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Research Paper

Effects of Climatic Variations and Changing Land Use/Land Cover on Flooding in Southern Nigeria

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Abstract
The prevalence of flooding in Nigeria in the past few years (with its devastating consequences) has become a source of concern for policymakers and researchers alike. Scholars have attributed the high frequency of flooding, particularly in the southern region of Nigeria, to several factors; climatic variation and land use/land cover changes are themes that fall under the domain of natural and anthropogenic causes of flooding, respectively. This study examined climatic variations and changing land use/land cover in southern Nigeria with the view of determining their synergistic effects on flooding. We adopted a mixed approach for data collection with the use of Geographic Information System (GIS), retrieval of primary data from meteorological stations in the region, and field surveys. Findings show a significant decrease in rural land uses like arable lands, wetlands, and undisturbed forests; while there was a corresponding increase in urban/peri-urban land uses like settlements and tree-crop plantations over the period from 1999 to 2019. The land use/land cover changes have manifested in the destabilization of the microclimate, distortion of the carbon circle, loss of biodiversity, reduction of ecosystem services of the natural areas, and flooding. The decadal rainfall trends over the past three decades show consistent extremities with mean rainfall duration decreasing while the mean intensity increases; aggravating soil erosion, urban runoff challenges, and flooding. Climatic variations (mainly extreme rainfall patterns) synergize with inefficient land use management to exacerbate flooding in southern Nigeria. While policymakers in this region may not have the standalone capacity to significantly control climate change and the consequential variations in the local microclimate, they can re-engineer land use policies to eliminate or substantially degrade anthropogenic factors that exacerbate flooding.

Keywords
Climate Change, Climatic Variation, Flooding, Land Use, Southern Nigeria

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1. INTRODUCTION

Climatic variability has been more intense in the past few decades; and that is evident in the fluctuations in rainfall duration and intensity, rise in temperature, drought, desertification, rise in surface water/sea levels, and flooding (Elisha et al., 2017; Ebele and Emodi, 2016). Increasing rainfall durations and intensity give rise to large amounts of runoff overflowing river banks, thereby subjecting floodplains and low-lying areas to flooding. Southern Nigeria has a tropical climate characterized by high temperatures and high precipitation (Akande et al., 2017). Rising river levels and ocean surges have frequently submerged towns and villages in parts of the Niger Delta, Lagos State, Imo State, Anambra State, Kogi State, and many other States in southern Nigeria (Anabaraonye et al., 2018). In the past three decades, temperature has increased approximately 0.2 to 0.3°C per decade, with similar variability in wind direction and intensity in various parts of southern Nigeria (Njoku et al., 2020). These have had significant impacts on the rainfall pattern with the attendant consequences of flooding (Umar and Gray, 2023).

Flooding is one of the most devastating natural disasters worldwide (Komolafe et al., 2015). Scholars have identified both natural and anthropogenic factors which cause or exacerbate flooding worldwide (Umar and Gray, 2023; Tramblay et al., 2021; MacLeod et al., 2021; Nkwunonwo et al., 2020; Louw et al., 2019). Some of the natural causes include excessive precipitation (MacLeod et al., 2021; Umar and Gray, 2023; Agbonkhese et al., 2014); nature of soil, its maximum moisture retention level (Tramblay et al., 2021); extreme weather conditions (Nigeria Hydrological Services Agency, 2020); and ocean surge/overflow of rivers (Nkwunonwo et al., 2020; Komolafe et al., 2015). The anthropogenic causes of flooding include uncontrolled urbanization (Ulor et al., 2022), construction on natural drainage pathways (Ogbonna et al., 2023; Njoku et al., 2010), poor physical infrastructure like collapsed storm drainage systems (Ogbonna et al., 2023), poor management of dams (Nigeria Hydrological Services Agency, 2020), ineffective land use management (Ogbonna et al., 2023; Adegboyega et al., 2018), deficient urban waste management (Nkwunonwo et al., 2020, Njoku et al., 2010), and ineffective environmental planning (Umar and Gray, 2023).

Flooding has become an annual occurrence in Nigeria with devastating impacts, especially in the coastal south (Elum and Snijder, 2023). Nigeria experienced the worst flood incidences in 2012 and 2022 respectively. The 2012 flood was mainly attributed to excessive rainfall across the country coupled with the overflow of the Lagdo Dam at the north-eastern border of Nigeria and Cameroon (Nigeria Hydrological Services Agency, 2020). The flood disaster of 2012 resulted to the death of over 360 persons, with 5,000 persons injured; 5,960 houses destroyed, more than two million people displaced, with a total cost of USD 17.3 billion (Federal Government of Nigeria, 2021; European Commission Joint Research Centre, 2018). The 2022 flood disaster which has been declared the worst in the history of Nigeria affected over 30% of the entire country; resulted in the death of over 600 persons, and more than 2.5 million displaced, with the actual cost yet to be determined (Ominabo, 2022). These flood occurrences had the most devastating impacts on the coastal plain of southern Nigeria. A vast area of Nigeria's densely populated and increasingly urbanized southern coast is a floodplain with elevations less than twenty feet above sea level (Sayne, 2011). Lagos and the Niger Delta region, with their network of estuaries, rivers, creeks, and streams, are situated lower than 10 feet above sea level (Sayne, 2011). With this topography, the southern coast of Nigeria is naturally vulnerable to flooding and therefore requires proper physical planning to guide urbanization, especially in the peri-urban settlements (Matemilola et al., 2019).

Urban and peri-urban landscapes are frequently under pressure from anthropogenic and natural forces (Njoku et al., 2010; Ulor et al., 2022). Anthropogenic activities often manifest in land use and land cover changes; altering natural ecological balance, and sometimes activating latent natural disasters. In low-income countries, newly urbanizing settlements are characterized by high population densities and cheaper rents compared to developed cities. These zones are usually dominated by informal trading, poor environmental sanitation, obsolete physical infrastructure, poor environmental planning, and lack of government attention. A combination of these factors initiates and exacerbates flooding and determines the spatiotemporal scale of flooding in both urban and rural areas. While natural causes of flooding emanate from wide sources, anthropogenic causes are attributable mostly to urban and peri-urban developments. Few studies have examined the synergistic role of natural and anthropogenic drivers to flooding in low-income countries, especially with particular attention to the impacts of the changing urban/peri-urban land uses. Assessing the flood risks of land use changes in urban/peri-urban areas is vital for understanding mitigation and adaptation measures for effective flood management. This study examined the synergistic effects of climatic variation and changing urban/peri-urban land use on flooding in southern Nigeria.

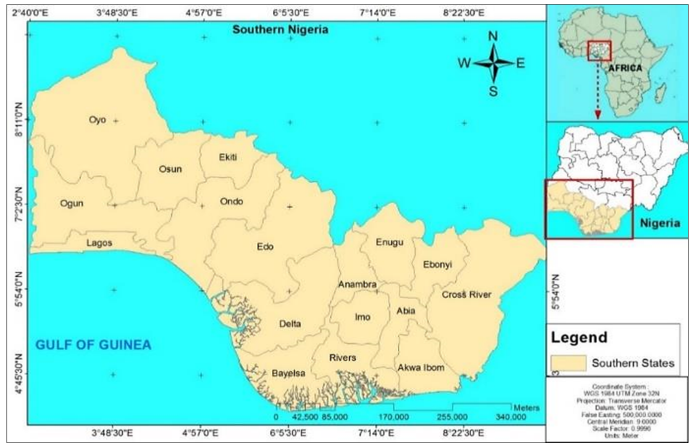

Figure 1. Location Map of the Administrative States in Southern Nigeria

2. EXPERIMENTAL SECTION

The study area encompasses the three geo-political regions of southern Nigeria: the south-west region made up of Lagos State, Ogun State, Ondo State, Oshun State, Oyo State, and Ekiti State; the south-east region made up of Enugu State, Anambra State, Abia State, Imo State, and Ebonyi State; and the south-south region made up of Rivers State, Edo State, Delta State, Bayelsa State, Akwa-Ibom State, and Cross-river State (Figure 1). The southern region of Nigeria lies between Longitudes 3° and 8° north, and latitudes 4° and 10° east in the West African region. It has a total landmass of 193,777 Sq.km stretching from the Atlantic coast of Lagos to the southern creeks of Cross-river State (Nwachi et al., 2023); with an extensive coastline measuring about 850 km (Fashae et al., 2022). Based on 2019 projections of the National Bureaux of Statistics [NBS] Nigeria (2020), southern Nigeria has a total population of 88,957,325 living in 17 States; which constitutes about 43.8% of the entire population of Nigeria (Table 1). This zone is the oil-rich region of Nigeria which supports vast ecosystem of species of terrestrial and aquatic flora and fauna and human settlements. Four ecological zones are dominant in the region: the lowland rainforest; the mangrove swamp forest; the coastal inland forest, and the freshwater forest (Merem et al., 2019; Gbiri and Adeoye, 2019). The climate of the region is marked by heavy rainfall with striking vacillation of wet and dry seasons all through the year. The rainfall regime is regulated by a binary local wind: the south-west monsoon which is moisture-laden wind from the Atlantic Ocean landward; and the north-east trade wind (locally known as Harmattan) which carries dust from the northern Sahara region southwards. Average temperature ranges from 22.1°C to 33°C thereby making the region experience a low rate of evapotranspiration. The topography of the region ranges from 1 m along the coastline to 55 m at locations further inland. The geology of the zone is characterized by an extensive sequence of sedimentary rocks of the Dahomey basin primarily consisting of localized alluvial sediments of the cretaceous and tertiary periods (Fashae et al., 2022). The southern region of Nigeria is marked by rapid urbanization and fast industrial growth due to oil exploration in the Niger Delta and global trade expansion in the Lagos axis. These exert much pressure on the natural hydrological circle and the entire ecosystem of the region.

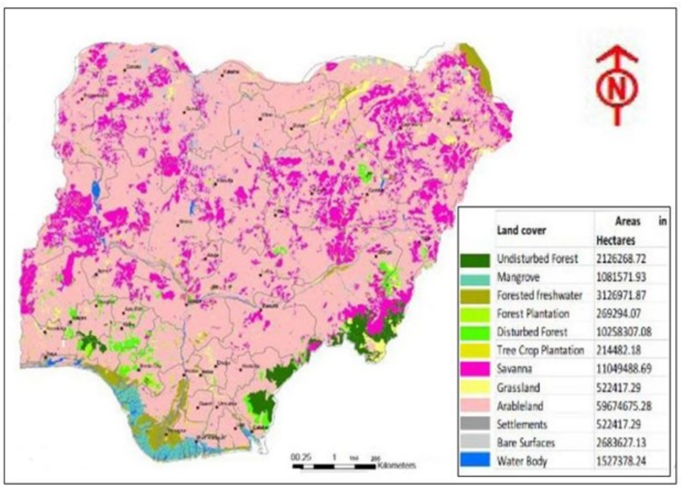

Figure 2. Nigeria Land Cover 1999 (Source: Adapted from United States Geological Survey (2022))

The study adopted a mixed approach for data collection; with the use of a Geographic Information System (GIS), retrieval of primary data from meteorological stations, and analysis of secondary data from different databases owned by government institutions and agencies. Sources of spatial data include the Nigeria Hydrological Services Agency (NIHSA), the Nigeria National Bureau of Statistics, the World Bank Group, the West African Service Centre on Climate Change and Adaptation Land Use (WASCAL) World City database, the Nigerian Meteorological Agency, and the National Emergency Management Agency of Nigeria (NEMA). Decadal climatic data covering the period from 1990 to 2019 were retrieved from meteorological stations in the various States across the region. We collected land use and land cover data which included both temporal and spatial Digital Elevation Models (DEM) with a resolution of 30 × 30 m, comprising of land use maps, climatic, bio-physical, and demographics data from the United States Geological Survey (United States Geological Survey, 2022) STRM30 (https://earthexplorer.usgs.gov/). The spatial data were analysed using Arc GIS 10.4 and were mapped across the period 1999 to 2019 to assess the dispersion of the regional land use changes and the resultant flood hazards. Demographic and socio-economic data for the population and flood-incidence data of the 2022 flooding in southern Nigeria were collected by questionnaire survey. We employed a multistage sampling technique involving cluster sampling, systematic random sampling, and simple random sampling to select 406 respondents from three cities in southern Nigeria (Lagos, Port-Harcourt, and Uyo) who participated in the study (Table 1). However, 390 completed questionnaires were retrieved and analysed. Quantitative data were analysed with descriptive statistics using Statistical Product and Service Solutions (SPSS) for Windows, version 21.0, and Microsoft Excel 2016.

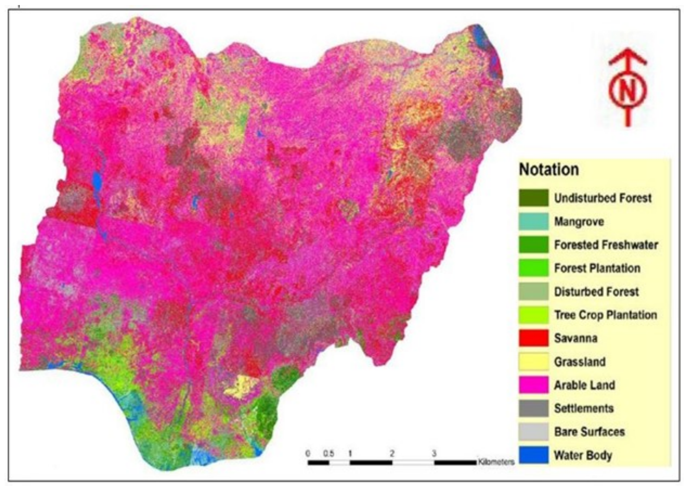

Figure 3. Nigerian Land Cover Map 2019 (Source: Adapted from United States Geological Survey (2022))

3. RESULTS AND DISCUSSION

3.1 Land-use Changes in Southern Nigeria

The Land use changes in southern Nigeria within the period (1999 – 2019) are shown in Figures 2 and 3, and quantitatively presented in Table 2. The Majority of the rural land uses recorded a decrease in area coverage while urban land uses recorded an increase. The biggest losers are 'arable land' (6.6%), 'bare surfaces' (2.1%), and 'forest plantations' (1.3%). The biggest gainers are 'settlements' – specifically urban settlements (8.7%), 'tree crop plantation' (2.1%), and 'mangrove forests' (0.3%). The pattern shows that the land use changes were due to various factors such as urbanization, agricultural expansion, industrialization, and infrastructure development. Southern Nigeria witnessed rapid urbanization during this period. Settlements in cities and towns have expanded, resulting in the conversion of agricultural

Table 1. Land Area, Population, and Questionnaire Distribution

s/n	State	Total Land Area (Sq. Km)	Population (2006 census)	Population (2019*)	Questionnaire Distribution	
1	Oyo	28,454	5,580,894	7,512,855	Distributed	Retrieved
2	Cross-River	20,156	2,892,988	4,175,020	-	-
3	Edo	17,802	3,233,366	4,461,137	-	-
4	Delta	17,697	4,112,445	5,307,543	-	-
5	Ogun	16,762	3,751,140	5,945,275	-	-
6	Ondo	15,500	3,460,877	4,969,707	-	-
7	Rivers	11,077	5,198,716	7,034,973	P.H. 136	129
8	Bayelsa	10,773	1,704,515	2,394,725	-	-
9	Osun	9,251	3,416,959	4,237,396	-	-
10	Enugu	7,161	3,267,837	4,396,098	-	-
11	Akwa-Ibom	7,081	3,902,051	4780581	Uyo 120	117
12	Ekiti	6,353	2,398,957	3,350,401	-	-
13	Abia	6,320	2,845,380	3,841,943	-	-
14	Ebonyi	5,670	2,176,947	3,007,155	-	-
15	Imo	5,530	3,927,563	5,167,722	-	-
16	Anambra	4,844	4,177,828	5,599,910	-	-
17	Lagos	3,345	9,113,605	12,772,884	Lagos 150	144
	Total	193,777	65,162,158	88,957,325	406	390

*Figures are estimates by National Bureaux of Statistics [NBS] Nigeria (2020)

lands and natural forests to built-up areas. This process has led to the growth of residential, commercial, and industrial land uses accompanied by increased infrastructure development. Within the period settlements have grown with over 16, 800 Sq. km, taking up suburban agricultural lands. These findings agree with other studies (Nkiruka et al., 2023; Richard and Okeke, 2023; Seun et al., 2022). Nkiruka et al. (2023) observed an increase in built-up areas by 9.4% and 9.5% between 2008 and 2013, and between 2013 and 2018 respectively in the lower Niger basin. Seun et al. (2022) also observed a 20% decline in vegetal coverage in the south-western States of Nigeria with strong climatic impacts like urban heat islands (6.4°C warmer urban neighbourhoods than rural areas), and the built-up areas having higher mean land surface temperature compared to areas with vegetation or water bodies.

Agricultural activities have increased in intensity to meet the growing population's food demands. The growth in intensity has resulted in the conversion of hitherto undisturbed forests and other natural areas into agricultural land while the available arable land has been subjected to continuous cultivation. There has been an increase in the cultivation of cash crops like palm oil, cocoa, rubber, and various food crops in the region. The pattern of land use change showed that a significant portion of the arable land (6.6%) has been lost to growth of settlements; tree crop plantations have increased by 2.1%. The impacts of emerging agricultural practices have been seen in greater incidences of soil erosion, land degradation, and increased levels of pathogens, nutrients, and chemicals in surface water. This is in line with the findings of Chikwendu et al. (2017) and Kughur et al. (2015) who observed that intensive agricultural practices in Nigeria destroy soil nutrients and soil quality leading to soil erosion, pollution of water bodies, and loss of biodiversity. Deforestation has been a major fallout of land-use change in southern Nigeria. The logging for timber and conversion of forests to settlements and agricultural lands has led to the loss of valuable forest cover. Deforestation has adverse impacts on biodiversity, ecosystem services, and climate regulation. During the period under review, 0.7% of undisturbed forest and 1.7% of forest plantations were lost in southern Nigeria primarily due to growth in settlements and agricultural expansion. The effects of this include an increase in urban runoff volume and flooding. These findings agree with Leon et al. (2022), and Gbiri and Adeoye (2019) who noted that deforestation alters climate variability and gives rise to global warming with greater occurrences of drought and wildfire.

Wetlands provide valuable flood storage, buffer storm surge, and assist in erosion control. Wetlands function as natural sponges that trap and slowly release surface water, rain, groundwater, and flood waters. Wetlands such as mangroves and swamps in the creeks of the Niger Delta have faced substantial land use changes. The results show that 0.4% (775 Sq. km) of the water bodies has been lost in the past 20 years. Wetlands have been reclaimed for urban development, agriculture, and recreation. These changes have negatively affected the ecosystem functions of wetlands and contributed to environmental challenges like coastal erosion, loss of habitat for wildlife, and food insecurity. These

Table 2. Land Use/Land Cover Changes in Southern Nigeria (1999-2019)

Land Use/Land Cover Class	1999 Land Cover		2019 Land Cover		%Change
	Sq.km	%	Sq.km	%	
Undisturbed Forest	2,131.6	1.1	775.1	0.4	- 0.7
Forested Freshwater	4,650.7	2.4	5,038.2	2.6	0.2
Mangrove	1,550.2	0.8	2,131.6	1.1	0.3
Forest Plantation	5,038.2	2.6	2,519.1	1.3	- 1.3
Disturbed Forest	4,456.9	2.3	4,069.3	2.1	- 0.2
Tree Crop Plantation	5,425.8	2.8	9,495.1	4.9	2.1
Arable Land	83,517.9	43.1	70,728.6	36.5	- 6.6
Settlements	63,171.3	32.6	80,029.9	41.3	8.7
Bare Surfaces	16,277.3	8.4	12,208.0	6.3	- 2.1
Water-body	7,557.3	3.9	6,782.2	3.5	- 0.4
Total	193,777	100	193,777	100	

findings corroborate Echendu (2022) and Dinsa and Gemeda (2019) who observed that over-utilization and mismanagement of wetlands affect biodiversity conservation and limit its ability to stabilize microclimates, and negatively affect food production.

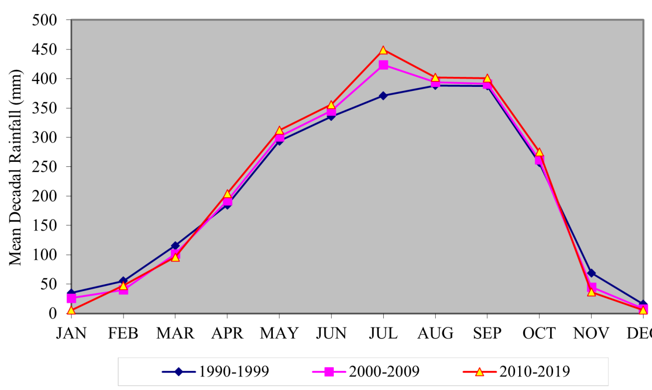

Figure 4. Decadal Trends of Rainfall Density in Southern Nigeria, 1990-2019

Changes in land use in southern Nigeria have also been visible in the areas of industrialization and infrastructural growth. The establishments of industries and associated infrastructure have led to land conversion for industrial sites, transportation networks, and other related facilities. Results from the land use analysis show that while settlements constituted 32.6% (63,171.3 Sq. Km) of the entire area in 1999, it increased to 41.3% (80.029.9 Sq. Km) in 2019 (Table 2). The construction of roads, highways, airports, and other infrastructures has expanded to meet the region's developmental needs. This has resulted in land conversion and fragmentation, impacting natural areas and altering the landscape. The urban transformation has altered the once forest-dominated landscape into built-up structures and impervious surfaces like roads, walkways, bridges, airports, and parking lots. These hard surfaces radically decrease infiltration thereby exposing the landscape to a greater volume of runoff and consequently flooding. These findings agree with previous studies on the fact that paved surfaces decrease the rate of infiltration leading to a greater volume of stormwater discharged from urban catchments (Ogbonna et al., 2023; Richard and Okeke, 2023; Sugianto et al., 2022; Adeyemi and Fashae, 2018; Sidek et al., 2016). Sugianto et al. (2022) specifically observed that the expansion of residential land and reduction of wetlands have led to an increase in soil saturation which affects the infiltration capacity of the soil thereby leading to greater flood incidence.

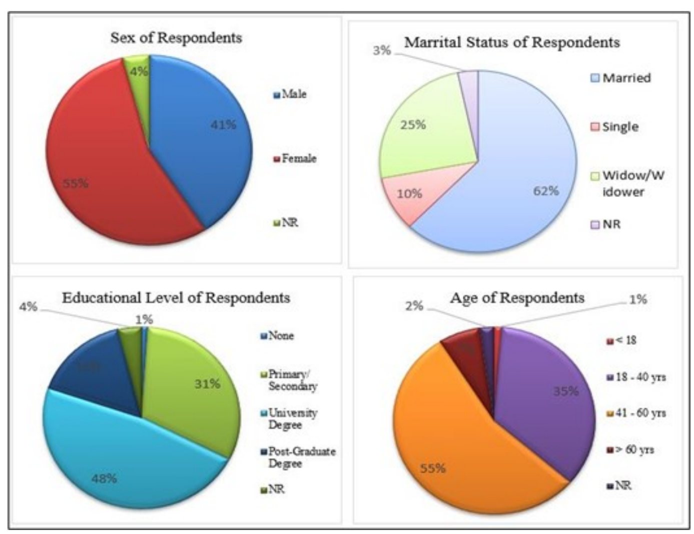

Figure 5. Socio-economic Characteristics of Respondents

3.2 Decadal Rainfall Analysis

The rainfall pattern in southern Nigeria has witnessed drastic changes over the past 30 years. Decadal rainfall data were collected from the meteorological stations in the various States across the region and the mean monthly figures were computed (Table 3). The results show a minimum of 10.9

mm in December and a maximum of 388.3 mm in August for the decade (1990 – 1999). The mean rainfall intensity for the six major rainfall months (May – October) was 339.16 mm. The 2000 – 2009 decade recorded a minimum of 5.86 mm in December and a maximum of 423.41 mm in July, while the mean rainfall intensity for the six major rainfall months (May – October) is 343.68 mm. The third decade following (2010 – 2019) recorded a minimum of 5.63 mm in January and a maximum of 438.21 mm in September, while the mean rainfall intensity for the six major rainfall months (May – October) was 347.25 mm. The decadal trends of rainfall (Figure 4) show consistent extremities with the average rainfall duration decreasing while the average intensity increases across the decades. The kurtosis of the rainfall graph increased each succeeding decade from 1990 to 2019. This implies less number of rainy days but with greater intensity. It is important to note also that while the overall rainfall average (Mean II) decreased from 203.80 mm in (1990 -1999) to 200.96 mm in (2000 – 2009), and to 195.15 mm in (2010 – 2019), the mean rainfall intensity for the six major rainfall months (May – October) increased from 339.16 mm to 343.68 mm, and 347.25 mm for the succeeding decades respectively.

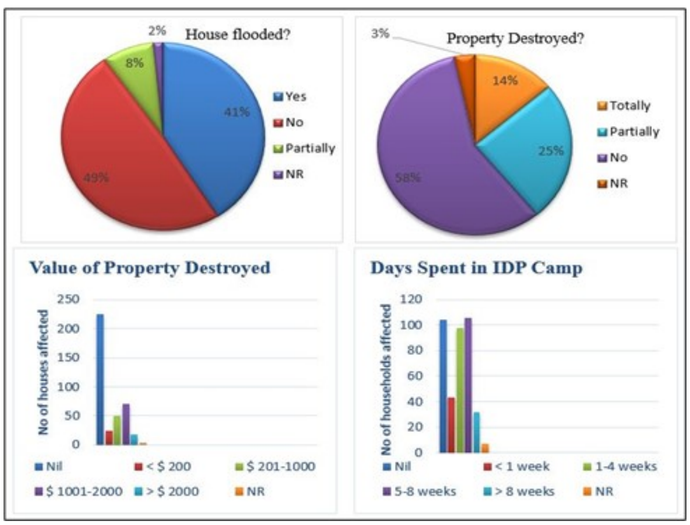

Figure 6. Effect of the 2022 Flooding on Properties

Increasing rainfall intensity in southern Nigeria has triggered urban runoff challenges leading to flooding. With high rainfall intensity coupled with an increase in paved surfaces, the soil becomes saturated quickly leading to an increase in the volume of surface runoff which overwhelms the natural drainage systems such as rivers and stormwater drains, causing them to overflow and resulting in flooding. High rainfall intensity in the region also leads to aggravated soil erosion, particularly in parts of Abia State, Imo State, Anambra State, and Delta State where the topography is characterized by steep slopes. These findings are in line with previous studies, Ulor et al. (2022) and Njoku et al. (2020) which observed fluctuation in rainfall patterns with increasing intensity especially in the southern states, with a total of 12 States in southern Nigeria in the flood-risk zone.

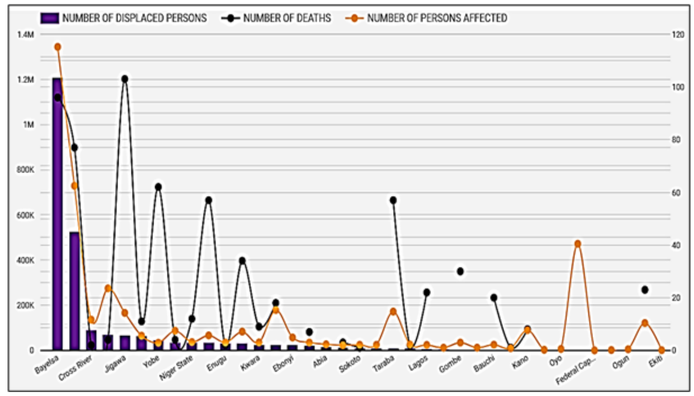

Figure 7. Nigeria 2022 Flood Incidence Dashboard (Source: https://nema.gov.ng/incidencedashboard.html)

3.3 Flood Incidence in Southern Nigeria

We carried out surveys in Lagos, Port-Harcourt and Uyo to collect data on the 2022 flood incidence in Nigeria. 390 respondents participated in the surveys: 144 in Lagos; 129 in Port-Harcourt; and 117 in Uyo. The male participants (55%) were slightly higher than the female (41%); 62% is married and 35% is single – either not yet married or lost the spouse (Figure 5). 90% of the participants were middle-aged (41-60 years) and the youth (18-40 years), disaggregated to 55% and 35% respectively. Most of the participants have sufficient education to understand and correctly respond to the survey instruments; 65% of the participants have at least a university degree. The 2022 flood incidence had devastating effects on most communities in southern Nigeria (Figure 6). 41% of the houses were completely flooded while an additional 8% were partially flooded. 14% of the houses were significantly destroyed, while another 25% were slightly damaged. 41% of residents claim to have lost properties; 21% lost properties valued at more than USD1000, and 4% lost properties worth more than USD2000. More than 25% of the respondents were displaced; at least 30% of those displaced spent more than one month in the Internally Displaced Persons (IDP) camps. 1.5% of respondents reported having lost a family relation to death as a result of the flood. Flood disaster has adversely impacted the southern region of Nigeria plunging 30% of the population to extreme poverty due to several losses both in human and material resources. These findings are in line with the official reports of the National Emergency Management Agency (NEMA) Nigeria (2022) on the flood disaster in Nigeria (Figure 7). According to the report, a total of 612 persons lost their lives across the nation; 3,219,780 persons were affected; 1,427,370 persons were displaced and 2,776 others suffered various degrees of injuries. A total of 181,600 houses were partially damaged

Table 3. Decadal Rainfall Values (1990-2019)

1990-1999												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	223.9	325.4	931.2	1846.1	2936.2	3354.6	3711.2	3883	3876.6	2568.2	687.1	109
Mean	22.39	32.54	93.12	184.61	293.62	335.46	371.12	388.3	387.66	256.82	68.71	10.9
Mean II = 203.8mm; mean (May-Oct) = 339.16 mm												
2020-2009												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	259.8	400.5	1011.4	1918.9	2829.9	3279.9	4234.1	3799.7	3858.4	2618.6	545.8	58.6
Mean	25.98	40.05	101.14	191.89	282.99	327.99	423.41	379.97	385.84	261.86	54.58	5.86
Mean II = 200.96; mean (May-Oct) = 343.68 mm												
2010-2019												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total	56.3	474.4	892.5	1643.9	2776.8	3433.2	3876.4	3933.1	4382.1	2433.3	697.7	217.9
Mean	5.63	47.44	89.25	164.39	277.68	343.32	387.64	393.31	438.21	243.33	69.77	21.79
Mean II = 195.15; mean (May-Oct) = 347.25 mm												

Source: NIMET 2021

across the nation; 123,807 houses were totally damaged, 176,852 hectares of farmland were partially destroyed, and 392,300 hectares of farmland got totally destroyed as a result of the floods.

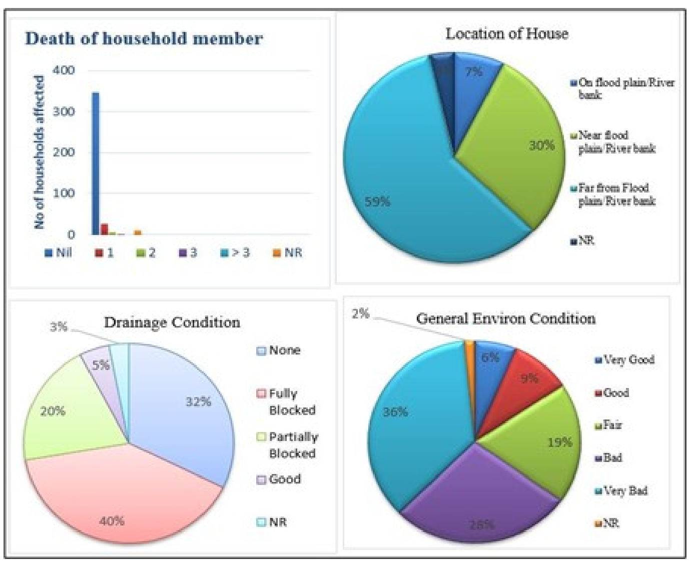

Figure 8. Environmental Factors which Contributed to the Flooding

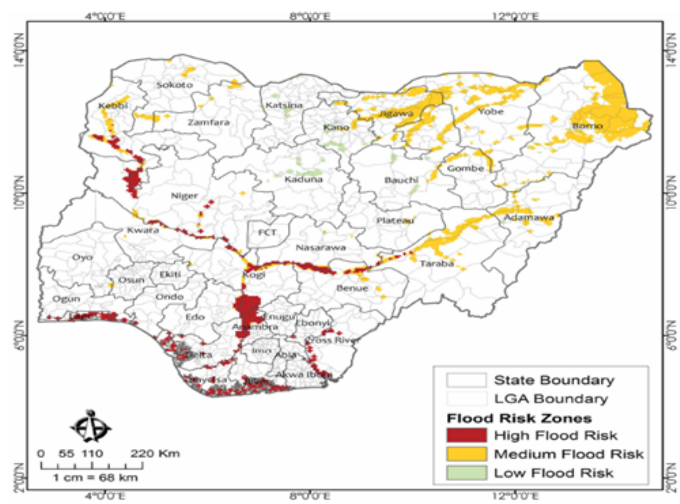

Figure 9. Flood-risk Map of Nigeria Showing Vulnerable States (Source: United Nations Environment Programme (http://www.grid.unep.ch))

The study also examined urban environmental factors which exacerbate flood incidence in southern Nigeria (Figure 8). The results show that 30% of the houses in southern Nigeria are located in areas considered as floodplain or low-lying areas susceptible to flooding. 7% of the houses lie directly on natural drainage courses. 32% of roads and streets in the towns do not have storm drain. Only 5% of the existing drainage channels are in good condition allowing free flow of runoff. 40% of the drains are completely blocked while 20% are partially silted with sand and solid wastes. As debris and waste accumulate in waterways they impede the flow of water, exacerbating flooding. 64% of the respondents believe that the sanitary conditions and general environmental cleanliness of their neighbourhoods are poor, and contribute to flooding. Waste management is a serious problem for cities in this region due to a weak governance framework and poor infrastructural base. This coupled with a high rate of urbanization puts cities in the region under pressure from physical development and space management. Between the years 2006 and 2019, the population of the region grew by 36.5%, from 65,162,158 to 88,957,325 (Table 1). This massive growth triggered urban land use changes which has reshaped the ecosystem. These results corroborate the finding of Ogbonna et al. (2023) who observed that massive physical development coupled with poor waste management in Aba (a city in the region) produce the pollution and alteration of natural drainage systems such as wetlands, streams, and floodplains thereby exacerbating flooding. The flood-risk map of Nigeria (Figure 9) shows that the most vulnerable states fall in southern Nigeria; and that is driven by the combination of climatic variation (primarily manifested by fluctuating rainfall patterns) and urban land use management problems arising from rapid urbanization, poor environmental planning, ineffective waste management system, and obsolete/inadequate physical infrastructure.

4. CONCLUSIONS

This study examined the effects of climatic variations and changing land use/land cover on flooding in southern Nigeria. The authors observed a significant decrease in rural land uses like arable lands, bare surfaces, and forest plantations; while there was a corresponding increase in urban/peri-urban land uses like settlements within the period (1999 -2019). Land use/land cover changes were due to factors such as rapid urbanization, growth of settlements, and agricultural expansion. The decadal trends of rainfall in southern Nigeria from 1990 to 2019 show consistent extremities with the mean rainfall duration decreasing while the mean intensity increases across the decades; aggravating soil erosion, urban runoff challenges, and flooding. Other anthropogenic factors which exacerbate flooding in the region include construction of structures on floodplains, obsolete physical infrastructure, inefficient waste management systems, and poor urban land use planning. Climatic variations in southern Nigeria, which manifest primarily in extreme rainfall patterns synergize with inefficient land use management practices like poor environmental planning and obsolete/inadequate physical infrastructure to exacerbate flooding. The policy implications of these findings is that governments should invest more in land use management and climate adaptation/mitigation projects as part of global efforts at addressing climate change.

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