soil and water.

Land cover refers to the tangible stuff present on the Earth's surface. Land coverings include grass, asphalt, trees, bare soil, water, and similar elements. Earth cover is a term coined by ecologist Frederick Edward Clements, with its nearest contemporary counterpart being vegetation. The Bureau of Land Management continues to use the phrase. Land cover differs from land use, even though the concepts are sometimes conflated. Land use refers to the manner in which people use land and engage in socio-economic activities. Urban and agricultural land uses are two of the most recognised categories of land use. At any given location, there may exist many and alternative land uses, the delineation of which may possess a political aspect (Fisher et al., 2005).

Heavy single burst occurrences in urban climates can be attributed to anthropogenic environmental modifications as well as the changes in global climate. Nowadays, social and economic growth of metropolitan areas, including the protection of individuals' lives and their property, depend heavily on rainfall and disaster flood poses (Brody et al., 2014; Zhang, 2021). As urbanization gains more momentum, researchers have realized the increased cases of floods in urban areas which affect cities the most (Dewan et al., 2012; Hammond et al., 2015). It is also noted that rainfall floods account for about one-third of the total annual losses worldwide caused by natural disaster (Zhou et al., 2019). The frequent occurrence of floods has resulted in the loss of a lot of lives in different parts of the world both economically and socially (Kundzewicz et al., 2014). Consequently, a group researcher noted that besides accelerated climate change, the occurrence and spread of floods have also increased in Canada (Whitfield et al., 2012).

There are several parts of Australia that experienced severe flood late December 2010 to January 2011, and it was estimated that 37 lives were claimed and also cost more than $31 billion. Every year, damages caused by flood are estimated to worth £1.1 billion in UK; the forecasted value for floods by 2080 is estimated at £27 billion under the worst-case scenario when no other adaptation measures are implemented (Foresight, 2004). Flood catastrophes in China occurred in 2021 and this affected 59.01 million persons, which also led to 590 deaths or missing, 152,000 houses, and direct economic loss estimated at 245.89 billion yuan. Similarly, floods struck Pakistan from 14 June to 30 August of 2021 and, according to the United Nations, about 32.75 million people were affected, 1162 people died, and the damage recorded was over $ 10 billion. The aim of this study is to assess the flood risk using Climate Data and Land Use/Land Cover in Urban Areas of Edo State, Nigeria.

1.2 Flood Projection and Evaluation of Flood Risks in Nigeria

A coupled hydrologic–hydraulic model has been effectively applied to simulate flood dynamics in the Upper Niger Basin. For instance, a group researcher utilized the MGB–IPH model (Modelo de Grandes Bacias – Instituto de Pesquisas Hidráulicas; Large Basin Model – Hydraulic Research Institute), a semi-distributed hydrological–hydraulic model that integrates runoff generation with floodplain hydraulics (Fleischmann et al., 2017). This model produced strong validation results across discharge, water level, and flooded-area data (e.g., Nash–Sutcliffe Efficiency > 0.7). This application contributes to a better understanding and management of water resources in Nigeria. According to a study, the coupled hydrologic and hydraulic model is valuable for detailed water balance estimation and seasonal dynamics of groundwater levels and surface water discharges, and, due to its physical foundation, can be extrapolated to analyse meteorological and land use scenarios (Waseem et al., 2020). Adefolalu brings out a discussion on the sources of flooding in the Niger River in regard to hydrometeorology (Adefolalu, 1992).

There is indication that floods can be better predicted and modelled using hydrological data. Writing about the flood hazards of the Niger Delta area, some researcher applied the geographic information system (GIS) and remote sensing techniques (Ukoje and Mavropoulos, 2019). In this aspect, the study shows how efficient geospatial tools are in assessing the risks of floods. The role of geographical study in flood risk management is evidenced by study on the use of GIS based flood hazard mapping in Lagos (Adeaga, 2006). Adelekan examined flood vulnerability of low-income urban coastal neighbourhoods, Lagos, Nigeria (Adelekan, 2010). Lagos urban poor coastal settlements: Assessment of their vulnerability to floods is the subject of analysis in this study. Participatory methods are used to identify solutions to community resilience and floods risks are determined.

The problem of municipal floods in Lagos, Nigeria is discussed (Ajibade et al., 2013). The study assesses the state of women in Lagos with regards to urban floods and their ability to cope. Outcomes should derive from gender integrated risk assessment in the community. Oladokun and Montasir have pointed out a possible way of solving the problem of the repeated flooding in Nigeria – the development of an early warning system (Oladokun and Montasir, 2014). This study focuses on the subject of developing flood early warning system in Nigeria. It emphasizes the importance of integrating means for making weather and water flow predictions and disseminating information.

Ologunorisa proposed to identify the extent to which the Niger Delta region of Nigeria is prone to flooding (Ologunorisa, 2004). This study places its emphasis on the Niger Delta and uses GIS, historical information and remote sensing to identify regions that are more susceptible to flooding. This is why it underlines the importance of practical methods of risk managing and flood forecasting. Thus, in their 2019 article, Komolafe et al. described the analysis of flood risk assessment and management in Nigeria. The present study assesses flood risk management in Nigeria currently, the application of IFM and the potential opportunities and challenges of IFM.

Some researchers indicated that floods in Nigeria manifest mostly in three forms: The three important types of flooding are the coastal flooding, river flooding, and urban flooding (Folorunsho and Awosika, 2001; Ologunorisa, 2004). Coastal flooding occurs in the low altitude areas of mangrove and freshwater marshes close or bordering the coast. River flooding occurs in flood prone areas of main rivers, but sudden and short-lived flash floods are associated with interior rivers that morph into deadly streams following heavy rainfall in a relatively short period. This type of flooding occurs in municipalities in plain or low geographical terrains, especially when insufficient surface control structures are installed, or when existing structures are blocked either by municipal waste or refuse, and eroded soil sediment (Folorunsho and Awosika, 2001; Ologunorisa, 2004). According to a study, different forms of flooding such as coastal flooding, river flooding, flash floods, urban floods, breach of levee, failure of dams and dams' spillages was observed in Nigeria (Etuonovbe, 2011).

2. Location Of The Study Area

Edo State is located in the southern region of the country Nigeria. It lies at 5°44'N to 7°34'N latitude and 5°4' E to 6°45 E longitude. These coordinates place the state right in the southern part of Nigeria. It shares border with the Delta State in the south; Kogi State in the north and Ondo state in the west. The state lies in an area of approximately 17,802 kilometres. Edo State is endowed with flat land, rolling hills and wooded area. The state has tropical climate with clearly defined short rain and long dry seasons. It is certainly rainy from April to October and dry from November to March of the following year. 'Benis' are historically significant and serve as the 'economic and cultural epicentre' of Edo State, the capital of which is Benin City. The ethnic groups that dominate Edo State include Bini, Esan, Etsako, Owan and Akoko-Edo. (Iwegie, 2013)

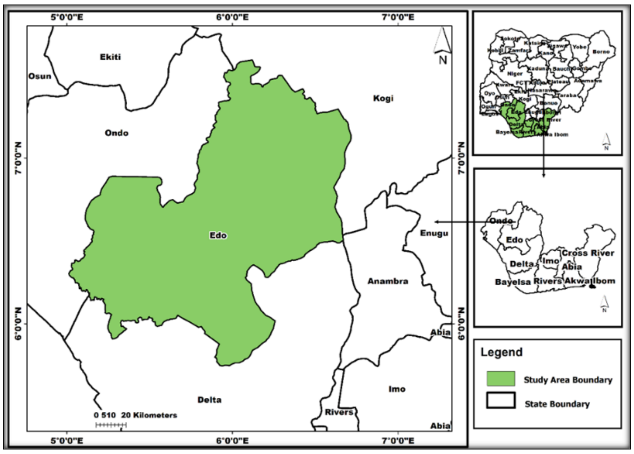

Figure 1: Location of the Study Area

The social, economic and occupational nature or socioeconomic activities in Edo State as well as its possible land use plan shows rich cultural history, diverse use of land and value of the state as a strategic territory. All of these things right from farming and trading until teaching and tourism contribute in supporting the state's economy and supporting its people. Edo state embraces a diverse pattern of land use and human and economic endeavour marks the state as culturally diverse, naturally endowed, and strategically located. The economic and living conditions of the inhabitants of the state is greatly influenced by this variety.

Farm Land Utilization; most of the crops grown in backyards by small holder farmers are yams, cassava, corns and plantains for home consumption. Other examples of cash crops include cashew nuts cocoa and oil palm and rubber produced by large scale farmers on large plantations. Forest reserves are special areas that are conserved to protect forest and other natural resources since the government simply sets aside big chunks of land. Okumu National Park and Okomu Forest Reserve are perfect examples. Since quotas were placed between growth in the economy and conservation of resources, deforestation is legal in some areas of forested land.

Their climate system is designated as a savanna climate also known as a tropical wet and dry zone climatic classification (Aw). The State undergoes two primary seasons: the wet season and the dry season. The rains range from April to October and characterized by high humidity, frequent and heavy rainfall and moderately high temperatures. Annually, the heaviest part of the rainy season is experienced from June to September, and the most, rainy month is August. Mean Monthly Precipitation: When it is high it could be as high as 200 – 300mm during the peak period (Oguntunde and Abiodun, 2012). The state experiences reliably high temperatures all year round, as the temperature varies between 22-32 degrees Celsius. The temperature is recorded to rise to 34 degrees Celsius during the months of March and April, but drops to about 21 degrees Celsius

3. Materials And Methods

The two primary datasets were employed in this study are remote sensing (RS) data for land use/land cover (LULC) mapping and meteorological data for climate analysis. Landsat 8 Operational Land Imager (OLI) images with a spatial resolution of 30 m, covering the path/row for Edo State, were obtained from the United States Geological Survey (USGS) Earth Explorer. Rainfall and temperature records were acquired from the Nigerian Meteorological Agency (NiMet) and complemented with Climate Research Unit (CRU) datasets, providing long-term averages and spatial variability of climatic factors influencing flood occurrence. Landsat imagery was pre-processed using ENVI 5.6 and ArcGIS 10.8 software. The preprocessing steps included radiometric calibration to convert digital numbers (DN) to top-of-atmosphere (TOA) reflectance, atmospheric correction using the Dark Object Subtraction (DOS) method to minimize atmospheric scattering, layer stacking to produce a composite image suitable for classification and clipping of the stacked image to Edo State's boundary for analysis.

A supervised classification technique employing the Maximum Likelihood Algorithm was used to classify the imagery into five LULC categories: built-up areas, agricultural land, bare ground, vegetation/forest, and water bodies. Training samples for these categories were identified through visual interpretation and validated with Google Earth. Rainfall and temperature data were analyzed using Microsoft Excel and ArcGIS. Heavy rainfall is emphasized due to its rapid and severe impacts, as the study area experiences high precipitation levels characteristic of a tropical wet climate. Mean annual rainfall was categorized into three vulnerability classes: low (1300–1500 mm), moderate (1600–2000 mm), and high (2100–2400 mm). Spatial interpolation using the Inverse Distance Weighting (IDW) technique was applied to generate temperature distribution maps, with temperature further classified into high, medium, and low zones. Flood risk mapping was conducted using the Analytical Hierarchy Process (AHP), a GIS-based multi-criteria decision analysis (MCDA) approach.

Three key parameters selected rainfall intensity, temperature, and LULC as input variables. A pairwise comparison matrix was constructed to assign weights to each parameter based on expert judgment and literature, and the consistency ratio (CR) was computed to ensure logical consistency, remaining below the acceptable threshold of 0.1. The standardized factor maps were subsequently combined through weighted overlay analysis in ArcGIS to produce a composite flood risk map. The flood risk map generated was classified into five categories: very low, low, moderate, high, and very high risk. The spatial extent of each risk category was quantified in hectares and expressed as a percentage of the total study area, enabling comparison of vulnerability patterns across Edo State.

4. Results

4.1 Classification of Land Use and Land Cover in the Study Area

The use of geographic information system (GIS) mapping was beneficial in the classification of land use and land cover in the study area. The assessments of the land use and the land cover characterization in the study area therefore remain crucial in the analysis and management of flood risks. The classified of Landsat 8 imagery produced five major land cover classes for Edo State: built-up areas, agricultural land, bare ground, water bodies, and vegetation/forest (Figure 3). Agricultural land was the dominant class, covering 48.93% of the state, followed by vegetation (26.08%), built-up areas (14.58%), water bodies (5.35%), and bare ground (5.06%) (Figures 2 – 3).mThe results highlight the significant influence of human activities such as deforestation, agricultural expansion, and infrastructure development on land cover.

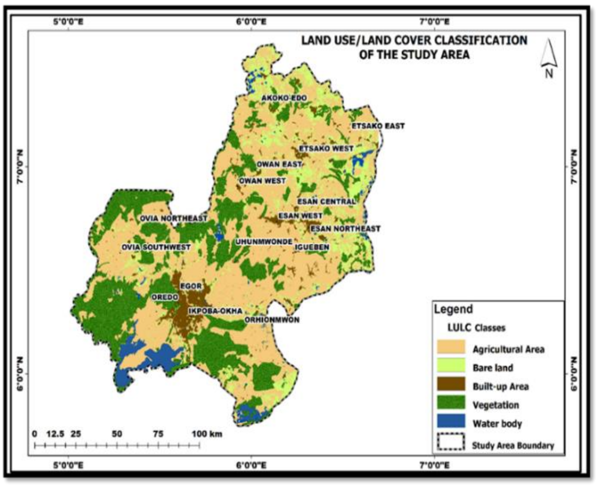

Figure 2: Land use/Land cover of Classification of the Study Area

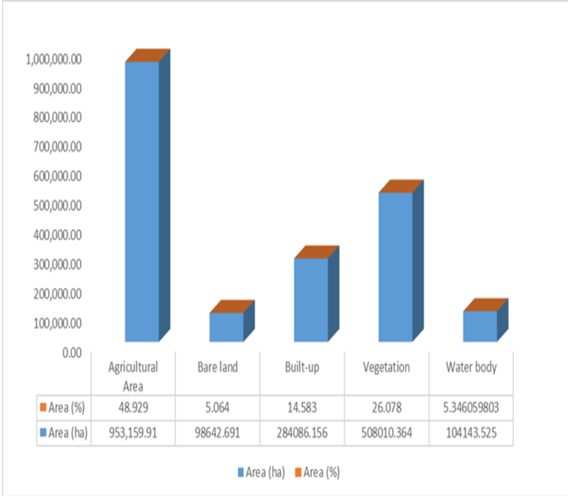

Figure 3: Land use/Land cover Distribution Chart of the Study Area

4.2 Rainfall

An analysis of rainfall data helps in understanding the flood hazard that is associated with precipitate in the study area. Rainfall analysis revealed spatial variability across the state (Figure 4). Areas in the southern and central parts recorded the highest annual rainfall (2100–2400 mm), corresponding to high flood vulnerability. Moderate rainfall zones (1600–2000 mm) covered much of the midlands, while northern areas received the lowest amounts (1300–1500 mm), representing lower vulnerability. (Figure 4). This distribution suggests that southern Edo, which coincides with the most urbanized and agriculturally intensive regions, faces the greatest exposure to flood hazards.

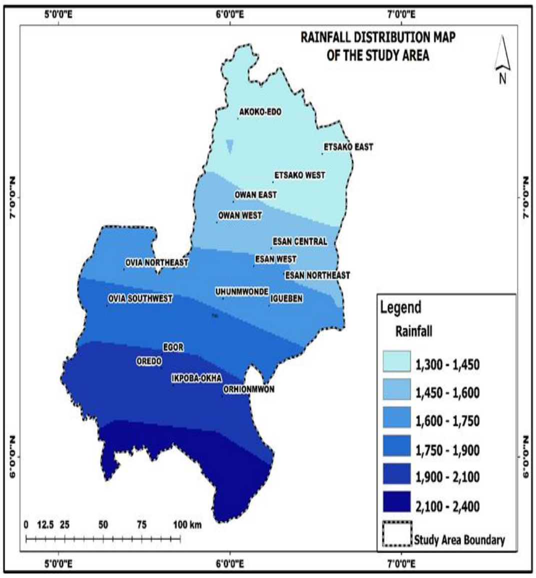

Figure 4: Spatial distribution of rainfall across Edo State.

4.3 Thermal Conditions

The temperature distribution analysis divided Edo State into three classes: high (30°C), medium (25°C), and low (22°C). The results show that the low-temperature zone accounted for the largest portion, covering 879,915.937 ha (45.40%), followed by the medium-temperature zone with 658,344.875 ha (33.97%), while the high-temperature zone occupied 399,783.832 ha (20.63%) (Figures 5 – 6). These spatial patterns indicate that nearly half of the state falls within relatively cooler zones, predominantly associated with forested and less disturbed areas, while urban and deforested regions exhibited higher surface temperatures. The higher temperature zones, concentrated in urban centers and northern parts of Edo State, are likely linked to the urban heat island effect and land cover alterations, which contribute to increased atmospheric moisture capacity and flood-generating rainfall events. Conversely, low-temperature areas correspond with regions that retain significant vegetation cover, where evapotranspiration moderates surface heating. Consequently, urban and deforested zones are more vulnerable to flood risk, while cooler, vegetated regions exhibit a moderating influence on surface heating and associated hydrological responses.

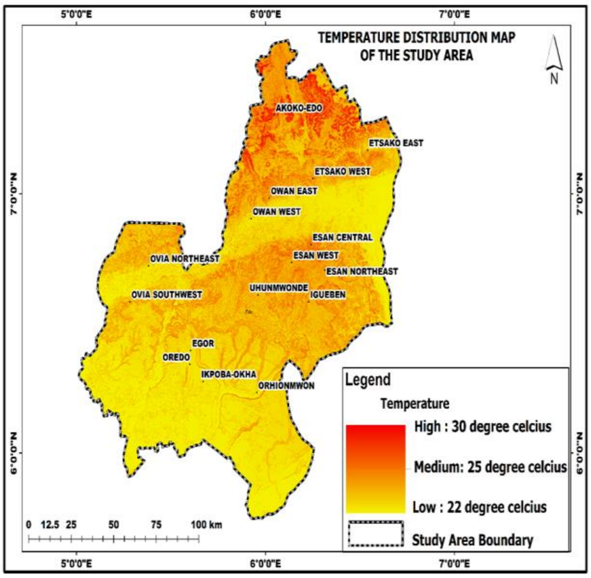

Figure 5: Temperature Distribution Map of the Study Area

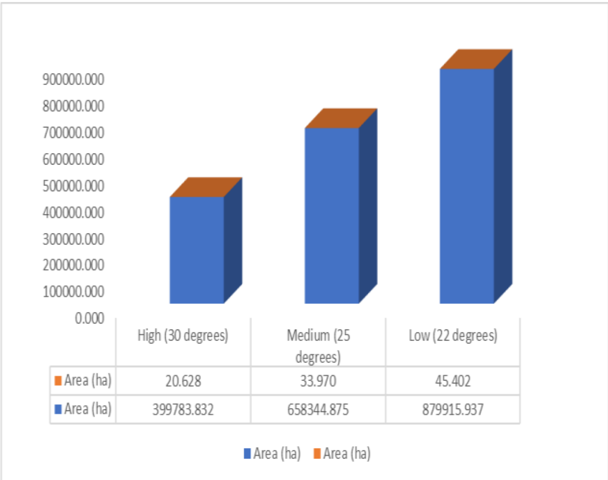

Figure 6: Temperature distribution chart for Edo State showing areal coverage of high, medium, and low temperature zone

4.4 Flood Risk Zonation

The flood risk analysis of the study area using AHP categorize the study area into five zones shown in Table 1 and Figure 7 together with the flood risk ratings. The most threatened areas were defined inside urbanized areas where natural vegetation has been altered and/or eliminated. The assessment of the flood prone area revealed that the Very Low Risk Prone area covers 93,159.91 hectares (4.783% of the total land area), Low Risk covers 198,642.691 hectares (10.197%), Moderation Risk covers 384,086.155 hectares (19.716%), High Risk flood prone area covers 598,010.364 hectares (30.698%) and Very High Risk covers 674,143.524 hectares (34.606%). Therefore, the study area may be described as being in a flood-prone area. The regions highlighted to experience a significantly higher flood risk can be attributed to gradient, absence of plant cover, vegetation compaction, shifts in precipitation and, changes in land management practices. This may lead to either the sealing and loss of fertile surface soil, siltation of river systems and even biodeterioration of local ecosystems; it will also have implications on agriculture, settlement, and infrastructural development that are all crucial for any comprehensive planning across the country.

Table 1: Flood Prone Areas Within the Study Area

Erosion Prone	Area (ha)	Percentage (%)
Very Low Risk	93,159.91	4.783
Low Risk	198,642.691	10.197
Moderate Risk	384,086.155	19.716
High Risk	598,010.364	30.698
Very High Risk	674,143.524	34.606
Total	**1,948,042.643**	**100**

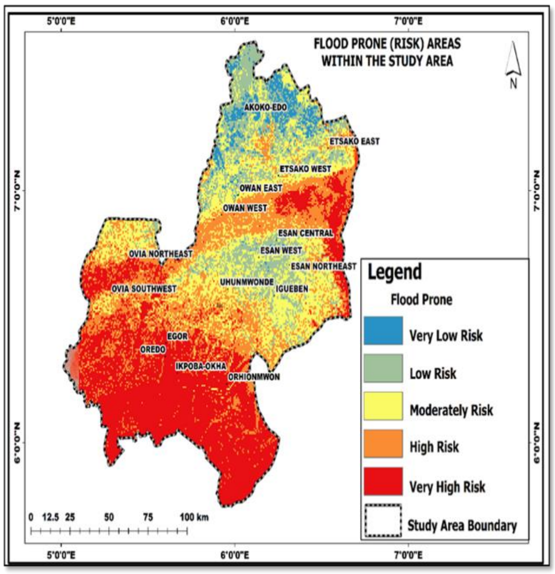

Figure 7: Flood Prone (Risk) Areas within the Study Area.

5. Discussion

5.1 Changes in the study area regarding Land Use/Land Cover

Several changes in land use and land cover (LULC) within the study area were identified, consisting of built-up areas (14.58%), agricultural land (48.93%), bare land (5.06%), water bodies (5.35%), and vegetation (26.08%). This composition provides a simplified representation of the study area. The predominance of agricultural land (48.93%) and the expansion of built-up areas (14.58%) indicate that anthropogenic activities are major drivers of flood risk in Edo State. Expansion in agriculture and urban development often involves deforestation, soil compaction, and construction activities such as roads and residential buildings, which collectively reduce the soil's infiltration capacity and increase surface runoff. Similar patterns were reported by a group researcher in Nigeria and globally, highlighting that rapid land cover changes intensify flood vulnerability (Komolafe et al., 2015; Hemmati et al., 2020). However, the impacts of these changes are not uniform. Evidence suggests that the highest flood risk areas were concentrated in low-lying urban and agricultural regions where natural vegetation cover has been significantly altered. Conversely, higher elevation areas with intact vegetation cover exhibited lower levels of risk. Furthermore, regions subjected to extensive logging show greater levels of topsoil erosion compared to areas designated for afforestation.

Rainfall variability played a critical role in shaping flood hazards, with high rainfall zones strongly correlating with areas of high flood risk. This agrees with who noted that precipitation intensity is the primary determinant of flood disasters in Nigeria (Umar and Gray, 2022). Furthermore, the role of temperature is not negligible: elevated temperatures in urban heat zones increase atmospheric moisture capacity, leading to more intense and localized precipitation, consistent with global climate change projections (IPCC, 2021).

Temperature is a critical factor influencing flooding patterns in the study area. Variations in temperature affect key hydrological processes such as evaporation rates, atmospheric moisture capacity, and sea level rise. Rising temperatures, driven by climate change, have increased atmospheric moisture retention, thereby intensifying precipitation events. In the Niger Delta, one of the main drivers of flooding is the increasing concentration of precipitation, particularly during the wet season (Figures 5–6). The interaction between rising air and sea surface temperatures contributes to enhanced flood hazards through increased precipitation intensity, elevated sea levels, and changes in soil saturation. These processes collectively heighten flood risks, particularly in areas with poor drainage and high exposure. Considering projected climate change impacts, including rising global temperatures, the study area is likely to face more frequent and severe flooding events in the future.

The integration of LULC, rainfall, and temperature data through AHP revealed that nearly two-thirds of Edo State (65.31%) lies within high to very high flood risk zones. These findings highlight the combined effect of human-induced land cover change, topographic vulnerability, and climatic stressors. This aligns with the conclusions of Adelekan (2010), who demonstrated that Nigerian urban centers are increasingly exposed to flood hazards due to poor planning and inadequate drainage infrastructure.

The spatial analysis underscores that flood risk distribution across the study area is uneven, with coastal regions and river floodplains are the most affected by floods. Urban centers exhibit significant flood vulnerability due to insufficient drainage strategies, unlike the areas that are elevated and have little risk of flooding. Anticipated climate change impacts are likely to intensify these risks, underscoring the urgent need for targeted interventions. These solutions should extend to improving infrastructure, restoring the natural environment, and regulating the land utilization in areas that are prone to flood so as to reduce the impacts of floods on the populations and the environment in general.

6. Conclusions

This study employed Geographic Information Systems (GIS) and Remote Sensing (RS) techniques for flood prediction and risk assessment in the Niger Delta Basin, with Edo State as a case study. The analysis was conducted using the Analytical Hierarchy Process (AHP), a GIS-based multi-criteria decision-making method, integrating key flood susceptibility factors such as rainfall intensity, land use/land cover (LULC), and temperature. These parameters were combined to develop a spatial flood risk map for the study area.

The classified Landsat imagery revealed five major land cover classes: built-up areas (14.58%), agricultural land (48.93%), bare land (5.06%), water bodies (5.35%), and vegetation/forested areas (26.08%). The dominance of agricultural land and expansion of urban areas highlight the significant influence of human activities, including deforestation, agricultural expansion, and infrastructure development (e.g., roads, housing), in altering natural infiltration capacities and increasing flood vulnerability. Areas with intensive logging exhibited substantial topsoil erosion, whereas zones designated for afforestation displayed greater environmental stability.

Temperature distribution analysis indicated that high-temperature areas covered 399,784.832 ha, medium-temperature zones spanned 658,345.875 ha, and low-temperature areas extended over 879,916.937 ha. Elevated air and sea surface temperatures were found to enhance precipitation, raise sea levels, and alter soil properties, collectively increasing flood risks. Climate change-induced temperature rise is expected to intensify these hazards, leading to more frequent and severe flooding events in the future.

Flood risk analysis classified the study area into five zones: Very Low Risk Area (VLRA) – 93,159.91 ha (4.78%), Low Risk Area (LRA) – 198,642.69 ha (10.20%), Medium Risk Area (MRA) – 384,086.16 ha (19.75%), High Risk Area (HRA) – 598,010.36 ha (30.70%), and Very High Risk Area (VHRA) – 674,143.52 ha (34.61%). The highest-risk zones were concentrated in low-lying urban and agricultural regions where natural vegetation has been extensively modified, while elevated areas with intact vegetation demonstrated lower susceptibility.

The findings underscore that flood hazards in Edo State are spatially heterogeneous. Coastal fringes and river floodplains represent the most vulnerable zones, while urban centers are particularly exposed due to inadequate drainage infrastructure. Conversely, elevated terrains remain relatively less affected. Given the expected intensification of flood hazards under climate change, proactive measures are essential. Recommended strategies include upgrading drainage and flood control infrastructure, restoring natural landscapes, and enforcing stricter land-use regulations in high-risk zones. These interventions will be critical to minimizing environmental degradation, safeguarding livelihoods, and supporting sustainable development in the region

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