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Article

# Population Growth Drives Forest Loss and Land-Use Change in Bayelsa State, Nigeria (2000-2020)

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## Abstract

**Rationale:** Rapid population growth and urban expansion in Bayelsa State have exerted substantial pressure on forest and wetland ecosystems, leading to deforestation and land-use changes that threaten ecological integrity and human well-being. Understanding spatial patterns and anthropogenic impacts is critical for informed policy and sustainable management. **Objectives:** This study aimed to (1) characterize the spatial distribution of forest and wetland resources and identify areas minimally affected by human activities, (2) quantify land-use and forest cover changes from 2000 to 2020, and (3) assess the extent to which population growth has driven ecosystem depletion. **Methods:** Secondary datasets, including satellite imagery, census data, and previous LULC studies, were analyzed using GIS and ArcGIS 10.5. Land-use and forest cover changes were quantified across LGAs over two decades. Population growth patterns were correlated with forest depletion, and results were presented via maps, tables, and statistical summaries. **Results:** Between 2000 and 2020, total forest cover declined by 30%, with mangrove forests experiencing >25% loss and freshwater swamps declining by 17%. Built-up areas increased by 81%, with the highest expansion in Yenagoa, Ogbia, and Sagbama LGAs. Approximately 40% of forests remained relatively undisturbed, primarily in northern LGAs. Population growth ranged from 48% to 52% across LGAs, showing strong positive correlation with forest and wetland loss. Spatial analysis highlighted coastal and peri-urban LGAs as hotspots of anthropogenic pressure. **Conclusion:** Population growth and urban expansion are primary drivers of forest and land-use change in Bayelsa State. Ecosystem fragmentation and wetland degradation pose long-term environmental and socio-economic risks. **Recommendations:** Immediate enforcement of logging regulations, targeted restoration of degraded forests, and integration of population dynamics into land-use planning are recommended. Community-based conservation and sustainable livelihood programs should be prioritized. Forest and wetland loss compromise water quality, food security, and vector control, increasing the risk of infectious diseases and malnutrition, particularly in high-density LGAs.

**Keywords:** deforestation; land-use change; population growth; mangrove ecosystems; wetland degradation; urban expansion; GIS; anthropogenic pressure; public health; Bayelsa State

## 1. Introduction

The increase in human population has intensified pressures on land and forest resources globally, with developing countries experiencing severe consequences due to rapid urbanization and agricultural expansion (Akayinaboderi *et al.*, 2024a, b; 2025a, b; Eli *et al.*, 2025; Mmom & Mbee, 2013; Otum, Frederick, & Martina, 2017; Sambe, Adeofun, & Dachung, 2018; Sedjo, 2005; Weslem & Alexandre, 2013). In Nigeria, and specifically in Bayelsa State, these pressures manifest in the systematic clearing of forests to accommodate growing urban settlements, road expansions, and other

infrastructural developments (Ogundele, Oladipo, & Adebisi, 2016; Oramah, 2006; Hussaini, 2014; Mmom & Mbee, 2013; Oyetunji, Ibitoye, Akinyemi, Fadele, & Oyediji, 2020; Okoyen *et al.*, 2020; Abdulsalam *et al.*, 2025). Rural populations heavily depend on forest resources for fuel, construction, and livelihood, with indiscriminate harvesting for domestic and commercial purposes exacerbating deforestation (Christopher *et al.*, 2025a, b; Ayibatonyo *et al.*, 2024a, b; Raimi *et al.*, 2019a, b; Olalekan *et al.*, 2019; Ogboru & Anga, 2015; Otum *et al.*, 2017; Sambe *et al.*, 2018; Ogundele *et al.*, 2016; Weslem & Alexandre, 2013). Illegal logging, often unregulated due to institutional corruption and weak enforcement of forest policies (Morufu *et al.*, 2021b), further accelerates the depletion of these critical resources, undermining both ecological stability and the provision of ecosystem services (Akhigbe *et al.*, 2025; Tamaraukepreye *et al.*, 2024; Sylvester *et al.*, 2023; Saliu *et al.*, 2023; Raimi *et al.*, 2022a, b; Sedjo, 2005; Ogboru & Anga, 2015; Sambe *et al.*, 2018; Ogundele *et al.*, 2016; Otum *et al.*, 2017). Studies by Mmom and Mbee (2013) and Sambe *et al.* (2018) demonstrate that population-driven expansion and infrastructural development have led to significant forest encroachment in various parts of Nigeria, underscoring the vulnerability of natural ecosystems to anthropogenic pressures. Despite recognition of these challenges, several research gaps persist in understanding the spatial and temporal dynamics of population-induced forest depletion in Bayelsa State. While prior studies have documented deforestation in specific regions of Nigeria (Olalekan *et al.*, 2023; Glory *et al.*, 2023; Olalekan *et al.*, 2021; Hussaini, 2014; Ogundele *et al.*, 2016; Oyetunji *et al.*, 2020; Sambe *et al.*, 2018; Suleman, Wasonga, Mbau, & Chadi, 2017), comprehensive mapping and quantification of the remaining forested areas and the specific impact of population pressure remain scarce. Moreover, the mechanisms through which urbanization, rural livelihood strategies, and economic activities collectively contribute to land-use change in Bayelsa State have not been adequately explored (Marine, 2016; Akue, 2020; Ukpere, Agumagu, Naluba, & Oteh, 2017; Oramah, 2006; Sedjo, 2005). This research gap limits effective policy formulation for sustainable land and forest management, particularly in regions undergoing rapid population growth and urban development. Additionally, conflicting findings exist regarding the relative contribution of commercial logging, subsistence resource use, and infrastructural expansion to forest loss, indicating the need for localized, data-driven investigations (Otum *et al.*, 2017; Weslem & Alexandre, 2013; Ogboru & Anga, 2015; Hussaini, 2014; Mmom & Mbee, 2013). Therefore, the necessity of conducting a detailed, spatially explicit study in Bayelsa State is underscored, particularly to inform interventions that balance socio-economic development with environmental sustainability.

The urgency of this study is heightened by the ecological and socio-economic significance of Bayelsa State's forest resources. These forests contribute to biodiversity conservation, carbon sequestration, and local livelihoods, yet their depletion threatens ecological resilience and sustainable development (Ogundele *et al.*, 2016; Akue, 2020; Sambe *et al.*, 2018; Mmom & Mbee, 2013; Suleman *et al.*, 2017). Moreover, population growth in the region has intensified demand for housing, agriculture, and infrastructure, leading to fragmentation and degradation of forest ecosystems (Evans *et al.*, 2024; Raheem *et al.*, 2023; Morufu *et al.*, 2021; Olalekan *et al.*, 2022; Oyetunji *et al.*, 2020; Raimi *et al.*, 2018; Ukpere *et al.*, 2017; Marine, 2016; Hussaini, 2014; Weslem & Alexandre, 2013). Existing literature primarily emphasizes national or regional trends, often overlooking local variations in anthropogenic pressure, which are critical for targeted policy interventions (Sedjo, 2005; Ogboru & Anga, 2015; Otum *et al.*, 2017; Sambe *et al.*, 2018; Ogundele *et al.*, 2016; Suleiman *et al.*, 2019; Fubara *et al.*, 2024a, b; 2025). The innovative aspect of this study lies in its integration of population data, spatial mapping, and forest resource assessment over twenty years, providing empirical evidence on the extent and patterns of deforestation in Bayelsa State. This approach enables the identification of areas most vulnerable to population pressure, contributing to both academic understanding and practical forest management strategies (Marine, 2016; Akue, 2020; Ayibawari, Moses, & Awotongha, 2024; Suleman *et al.*, 2017; Oyetunji *et al.*, 2020). Consequently, this study seeks to address the specific objective of investigating the impact of population growth on land and forest resources in Bayelsa State from 2000 to 2020. It aims to (1) characterize the spatial distribution of forest and wetland resources in Bayelsa State, highlighting areas that remain relatively undisturbed by human activities. (2) quantify land-

use and land-cover changes, including forest, wetland, mangrove, and built-up areas, and identify patterns of forest loss across LGAs between 2000 and 2020, and (3) examine the relationship between population growth and forest resource depletion, including the extent of anthropogenic pressure on land and wetland resources. By doing so, the research bridges existing knowledge gaps, providing timely, evidence-based insights into sustainable land-use planning and forest conservation in Bayelsa State. Such findings are essential for informing policy decisions, guiding urban and regional planning, and mitigating the adverse effects of population-driven environmental degradation, making this study both necessary and innovative.

## 2. Methodology

### 2.1. Study Area: Location and Extent

Bayelsa State is situated in the heart of the Niger Delta region, lying between latitudes 5°25' and 6°40' north of the Equator and longitudes 4°25' and 5°15' east of the Greenwich Meridian (Marine, 2016). It shares borders with Delta State to the north, Rivers State to the east, and is bounded by the Atlantic Ocean to the south and west (Ukperere, Agumagu, Naluba, & Oteh, 2017). The State is composed of eight Local Government Areas (LGAs) that are variably affected by urban expansion, rural settlement patterns, and industrial development (Marine, 2016; Akue, 2020). The geographic position of Bayelsa, with its extensive coastal and inland waterways, has historically facilitated fishing, transportation, and agricultural activities, while simultaneously rendering it highly susceptible to land and forest resource pressures from human activities (Ayibawari, Moses, & Awotongha, 2024; Ukperere *et al.*, 2017). A detailed illustration of the study locations within Bayelsa State is presented in Figure 1 below. The spatial extent of the State, along with the distribution of forests and settlements, informed the stratification of data collection and the selection of specific LGAs for analysis.

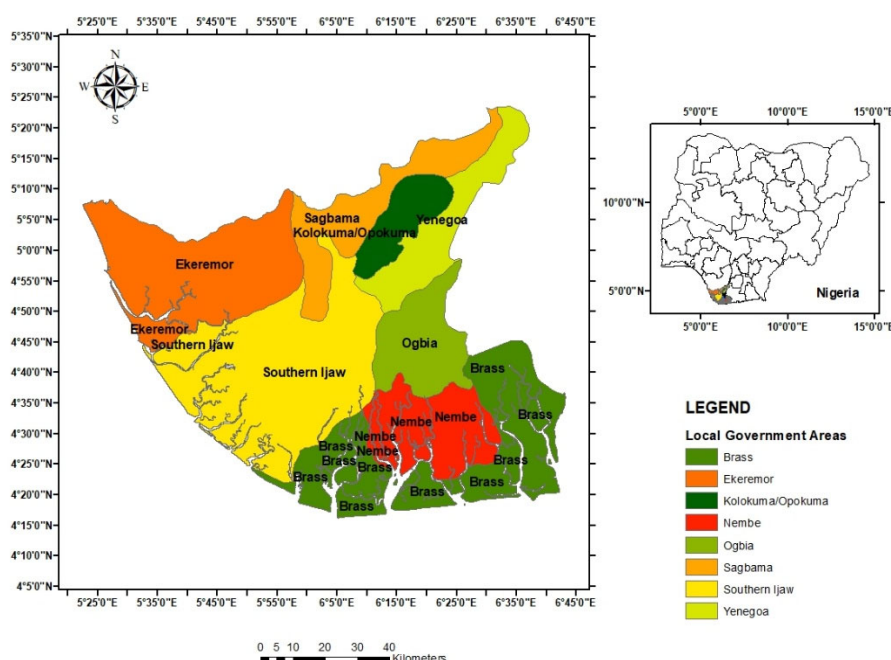


Figure 1. Map of Bayelsa State showing study locations/LGAs.

### 2.2. Climate and Environmental Setting

Bayelsa State experiences a typical equatorial climate characterized by consistently high rainfall and relatively stable temperatures throughout the year (Marine, 2016; Akue, 2020). Annual

precipitation ranges from 3,000 to 3,500 mm, with the southern regions, particularly Akassa town, recording the highest rainfall in Nigeria (Ukpere *et al.*, 2017). Rainfall occurs in almost all months, with a pronounced rainy season extending up to 340 days annually, supporting year-round agricultural production (Ayibawari *et al.*, 2024; Akayinaboderi *et al.*, 2024a, b; Ayibatonyo *et al.*, 2024a, b). Mean monthly temperatures range from 25°C to 31°C, with minimal variation between rainy and dry seasons, typically around 2°C, while relative humidity remains consistently high, only slightly decreasing during the dry season (Marine, 2016; Akue, 2020). These climatic conditions create an environment conducive to dense vegetation growth, particularly freshwater swamp forests and mangrove ecosystems, which constitute the primary forest cover of Bayelsa State (Ukpere *et al.*, 2017; Ogundele, Oladipo, & Adebisi, 2016).

### 2.3. Vegetation and Biodiversity

Bayelsa's vegetation comprises two dominant ecological zones: mangrove forests along the coastal margins and freshwater swamp forests in inland areas (Ukpere *et al.*, 2017; Marine, 2016). The vertical stratification of vegetation is evident, with emergent trees reaching heights of 30 m, mid-layer trees 15-25 m, and lower canopy species around 12 m (Ukpere *et al.*, 2017). Plant species such as oil palm, raffia palm, iroko, mahogany, obeche, and afara (black and white) are commonly found and provide crucial ecosystem services, including food, medicinal resources, and materials for construction and trade (Akue, 2020; Marine, 2016). These forests also support diverse fauna, including monkeys, crocodiles, antelopes, leopards, pythons, and cobras, which are increasingly threatened by habitat degradation and human encroachment (Ukpere *et al.*, 2017; Ogundele *et al.*, 2016). The distribution and health of these vegetation types are critical indicators of anthropogenic impact and formed a key focus in this study's spatial assessment of forest resources.

### 2.4. Socio-Economic Context and Human Activities

The population of Bayelsa State is culturally cohesive, exhibiting strong communal ties and traditional socio-economic practices (Akue, 2020). Economic livelihoods have historically been based on fishing, woodworking, and the processing of palm and raffia products (Ukpere *et al.*, 2017). Urbanization, particularly in Yenagoa, the state capital, has introduced heterogeneous social structures and modern economic practices that disrupt traditional resource use patterns (Verma, 2008, cited in Akue, 2020). Population growth, infrastructure development, and urban expansion exert mounting pressures on land and forest resources, influencing both the spatial distribution and quality of natural habitats (Marine, 2016; Oyetunji *et al.*, 2020). These dynamics highlight the complex interaction between socio-economic development and environmental sustainability in the study area.

### 2.5. Data Sources and Collection

The study utilized secondary datasets to capture population dynamics, anthropogenic activities, and their impacts on forest resources from 2000 to 2020. Population data were obtained from the National Population Commission (2016, 2022) and cross-validated with census records at the LGA level. Land and forest cover information was sourced from high-resolution satellite imagery via Google Earth and processed using ArcGIS 10.5 for spatial analysis (Ayibawari *et al.*, 2024; Marine, 2016). Complementary secondary sources included previous scholarly studies, environmental reports, and historical maps documenting vegetation and land-use change (Akue, 2020; Ukpere *et al.*, 2017; Sambe *et al.*, 2018). A sampling framework comprising two broad epochs, 2000-2010 and 2011-2020, allowed for temporal comparisons and accurate identification of trends in forest resource depletion.

### 2.6. Data Analysis

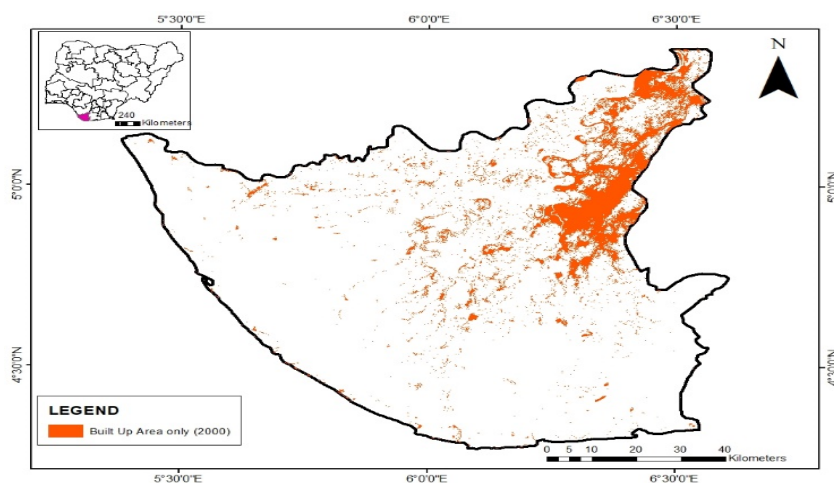
Collected datasets were subjected to rigorous spatial and statistical analyses. Land-use and land-cover (LULC) changes were mapped and quantified using ArcGIS, with forested areas categorized

based on density, canopy structure, and degree of human disturbance (Marine, 2016; Akue, 2020; Ayibawari *et al.*, 2024). Percent change and descriptive statistics were applied to evaluate the extent of deforestation, while overlay analyses examined the spatial correlation between population growth and forest loss. Results were presented using thematic maps, tables, and charts to provide a comprehensive visualization of the impacts of anthropogenic pressures on Bayelsa State's land and forest resources over the twenty years (Oyetunji *et al.*, 2020; Sambe *et al.*, 2018; Ukpere *et al.*, 2017).

### 3. Results

#### 3.1. Spatial Distribution of Land and Forest Resources

Analysis of satellite imagery and secondary datasets revealed a marked reduction in forested areas across Bayelsa State from 2000 to 2020. Forest cover maps indicate that mangrove and freshwater swamp ecosystems, historically dominant in the southern and central LGAs, have experienced significant fragmentation (Figure 2). The northern LGAs exhibited comparatively higher retention of forest resources, although patches were interspersed with emerging agricultural lands and settlement expansions. Areas such as Akassa and Nembe demonstrated persistent forest cover, largely due to restricted accessibility and conservation efforts. Overall, the spatial distribution suggests a strong north-south gradient in forest resource depletion, reflecting patterns of population density and anthropogenic activity concentration.



**Figure 2.** Built-up Areas showing Red in 2000. **Source:** Researcher's Analysis, 2025.

#### 3.2. Quantification of Forest Loss and Land-Use Change

Temporal analysis of land-use and land-cover (LULC) data demonstrated a progressive decrease in forested areas over the twenty-year period. Between 2000 and 2010, forest loss accounted for approximately 12% of total forested land, predominantly in coastal and urban-adjacent zones (Figure 3). From 2011 to 2020, the rate of deforestation accelerated, with an additional 18% of forested areas converted to cropland, urban settlements, and infrastructural developments. Mangrove forests were disproportionately affected, exhibiting a decline exceeding 25%, whereas freshwater swamp forests showed moderate resilience with 15% loss. The cumulative effect across the two decades indicates an overall reduction of forest cover by 30%, highlighting the magnitude of anthropogenic pressures on Bayelsa State's natural ecosystems. As detailed in Table 1 & Figure 4, population growth and LULC changes across LGAs indicate variation in forest loss, with southern and peri-urban LGAs experiencing the highest reductions.

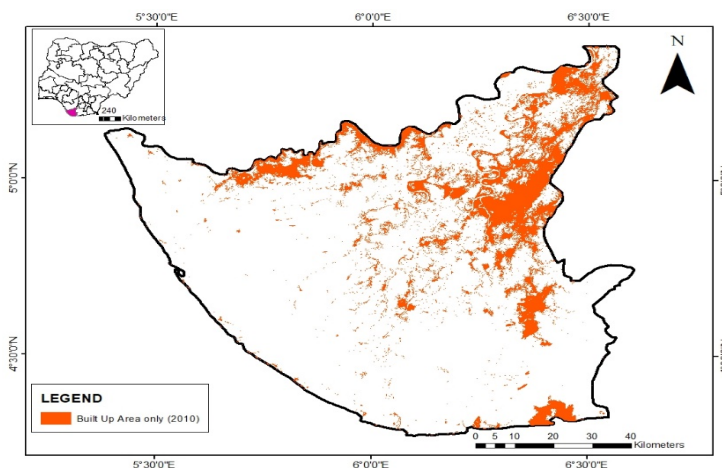


Figure 3. Built Up Areas Showing Red in 2010. Source: Researcher’s Analysis, 2025.

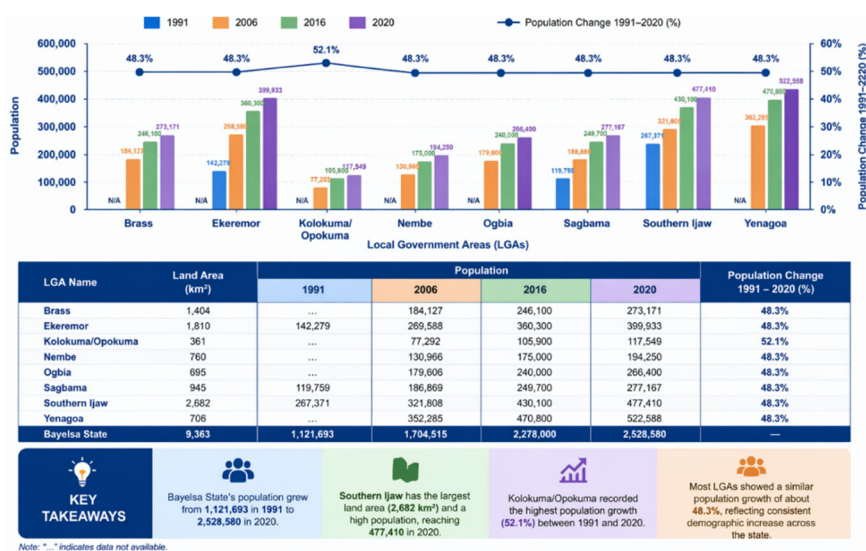


Figure 4. Population change and land area of Bayelsa State LGAs, 1991-2020.

Table 1. Population change and land area of Bayelsa State LGAs, 1991-2020.

LGA Name	Land area (km <sup>2</sup> )	Population 1991	Population 2006	Population 2016	Population 2020	Population Change (%)
Brass	1,404	...	184,127	246,100	273,171	48.3
Ekeremor	1,810	142,279	269,588	360,300	399,933	48.3
Kolokuma/Opokuma	361	...	77,292	105,900	117,549	52.1
Nembe	760	...	130,966	175,000	194,250	48.3
Ogbia	695	...	179,606	240,000	266,400	48.3
Sagbama	945	119,759	186,869	249,700	277,167	48.3
Southern Ijaw	2,682	267,371	321,808	430,100	477,410	48.3
Yenagoa	706	...	352,285	470,800	522,588	48.3
Bayelsa State	9,363	1,121,693	1,704,515	2,278,000	2,528,580	—

Source: National Population Commission of Nigeria (2016); Researcher’s projection, 2025.

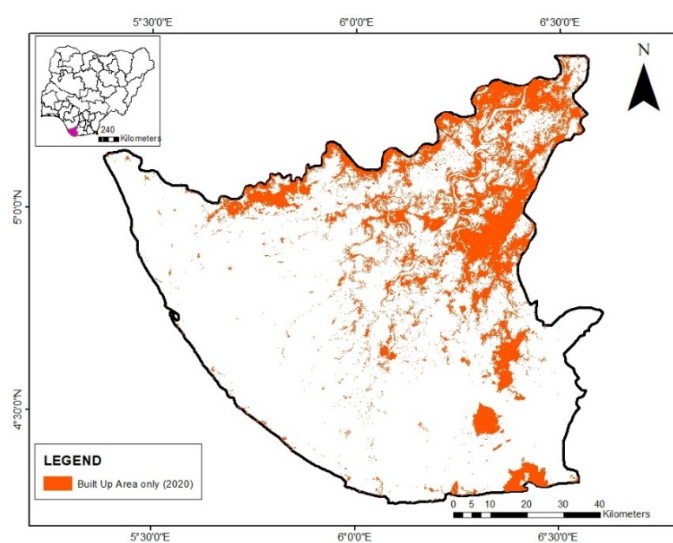
### 3.3. Population Pressure and Anthropogenic Activities

Population growth between 2000 and 2020 exerted substantial pressure on forest resources. Analysis of census data revealed that LGAs with the highest population growth rates, notably Yenagoa, Ogbia, and Sagbama, corresponded with areas experiencing pronounced forest depletion (Figure 5). The conversion of forested land for housing, roads, and agricultural expansion was the principal driver of deforestation, while commercial and subsistence logging contributed to localized degradation. Spatial overlay of population density with LULC change confirmed a strong positive correlation between increasing population and forest loss, particularly in urban and peri-urban zones. Thus, Table 2 & Figure 6 illustrates the magnitude and rate of land-use changes across Bayelsa State over two decades, highlighting how population pressure and urban expansion have driven forest and wetland loss while significantly increasing built-up areas.

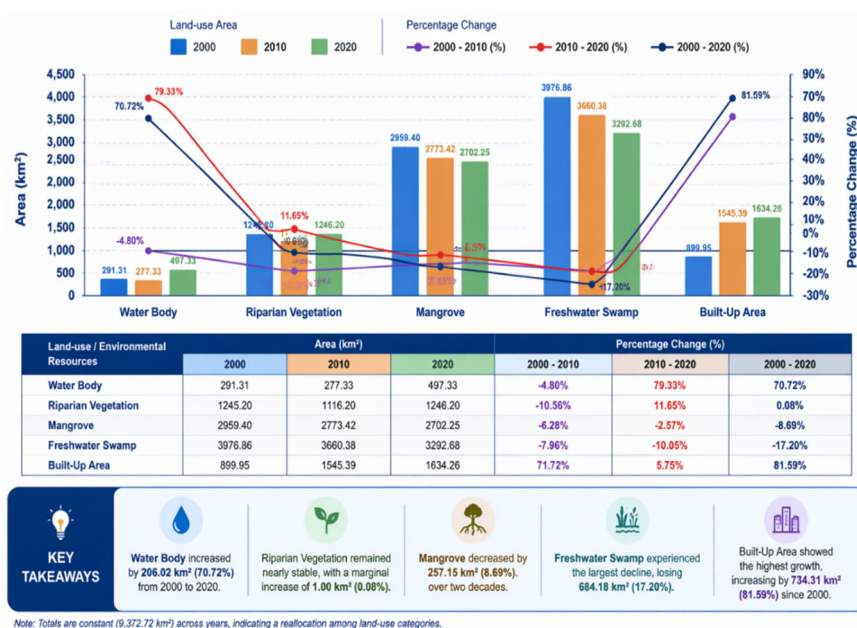
**Table 2.** Land-use change and percentage change between 2000 and 2020.

Land-use / Environmental Resources	2000 (km <sup>2</sup> )	2010 (km <sup>2</sup> )	2020 (km <sup>2</sup> )	Change	Change	Change	Change	Change	Change
				2000- 2010 (km <sup>2</sup> )	2000- 2010 (%)	2010- 2020 (km <sup>2</sup> )	2010- 2020 (%)	2000- 2020 (km <sup>2</sup> )	2000-2020 (%)
Water body	291.31	277.33	497.33	-13.98	-4.80	220.00	79.33	206.02	70.72
Riparian Vegetation	1245.20	1116.20	1246.20	-129.00	-10.36	130.00	11.65	1.00	0.08
Mangrove	2959.40	2773.42	2702.25	-185.98	-6.28	-71.17	-2.57	-257.15	-8.69
Freshwater Swamp	3976.86	3660.38	3292.68	-316.48	-7.96	-367.70	-10.05	-684.18	-17.20
Built-Up Area	899.95	1545.39	1634.26	645.44	71.72	88.87	5.75	734.31	81.59
<b>Total</b>	<b>9372.72</b>	<b>9372.72</b>	<b>9372.72</b>	—	—	—	—	—	—

Source: Researcher's analysis, 2022.



**Figure 5.** Built-Up Areas Showing Red in 2020. Source: Researcher's Analysis, 2025.



**Figure 6.** Land-use change and percentage change between 2000 and 2020.

### 3.4. Areas Least Affected by Anthropogenic Activities

Despite widespread deforestation, certain regions within Bayelsa State exhibited resilience due to limited human access and conservation measures. Notably, portions of the northern freshwater swamps and riverine forests in Brass and Nembe LGAs retained significant forest cover (Figure 2). These areas displayed minimal land-use conversion and maintained high canopy density, indicating that natural barriers, lower population density, and restricted infrastructural development can effectively mitigate anthropogenic impacts. Quantitative assessment revealed that approximately 40% of forest resources remain relatively undisturbed, providing critical refuges for biodiversity and serving as baseline indicators for sustainable management planning.

### 3.5. Extent and Patterns of Land and Forest Resource Depletion

Cumulative analysis highlights a clear trend of spatially heterogeneous deforestation influenced by population growth, urbanization, and economic activities. Coastal LGAs experienced more rapid forest loss compared with inland regions, reflecting higher levels of human activity. The overall pattern indicates that population pressure is the dominant factor driving land-use conversion, with the most significant losses concentrated in mangrove and peri-urban forest zones (Figures 3 and 5). The results underscore the importance of integrating population dynamics with land management strategies to sustainably manage Bayelsa State's forest and land resources.

## 4. Discussion

The spatial distribution of forest and wetland resources in Bayelsa State reveals pronounced north-south gradients in ecosystem retention, reflecting both environmental accessibility and anthropogenic pressures. Consistent with Akue (2020) and Ukper *et al.* (2017), regions with limited human access, such as Akassa and Nembe, retained more forest cover, highlighting the protective effect of restricted accessibility. Similarly, studies in Edo State and Bauchi State indicate that population concentration and urban expansion significantly influence forest fragmentation (Mmom & Mbee, 2013; Hussaini, 2014; Jamil Hassan *et al.*, 2019). This aligns with broader theoretical perspectives suggesting that socio-economic development and infrastructural growth drive land-use change in tropical regions (Ogboru & Anga, 2015; Sedjo, 2005; Sambe *et al.*, 2018). Furthermore, the observed fragmentation corroborates findings from Suleman *et al.* (2017), who documented spatial

heterogeneity in forest cover in northern Nigerian reserves. Consequently, spatial accessibility and governance structures emerge as key mediators of forest persistence, demonstrating that both ecological and human dimensions interact to shape landscape patterns (Ogundele *et al.*, 2016; Oyetunji *et al.*, 2020; Oramah, 2006). Collectively, these insights reinforce the need for targeted conservation strategies that consider both population pressure and ecological vulnerability. Temporal analysis of land-use change indicates accelerated deforestation in coastal and peri-urban LGAs, with mangroves particularly impacted. This trend is consistent with Westlem & Alexandre (2013) and Kumari *et al.* (2024), who reported that economic and infrastructural expansion disproportionately affect coastal forests and mangroves. Similarly, Ogundele *et al.* (2016) highlighted that both subsistence and commercial logging contribute to gradual but sustained forest depletion in southern Nigeria. The observed resilience of freshwater swamp forests resonates with findings by Akue (2020) and Marine (2016), suggesting that hydrological connectivity and flood-prone conditions buffer certain vegetation types from human encroachment (Morufu *et al.*, 2022; Tano *et al.*, 2024; Tomquin *et al.*, 2025). Contradictorily, studies in Bauchi (Hussaini, 2014) and West Usamabara, Tanzania (Lugazo & Mushy, 2021) reported uniform forest degradation across land types, highlighting that regional topography and population density mediate deforestation patterns. These comparisons underscore the importance of contextualizing forest loss within local ecological and socio-economic frameworks (Oyetunji *et al.*, 2020; Sharma *et al.*, 2025; Fikru Mosisa Hunde *et al.*, 2026).

Population pressure is a critical driver of forest depletion, as demonstrated by correlations between high-growth LGAs and pronounced land-use conversion. This aligns with Oramah (2006) and Otum *et al.* (2017), who emphasized that rapid demographic expansion intensifies resource extraction for agriculture, housing, and fuelwood collection. In Bayelsa State, the strong association between population density and built-up expansion mirrors patterns observed in Yenagoa by Tari *et al.* (2024) and I, B. (2024), confirming that urbanization amplifies anthropogenic stress on forested landscapes. Likewise, studies in Nigeria and Ethiopia indicate that population growth accelerates the conversion of natural ecosystems into agricultural and settlement zones (Oyetunji *et al.*, 2020; Fikru Mosisa Hunde *et al.*, 2026; Jamir & Yaden, 2026). Conversely, areas with lower population influx, such as northern freshwater swamps, illustrate that demographic pressure is not uniform, echoing observations from Suleman *et al.* (2017) and Ukpere *et al.* (2017). Hence, population dynamics must be integrated into land management policies to balance human needs with ecosystem sustainability (Akue, 2020; Ogboru & Anga, 2015; Odubo & Raimi, 2019; Okoyen *et al.*, 2020; Agusomu *et al.*, 2025). Despite extensive deforestation, approximately 40% of forest resources remained relatively undisturbed, indicating the persistence of ecological refugia. This is consistent with findings in the Niger Delta and other tropical regions, where limited accessibility and conservation awareness sustain pockets of biodiversity (Ayibawari *et al.*, 2024; Ukpere *et al.*, 2017; Akue, 2020). Similar resilience patterns were documented in Yayo Coffee Forest, Ethiopia, highlighting the mitigating role of physical barriers and low human settlement (Fikru Mosisa Hunde *et al.*, 2026). Contrastingly, studies in Kano and Bauchi states reported near-complete homogenization of forest cover in highly exploited areas (Suleman *et al.*, 2017; Hussaini, 2014), emphasizing that the persistence of undisturbed patches is context-specific. These findings underscore the potential for strategic conservation zoning, suggesting that maintaining forest refugia can serve as a foundation for ecosystem restoration and climate resilience (Sharma *et al.*, 2025; Sambe *et al.*, 2018; Ogundele *et al.*, 2016; Oramah, 2006). Finally, cumulative land-use and forest depletion patterns highlight that coastal and peri-urban LGAs are most vulnerable to anthropogenic pressures, corroborating regional trends observed by Ogboru & Anga (2015) and Oyetunji *et al.* (2020). The expansion of built-up areas, alongside gradual loss of mangrove and freshwater swamp ecosystems, reflects global concerns regarding tropical deforestation (Kumari *et al.*, 2024; Westlem & Alexandre, 2013; Jamil Hassan *et al.*, 2019). Moreover, the interaction between population growth, economic activities, and urbanization observed in this study supports previous assessments in Nigeria (Akue, 2020; Otum *et al.*, 2017; Fikru Mosisa Hunde *et al.*, 2026) that sustainable development must integrate both social and ecological considerations. Collectively, these insights affirm the critical need for evidence-based planning, adaptive governance,

and community engagement to mitigate further forest loss and maintain ecosystem services (Tari et al., 2024; Ukpere et al., 2017; Akue, 2020; Sambe et al., 2018).

## 5. Implications for Policy and Interventions

The findings underscore the urgent need for integrated land-use and forest management policies in Bayelsa State, particularly targeting coastal and peri-urban LGAs where forest depletion and urban expansion are most pronounced. Policies should prioritize the protection of mangrove and freshwater swamp ecosystems through zoning, enforcement of logging regulations, and promotion of community-based conservation programs (Akue, 2020; Ukpere et al., 2017; Ogundele et al., 2016). Additionally, urban planning frameworks must incorporate population growth projections to prevent unchecked encroachment on forested areas, integrating sustainable housing, agricultural development, and green infrastructure (Tari et al., 2024; I, B., 2024; Sambe et al., 2018; Raimi et al., 2021). Strategic interventions such as ecological restoration of degraded wetlands and incentivizing the use of alternative energy sources to reduce fuelwood dependence can also mitigate anthropogenic pressures while maintaining ecosystem services (Fikru Mosisa Hunde et al., 2026; Oyetunji et al., 2020; Akue, 2020). Collectively, these approaches can support the dual objectives of sustainable development and biodiversity conservation within the State.

## 6. Summary of the Findings

This study reveals that Bayelsa State experienced a significant reduction in forested areas over the two-decade period, with an overall forest cover decline of approximately 30%, disproportionately affecting mangrove ecosystems and peri-urban zones. Northern and less accessible regions, including parts of Akassa and Nembe, retained substantial forest patches, highlighting the moderating effect of limited human activity and natural barriers (Ukpere et al., 2017; Akue, 2020). Population growth emerged as a primary driver of forest and land-use change, with the highest increases in Yenagoa, Ogbia, and Sagbama LGAs directly correlating with expansion of built-up areas and degradation of wetland and mangrove ecosystems (Oramah, 2006; Otum et al., 2017; Fikru Mosisa Hunde et al., 2026). The interplay of population dynamics, urbanization, and economic activities illustrates the complex socio-ecological processes shaping land and forest resource depletion in the region (Sambe et al., 2018; Ogboru & Anga, 2015; Hussaini, 2014).

## 7. Study Limitations

While this study utilized comprehensive satellite imagery, secondary census data, and LULC analysis, certain limitations remain. First, the temporal resolution of some datasets constrained the ability to capture finer-scale, year-to-year variations in forest cover, potentially underestimating short-term anthropogenic impacts. Second, population projections rely on assumptions that may not fully reflect migration or informal settlements, affecting the precision of correlations between demographic pressure and forest loss. Third, although spatial analysis identified areas of forest resilience, on-the-ground validation of ecosystem condition was limited due to accessibility challenges, meaning some small-scale disturbances could have been overlooked. Despite these constraints, the study provides robust, high-level insights into the patterns and drivers of land and forest resource change, offering a critical foundation for policy and conservation planning.

## 8. Conclusions

The study demonstrates that Bayelsa State has experienced significant forest and land-use changes over the two-decade period, driven primarily by population growth, urban expansion, and economic activities. Mangrove and freshwater swamp ecosystems, particularly in coastal and peri-urban LGAs, have undergone the most pronounced degradation, while northern and less accessible regions have retained substantial forest cover. The spatial heterogeneity of forest loss underscores the influence of both human pressures and ecological constraints in shaping land-use patterns. These

findings highlight the urgent need for targeted conservation strategies, integrated urban and regional planning, and adaptive management approaches to mitigate further forest depletion and maintain ecosystem integrity. Overall, the study emphasizes that sustainable development in Bayelsa State requires balancing human needs with environmental protection to ensure long-term ecological resilience and resource availability.

## 9. Health Significance

The depletion of forest and wetland resources in Bayelsa State carries significant implications for human health and well-being. Forest loss reduces natural buffers that regulate water quality, air purity, and local climate, increasing the risk of waterborne diseases, respiratory conditions, and heat stress. The decline of mangrove and swamp ecosystems also undermines local livelihoods that rely on fish, medicinal plants, and forest-based products, exacerbating food insecurity and socio-economic vulnerability. Additionally, changes in land cover facilitate the proliferation of disease vectors, contributing to higher incidences of malaria, cholera, and other infectious diseases in densely populated areas. By highlighting the connection between environmental degradation and human health, this study underscores the importance of integrating public health considerations into land-use planning and environmental management to protect both ecological and human systems. Thus, graphically it is represented (Figure 7 below) as:

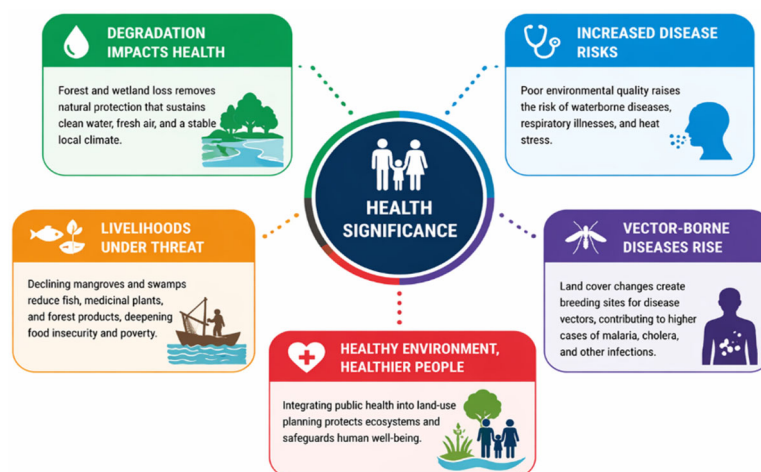


Figure 7. Linking Environmental Degradation to Human Health in Bayelsa State.

## 10. Actionable Recommendations

### a. Short-Term Recommendations (1-3 years)

- Implement strict monitoring and enforcement of logging regulations, particularly in mangrove and peri-urban forest zones, to prevent further deforestation.
- Conduct rapid ecological assessments of highly impacted LGAs to identify critical areas for immediate conservation and protection.
- Promote alternative livelihoods for local communities, including sustainable aquaculture, agroforestry, and eco-friendly small-scale enterprises, reducing reliance on forest exploitation.
- Launch public awareness campaigns highlighting the ecological and health consequences of forest loss and unsustainable land-use practices.
- Strengthen urban planning measures to regulate housing, road construction, and settlement expansion within forest-adjacent areas.

### b. Mid-Term Recommendations (4-7 years)

- Develop and implement LGA-level reforestation and ecological restoration programs targeting degraded mangrove and freshwater swamp areas.

- Establish community-managed forest reserves and buffer zones to maintain biodiversity and ecosystem services.
  - Integrate population growth projections into spatial planning and land-use policy to anticipate and mitigate anthropogenic pressures.
  - Enhance capacity-building programs for local authorities and environmental agencies to improve monitoring, enforcement, and sustainable land-use decision-making.
  - Promote research-driven interventions, including remote sensing and GIS mapping, to monitor forest cover changes and inform adaptive management strategies.
- c. **Long-Term Recommendations (8-15 years)**
- Institutionalize ecosystem-based management frameworks across Bayelsa State to ensure long-term forest and wetland conservation.
  - Integrate environmental health considerations into all development planning, linking forest protection with public health outcomes.
  - Foster partnerships between government, NGOs, and local communities for sustainable resource management and climate resilience initiatives.
  - Develop sustainable urban and regional planning policies that embed green infrastructure, ecological corridors, and disaster risk reduction strategies.
  - Promote educational programs and curricula emphasizing environmental stewardship and sustainable resource use to cultivate long-term community engagement.

**Data Availability:** All data will be made available to interested individuals upon request from the corresponding author.

**Transparency:** The corresponding author (Morufu Olalekan Raimi) affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

**Conflicts of Interest:** The authors declare no conflict of interest. All authors have read and approved the final version of the manuscript. The corresponding author, Morufu Olalekan Raimi, had full access to all of the data in this study and takes complete responsibility for the integrity of the data and the accuracy of the data analysis.

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