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Land Cover Transformation and Population Growth: Impacts on Coastal Environment of The Gambia (1990–2020)

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Abstract: The coastal zone of The Gambia, which contributes 36% to the country's GDP, has experienced considerable transformation due to increased socioeconomic development and urbanisation. This growth has significantly altered the coastal landscape, intensifying pressure on the environment and increasing vulnerability to climate hazards. A study used cloud-free Landsat imagery from 1990, 2000, 2010, and 2020 for assessing land use and land cover (LULC) changes and population growth. The analysis classified LULC into five categories: barren land, built-up areas, vegetation cover, water bodies, and wetlands. The findings highlighted dramatic changes in LULC over the past three decades. Barren land increased by 46%, and built-up areas surged by 680%. In contrast, vegetation cover decreased by 35%, water bodies by 31%, and wetlands by 14%. These transformations correlate with rising population densities along the coastline, particularly within 10–25 km of the shore. The substantial growth in built-up areas and reduction in vegetation are directly linked to urbanisation and population pressure. This rapid change exacerbates the vulnerability of coastal communities to extreme weather events such as flooding and tropical windstorms. To address these challenges, it is crucial for the government and stakeholders to implement policies that manage coastal congestion and encourage development in inland regions. Such measures should consider the impacts of population growth on coastal environments and aim to ensure the long-term sustainability of The Gambia's coastal ecosystems by mitigating risks associated with climate change.

Keywords: coastal zone; climate change; population; land use land cover; transformation

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1. Introduction

Climate change has different magnitudes of negative impacts on the health and socioeconomic wellbeing of populations [1]. Population growth drives land use and land cover (LULC) changes, transforming natural areas into built-up spaces to meet housing and infrastructure demands while also reshaping population distribution and settlement patterns, especially within coastal environments [2]. LULC and climate change are major factors driving landscape transformations, which affect biodiversity and sustainability, highlighting the importance of ongoing long-term monitoring to observe these changes [3]. These LULC changes, influenced by regional policies and human activities, have resulted in higher agricultural output and created job opportunities in established agricultural

regions [4]. As significant and unchecked global changes can severely impact the functioning of ecosystems, research on LULC changes plays a vital role in shaping policies and strategic plans [5]. The visual representations of spatial data in LULC analysis offer a clear understanding of spatial, environmental, and socioeconomic shifts, which enables governments to mitigate costs and adverse effects while aiding in land-use planning and urban growth forecasting [6].

The coastal regions, especially in developing countries, are most vulnerable to coastal erosion, deforestation, and tropical windstorms. Climate change hazards cause environmental changes through multiple stressors at different periods [7]. For instance, Mandal et al. [8] explained that the destruction of forest areas predisposed the coastal ecosystem to natural threats that impact land cover change and several other climate and non-climate stressors, which manifest at global and local scales and threaten marine ecosystems, making it difficult for aquatic organisms to adapt to changes in their natural environments [9].

The Gambia's coastal environment is a region of socioeconomic importance, where various activities, including tourism, artisanal fishing, and cultural, aesthetic and religious activities are prevalent. It also provides important ecosystem services, including habitats and breeding grounds for aquatic animals, plants, and migratory birds. Diverse socioeconomic activities, including fisheries and hotel industries, which is increasing within the coastal environment, contribute 36% of the country's GDP [10]. However, these activities are negatively impacted due to accretion and erosion of the coastline, which threaten the livelihood of communities within this environment. As the demand for marine and freshwater resources and their habitats continue to grow in The Gambia, opportunities to conserve much of the coastal land and water environment are dwindling. This has resulted in an increased coastal population with an associated high infrastructural development, mining, and exploitation of coastal resources, ultimately posing significant challenges to coastal inhabitants [11–13]. This observed degradation of the coastal environment in The Gambia is expected to continue to exert increasing adverse effects into the future, irrespective of the actions towards land transformation.

Consequently, coastlines, which are an interface between the land and the ocean, have suffered significant conversion due to intense human activities in the last two decades, leading to the vulnerability of these areas to climate change [14]. There is a lack of awareness and understanding of the causes of land degradation, which affects the development of environmental policies, population and poverty, and societies' response to economic opportunities [15]. Therefore, there is an urgent need to prioritise the increased awareness and understanding, with regard to decision-makers and coastal inhabitants whose livelihoods depend on the coastal resources, on how to deal with natural and human-induced hazards [16]. In the same vein, there is a need for improved socioeconomic and technical skills, awareness and understanding, and living conditions of individuals at community levels, especially around low-lying coastal areas, in order to address the impact of climate change [17,18]. This will address the lack of understanding of land cover transformation, which affects the development of environmental policies, population and poverty, and a society's response to economic opportunities [15]. This will help to address the conflicting interest between human socioeconomic activities, which negatively affect the coastal environment, and human wellbeing [19]. Successful environmental management will help to address the conflict between human socioeconomic activities, such as urbanisation, tourism, industrialisation, energy activities, port activities and agriculture, and the need to preserve natural coastal ecosystems and their ecological processes [20–22]. As the widespread land transformation instigated by human activities continues to increase over time, effective and efficient evaluations of LULC changes in coastal areas are necessary for informing relevant

stakeholders in developing more vibrant coastal management policies by incorporating substantial vulnerabilities, adaptation, and mitigation issues [23].

As the African settlements increase around the coastline and urban areas, they will be confronted with the adverse effects of changing climate, which results in extreme temperature effects, coastal erosion, increased health hazards, and food insecurity, thereby increasing their vulnerability and risk levels [24,25]. LULC change driven by individuals' responses to economic opportunity, as mediated by institutional factors, is an important subject significant to the study of global forest change and holds major implications for sustainable development [26]. Land is always subject to increased transformation, which makes it scarce around coastal and urban areas with a high rate of industrialisation and urbanisation, where it is considered a crucial asset for growth and advancement [23,27].

For Ofori et al. [28], increased socioeconomic development and urbanisation are expected to negatively impact Sub-Saharan Africa as it continues to expose more of its population to climate hazards due to its inadequate capacity to address climate change challenges. Most of the climate-induced pressures experienced by coastal communities were caused by the exploitation of coastal resources by humans for food, fuel for household functions, and other essential services available along the coasts [29]. Therefore, most of these threats facing coastal ecosystems and inhabitants are enhanced by humans as they continue to be attracted to coastal zones for socioeconomic development, urbanisation, food, and other essential services [30,31].

Overall, several studies have confirmed that the coastal environment is vulnerable to climate change effects, and the changes in land cover and population growth are major triggers for the increased impacts on the coastal environment and inhabitants [11–13,32,33]. In addition, these studies not only highlight the importance of enhancing awareness of the population about the dangers of living in coastal lowlands but also emphasise the need to assess the impact of LULC changes on the coastal ecosystems and biodiversity. This is necessary to guide the government and relevant stakeholders in providing more reliable and effective programs, which would protect the environment and the coastal communities from climate-related hazards and help in allocating priorities for funding and development projects within the coastal zones.

This study seeks to address the following research questions:

1. What are the main trends in LULC changes and their associated impacts in The Gambia's coastal zone from 1990 to 2020?
2. How does population growth affect LULC changes in The Gambia's coastal zone?

This study adopts an integrated approach, combining satellite imagery analysis, statistical methods, and community engagement, to investigate the relationship between population dynamics and LULC changes. Therefore, this research assesses the magnitude of land cover conversion along the coastal zone of The Gambia, specifically to uncover the levels of LULC changes and their effect on the coastal ecosystems and communities living around the coast. This is important for the development of adaptation and mitigation strategies in reducing future damage to the coastal ecosystems, communities, and the biodiversity they support. The structure of the paper is organised as follows: Section 1 provides a concise introduction to LULC, including a review of previous studies on LULC and its relationship with population growth. Section 2 outlines the data and methodologies employed in this study. The results are presented and analysed in Section 3, while Section 4 explores the key findings and their implications. Finally, Section 5 concludes the paper with recommendations based on the study's outcomes.

2. Materials and Methods

2.1. Study Area

The total land area of The Gambia is 11,000 km^2. About one-fifth of its surface is area water, with the river Gambia running 680 km from the Futa Jallon in the Republic of Guinea to the Atlantic Ocean and dividing the country into North and South Banks. The country's coastline is 80 km, which extends from Buniadou Point and Kerenti Bolong in the north to the point of entry of Allanhein in the south (Figure 1). The country is located within the tropical sub-humid eco-climatic zone [34], distinguished by the Sudano Sahelian Climate, and dominated by irregular dry Harmattan Northern Winds from the Sahara Desert and South-Westerly Monsoon winds from the Atlantic Ocean [35].

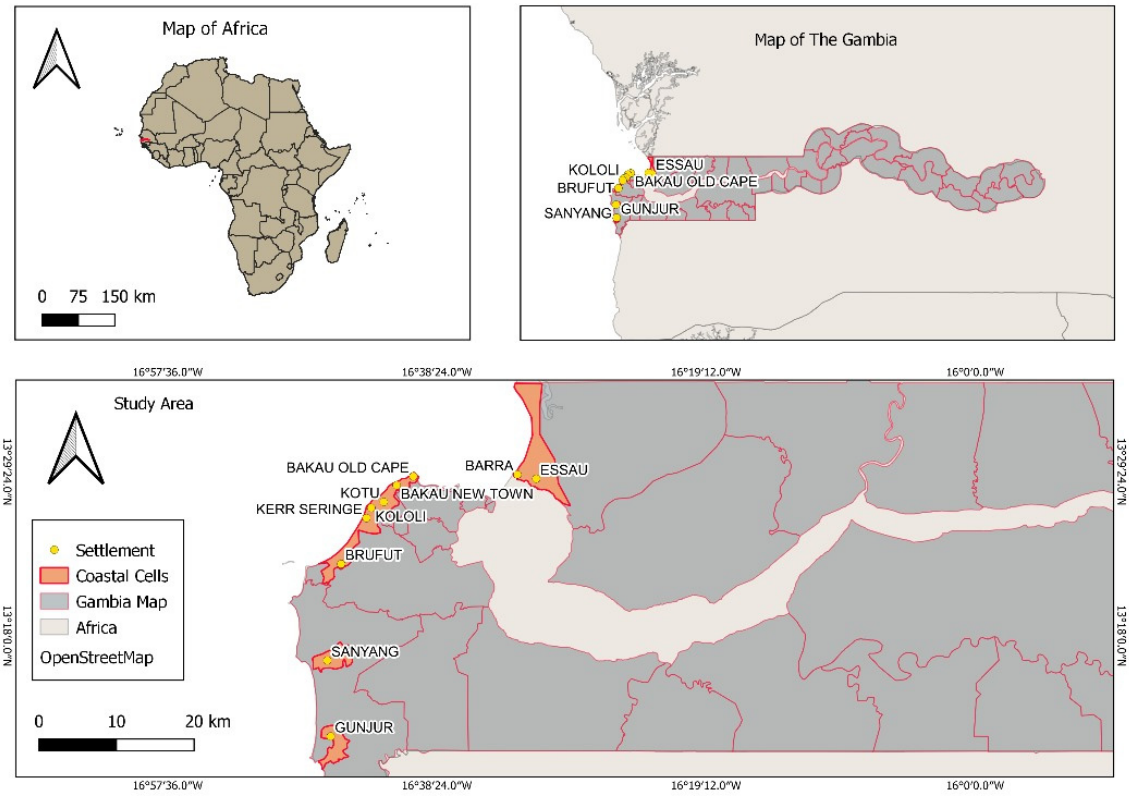


Figure 1. Map of the coastal zone of The Gambia. Note: The map of Africa (top left) is not to scale and is included for reference to illustrate the location of The Gambia within Africa.

The climate of The Gambia's coastline is expected to be significantly impacted by sea level rise, with inundation levels ranging from 2 m to 10 m by 2100. This will be accompanied by coastal erosion, flooding, a reduction in rainfall or erratic rainfall patterns (approximately 35%), and saltwater intrusion into wells and other environments [36]. However, projections for the period beyond 2050, particularly for 2100, involve significant uncertainty, and while general trends can be identified, the exact magnitude and timing of these impacts remain highly unpredictable [36]. There is an increase in the annual maximum temperature, which is higher than the decreases in the annual minimum temperature and indicates that the coastal zone of The Gambia experienced more warming than cooling from 1986 to 2016 [12].

Apart from the terrestrial habitats, the coastline also has different other habitats, such as mangrove forests and wetlands, sandy beaches, brackish water and mudflats, which provide important ecosystem services, including breeding and nursery grounds to organisms. The Gambia's population is estimated in 2020 at 2.5 million with an annual growth rate of 2.6% [37], with 37% of its estimated population residing within 10–25 km of the coastline.

The main occupations of most of The Gambians around the coastline include agriculture, trade, service industry, fishing and horticulture. There has also been growing private sector involvement in tourism and hospitality industries, sand mining, and the establishment of factories along the coast. Fishing activities such as the exploitation of coastal vegetation for fish processing and clearing of land for agriculture continue to transform the coastal ecosystems, thereby exerting extensive pressure on the coastal environment.

2.2. Data

Using LULC change classification, three Cloud free Landsat imageries for the years 1990, 2000, 2010 and 2020 were downloaded from the United States Geological Survey website. Landsat was considered for this study because of its temporal resolution and the attributes of the satellite images used (Table 1). The population data for the coastal zone of The Gambia were downloaded from the Center for International Earth Science Information Network-CIESIN in their Low Elevation Coastal Zone (LECZ) Urban-Rural Population and Land Area Estimates, 2021 (Table 2) and The Gambia Bureau of Statistics (GBOS), 2020. In addition, community focus group discussions were held in 10 coastal communities (Barra, Essau, Bakau Old Cape, Fajara, Kotu, Kololi, Kerr-seringe, Brufut, Sanyang and Gunjur) where community members, including males and females, gathered to discuss their perception, and opinions on the situation of environmental degradations within their environment in October 2021. Key informant interviews were also conducted, where individuals with good knowledge of the environment, including community leaders, professionals and residents, were interviewed during the period.

Table 1. Satellite data type and their characteristics.

Satellite	Sensor	Year	Spatial Resolution	Acquisition Date	Path/Row
Landsat 5	TM	1990	30	3 November 1990	205/051
Landsat 7	ETM+	2000	30	6 November 2000	205/051
Landsat 7	ETM+	2010	30	20 December 2010	205/051
Landsat 8	OLI/TIRS	2020	30	21 November 2020	205/051

Table 2. Population of coastal zone 1990 to 2020.

Date	Population of the Gambia	Pop	% of the Population Living Within 10–25 km of the Coast	% Increase of Population Living Within 10–25 km of the Coast from 1990 to 2020
1990	1,040,616	303,662	29.18%	213%
2000	1,437,539	454,531	31.62%	
2010	1,937,275	606,345	31.30%	
2020	2,573,995	950,010	36.91%	

Source: Center for International Earth Science Information Network (CIESIN), Columbia University [37]; The Gambia Bureau of Statistics [38].

2.3. Land Use Land Cover

Image Preprocessing and Classification

Before the LULC classification, the downloaded images were preprocessed using the Earth resource data analysis system [39]. As part of the preprocessing, a spatial subsetting was performed to reduce the image to the study area, after which atmospheric corrections were performed to enhance the image quality. High-resolution images from Google Earth, topographic maps, aerial photographs and ground-based knowledge after a detailed field survey were used to select training samples for the supervised classification. All the preprocessed images were categorised into five (5) major LULC classes using the

supervised classification method and Support Vector Machine (SVM) classification as the decision rule for the supervised classification algorithms. The classes used were water bodies, vegetation, built-up, barren land, and wetlands. The decision to use these classes was informed by the Food and Agriculture Organisation (FAO) [40] LULC classification scheme, which uses a consistent and systematically applied classification system to fully describe the LULC classes. This system also responds to the need for consistent and reliable assessment and monitoring of LULC resources within a region for sustainable management of resources, environmental protection and food security.

2.4. Statistical Analysis

The percentage change in the LULC variables (barren land, built-up, vegetation cover, water, and wetlands) and the population for the different periods (1990, 2000, 2010, and 2020) was calculated to determine the degree to which population increase is related to changes in the LULC change classes from 1990 to 2020. Furthermore, to estimate the linear relationship between LULC change classes and population growth, a correlation analysis was conducted to measure the degree to which the different classes of LULC changes relate to each other. This is given as

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\left[n\sum x^2 - \left(\sum x\right)^2\right]\left[n\sum y^2 - (\sum y)^2\right]}$$

where

n = number of values or elements
$\sum$x = sum of the x values
$\sum$y = sum of the y values
$\sum$xy = sum of the products of x and y values
$\sum x^2$ = Sum of squares of x values
$\sum y^2$ = sum of squares of y values

3. Results

3.1. Land Use Land Cover Changes

Maps of the coastal region were produced for each study year to show the LULC changes in the coastal environment using 1990 as the base year. The total land area and the percentage of LULC changes from 1990 to 2020 are presented in Table 3.

Table 3. LULC change statistics from 1990 to 2020.

LULC Classes	LULC_1990 (ha)	LULC_1990 (%)	LULC_2000 (ha)	LULC_2000 (%)	LULC_2010 (ha)	LULC_2010 (%)	LULC_2020 (ha)	LULC_2020 (%)
Barren land	269.44	28.69	364.23	38.77	393.11	41.85	393.42	41.88
Built-up	12.8	1.36	39.78	4.23	47.93	5.10%	99.8	10.62
Vegetation cover	543.85	57.91	432.48	46.04	399.66	42.55	351.44	37.41
Waterbodies	13.27	1.41	13.02	1.39%	13.48	1.44	9.15	0.97
Wetlands	99.84	10.63	89.85	9.57%	85.15	9.07%	85.56	9.11
Total	939.19	100%	939.36	100%	939.32	100%	939.38	100%

The LULC map in 1990 (Figure 2) measures a total land area of 939.2 ha of the coastal The Gambia's coastal area (Table 3). This total area included barren land (269.4 ha), built-up (12.8 ha), vegetation cover (543.9 ha), waterbodies (13.3 ha) and wetlands (99.8 ha). The proportion of LULC change classes in 1990 presented in Table 3 shows that the total area comprises 28.7% barren land, 1.4% built-up, 57.9% vegetation cover, 1.4% water bodies, and 10.6% wetlands.

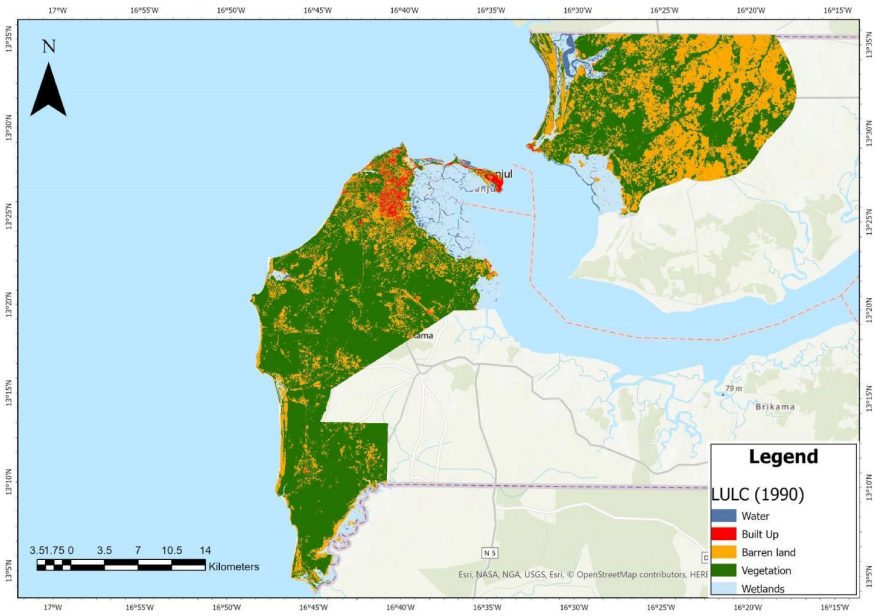


Figure 2. LULC change map of the coastal zone of The Gambia for 1990.

The LULC map for 2000 (Figure 3) shows the LULC areas were estimated as barren land (364.2 ha), built-up (39.8 ha), vegetation cover (432.5 ha), waterbodies (13.0 ha), and wetlands (89.89 ha) (Table 3). This represents 38.8%, 4.2%, 46.0%, 1.4%, and 9.6% of barren land, built-up, vegetation cover, waterbodies, and wetlands, respectively.

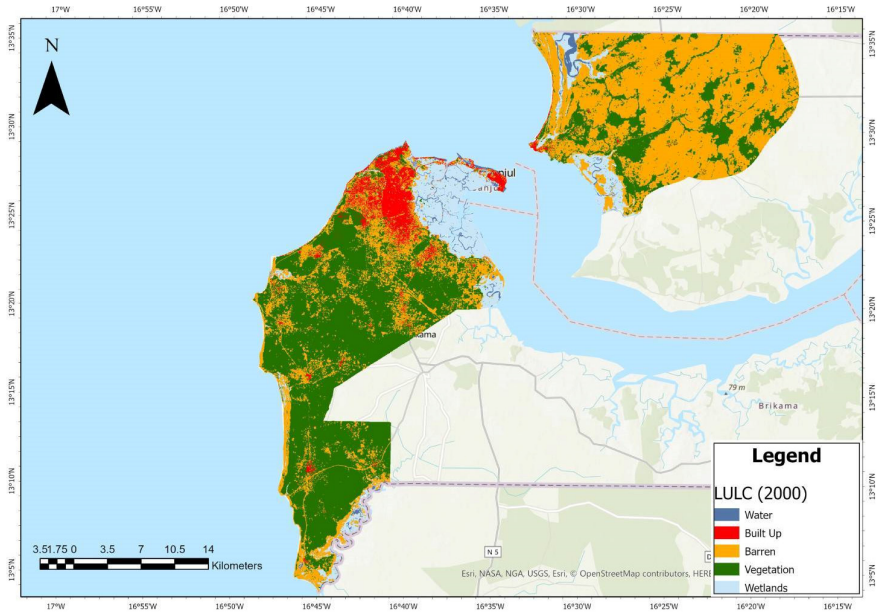


Figure 3. LULC change map of the coastal zone of The Gambia for 2000.

The LULC map for 2010 (Figure 4) measured a total land area of 939.32 ha (Table 3). This includes 393.1 ha of barren land, 47.9 ha of built-up, 399.7 ha of vegetation cover, 13.5 ha of water bodies and 85.2 ha of wetlands. These represent 41.9%, 5.10%, 42.6%, 1.4%, and 9.1% of barren land, built-up, vegetation cover, water bodies and wetlands of the total land area, respectively.

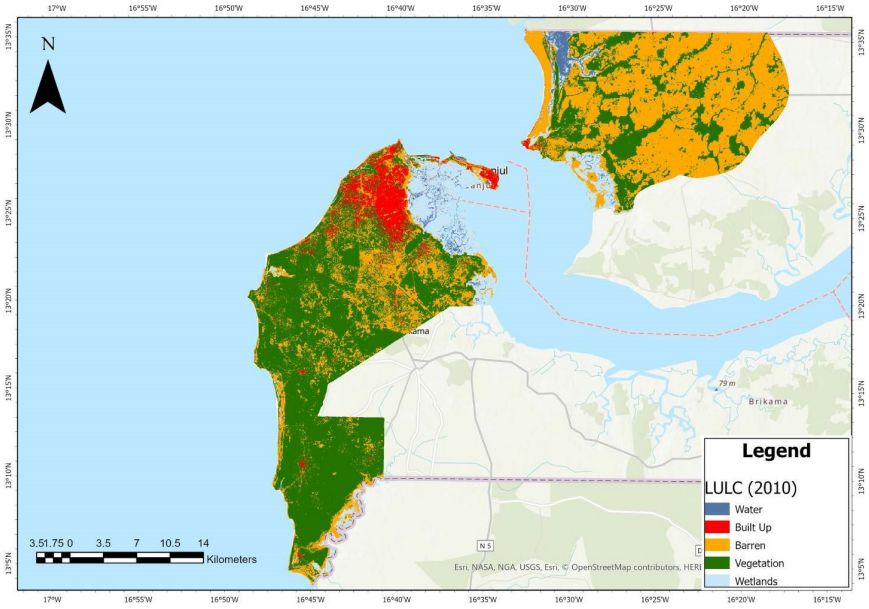


Figure 4. LULC change map of the coastal zone of The Gambia from for 2010.

For 2020, the total measured land area was 939.38 ha (Table 3 and Figure 5). This includes 393.4 ha of barren land, 99.8 ha of built-up, 351.4 ha of vegetation cover, 9.2 ha of water bodies and 85.6 ha of wetlands, representing 41.9%, 10.6%, 37.4%, 1.0%, and 9.1% of barren land, built-up, vegetation cover, water bodies and wetlands, respectively (Table 3).

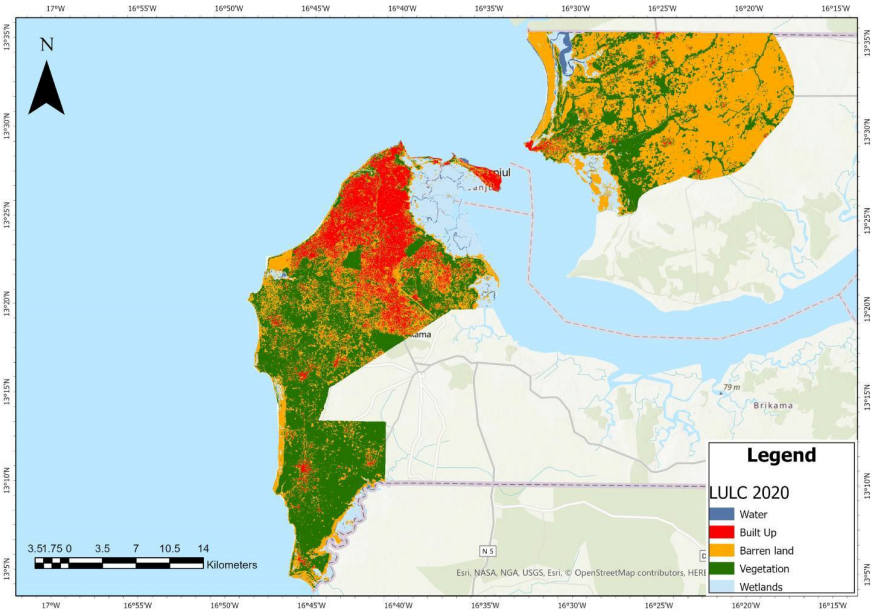


Figure 5. LULC change map of the coastal zone of The Gambia from for 2020.

The percentage LULC change from 1990 to 2000 (Figure 6) indicates that barren and built-up increased by 35.2% and 210.7%, respectively, while vegetation cover, water bodies and wetlands decreased by 20.5%, 1.9% and 10.0%, respectively.

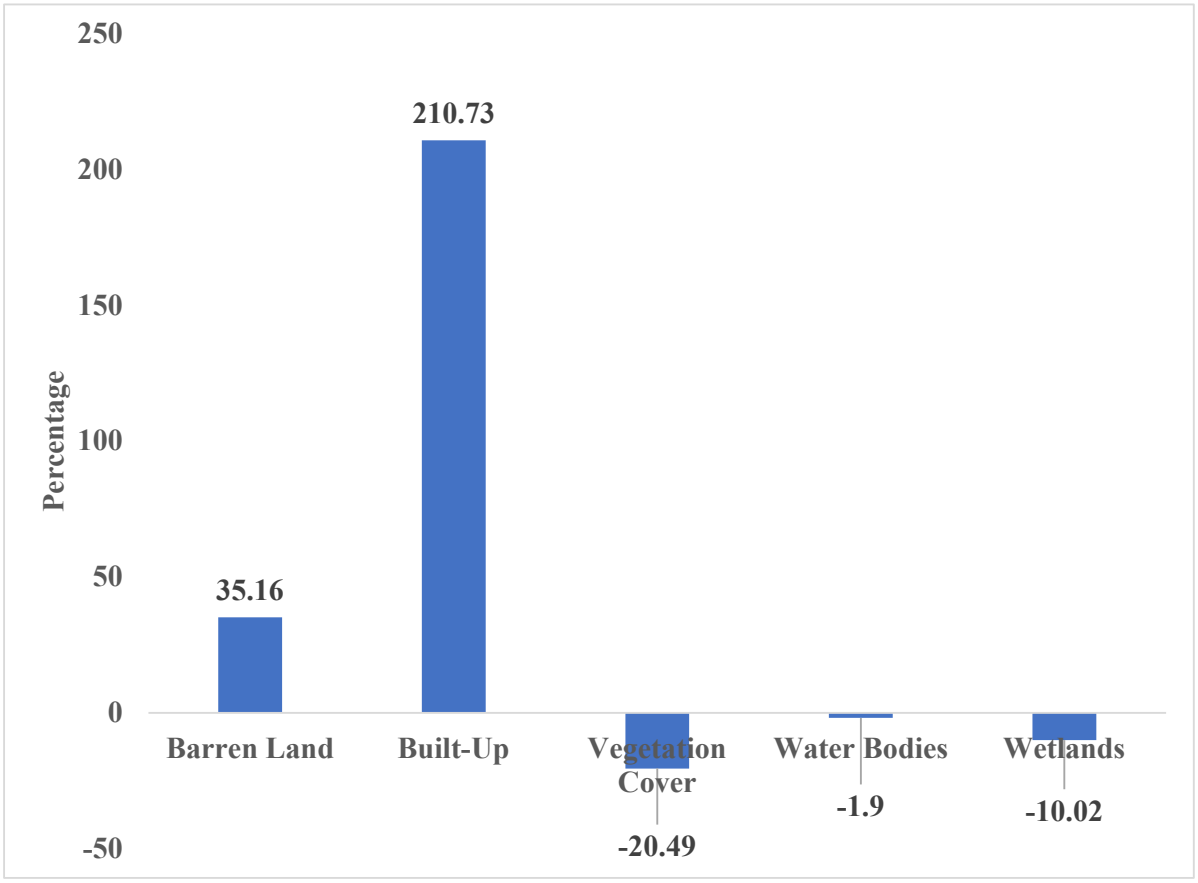


Figure 6. LULC changes in the coastal zone of The Gambia from 1990 to 2000 in percentages.

The LULC change from 1990 to 2010 shows an increase in barren land, built-up and water bodies by 45.9%, 274.4% and 1.6%, respectively, and a decrease in vegetation cover and wetlands by 26.5% and 14.7%, respectively (Figure 7).

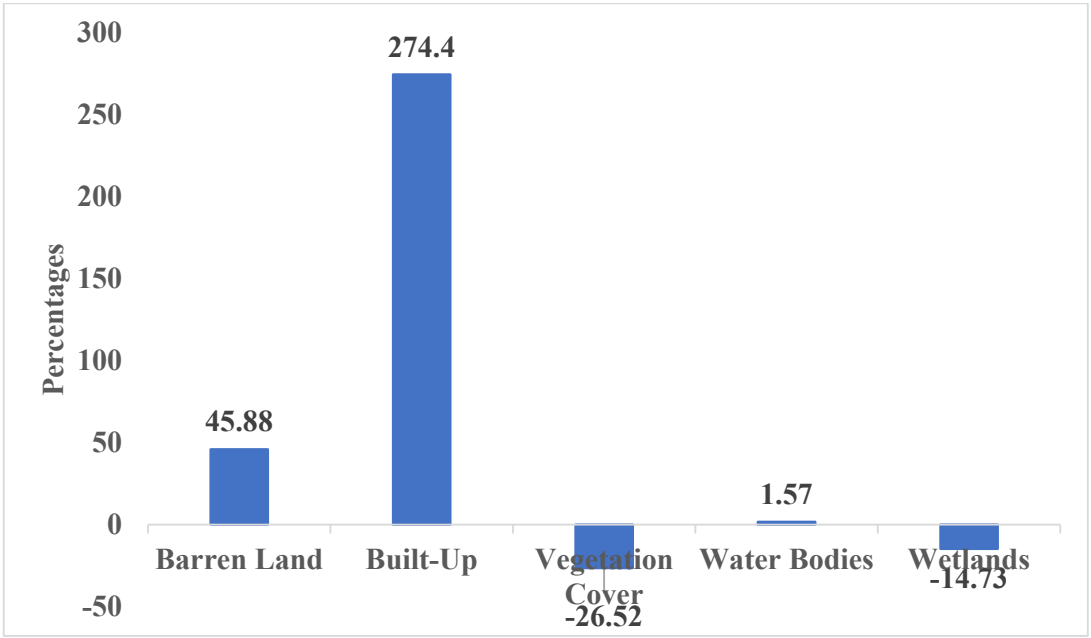


Figure 7. LULC changes in the coastal zone of The Gambia from 1990 to 2010 in percentages.

In terms of percentage change in the LULC classes, there is an increase in barren land (46.0%) and built-up (679.5%) and a decrease in vegetation cover (−35.4%), water bodies (−31.1%) and wetlands (−14.3%) from 1990 to 2020 (Figure 8).

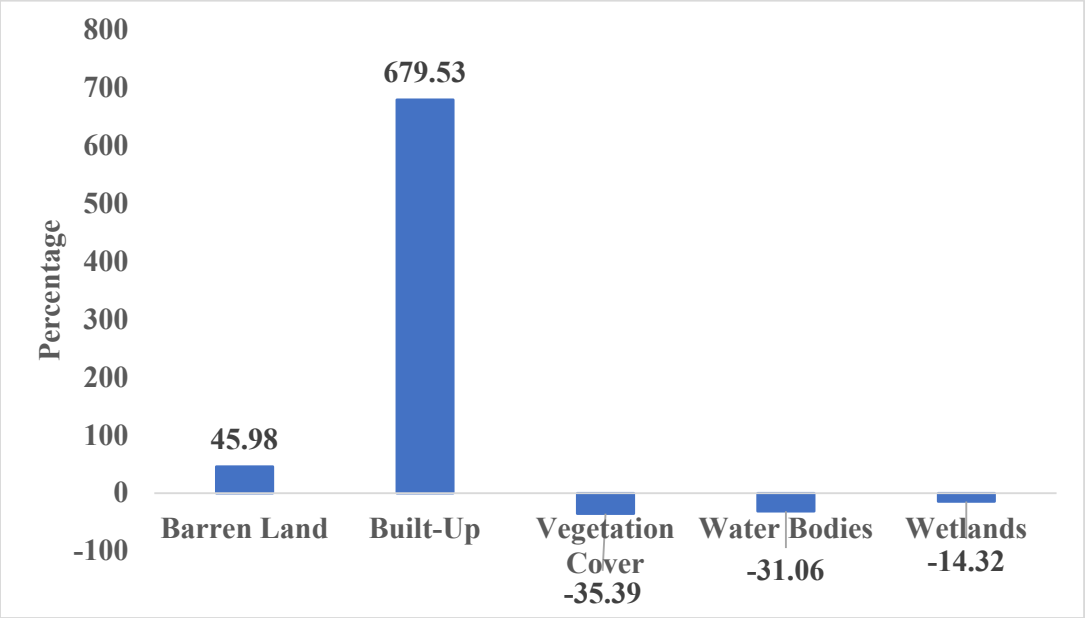


Figure 8. LULC changes in the coastal zone of The Gambia from 1990 to 2020 in percentages.

3.2. Relationship Between LULC Change and Population

Table 4 displays the Pearson correlation matrix for LULC change variables and the population living within 10–25 km of coastline from 1990 to 2020. The results highlighted a significant association between some of the variables. Specifically, there is a significant correlation between barren land and vegetation cover at 5% significance level. There is a significant negative relationship between barren land and wetlands, between built-up and vegetation cover, and between built-up and water bodies at 5% and 10% significance levels, respectively. While the population had a positive correlation with built-up at a 5% significance level, it had a negative correlation with vegetation at 10% significance level. These relationships between the variables indicate that the increase in population along the coast is an essential factor that can describe the increases in built-up and the decrease in vegetation cover.

Table 4. Correlation between LULC change class and population of the coastal zone of The Gambia from 1990 to 2020.

Variables	Barren	Built-up	Vegetation	Waterbodies	Wetlands	Population
Barren	1					
Built-up	0.7683	1				
Vegetation	−0.9653 **	−0.9089 *	1			
Water	−0.4197	−0.9006 *	0.6416	1		
Wetlands	−0.9964 **	−0.7717	0.9640 **	0.4195	1	
Population	0.7739	0.9910 **	−0.9082 *	−0.8724	−0.7882	1

** Correlation is significant at the 0.05 level (2-tailed test). * Correlation is significant at the 0.10 level (2-tailed test).

4. Discussion

The findings of this research have demonstrated that the coastal environment has undergone significant transformation because of multiple stressors within the last 30 years. The LULC map and the area under each LULC class calculated indicate the extent of modification for each of the LULC characteristics along the coastal zone of The Gambia from 1990 to 2020. Using the characteristics of LULC in 1990 as the base year, it was

discovered that there are changes in all LULC classes. While barren land and built-up have increased, there is a substantial reduction in vegetation cover, water bodies and wetlands. The increase in human population along the coastline is associated with increased built-up such as housing, health and education amenities and transport infrastructure to serve the needs of the growing population from 1990 to 2020. Herrmann et al. (2020) [19] explained that an increase in the coastal population of The Gambia will result in increased infrastructure development, which will affect the coastal LULC patterns. The interviewed community members also expressed the impacts of population increases along the coastal areas, which include loss of ecological services, beach erosion, saltwater intrusion into wells and farmlands, and loss of lives and property.

Barren land has increased for the past 30 years along the coast and is observed to be significantly associated with a reduction of vegetation cover and wetlands. This is mainly due to deforestation and the activities of mining companies operating along the coast. Various researchers have established that as humans continue to derive essential goods and services from the use of land and environments, the state of the degradation of the environments over time will be determined by the socioeconomic processes which alter their landscape [14,41]. Abd El-Kawy et al. [4] explained that mining and land alteration by anthropogenic activities for agricultural purposes and socioeconomic developments are key drivers of land modification in the Western Nile Delta of Egypt. The community members also confirmed that the vegetation cover of the coastal areas has reduced over the years. For instance, in a focus group discussion, a member noted the following:

The forest cover and landscape have drastically changed due to human activities such as unregulated logging for fuel wood or charcoal, human settlement, urbanisation and industrial activities of real estate developers. This has negatively impacted not only our environment but also our households' discomfort, including hot weather due to rising temperatures on land and in the sea (Focus Group Discussion, 2021).

The 680% increase in the built-up from 1990 to 2020 in The Gambia is a result of increased population along the coast. This study confirms that while population increase is associated with an increase in built-up to meet the demand of the growing population, it has also significantly caused the disappearance of most of the vegetation cover. Built-up has been identified as the utmost irreversible human impacts on the environment and ecosystems due to urbanisation and population growth, thereby calling for more research and increased understanding of LULC transformation patterns occurring at local and international scales [25]. The association between urbanisation and built-up also contributed to the land transformation patterns and loss of vegetation cover in The Gambia, thereby exposing coastal communities to climate change hazards and thus increasing their vulnerability to climate change. Similar results were found by Amuzu et al. [11,12], who argued that infrastructure development, population dynamics, and LULC changes are among the elements that negatively impact the coastal inhabitants and the environment. A community member during a focus group discussion also indicated the following:

The reduction in vegetation cover has resulted in hotter temperatures on land and the sea, intrusion of salt water in our wells and farmlands and windstorms destroying our buildings (Focus Group Discussion, 2021).

The coastal zone of The Gambia, which was dominated by vegetation cover of about 57% of total LULC in 1990, had experienced a significant reduction by 35% in 2020, mainly due to increased population, thereby increasing the built-up and barren land. In other West African countries, mangroves and other vegetation cover along the coast are cleared to establish structures such as fish and shrimp ponds, human settlements, agriculture and industrial development [30]. The following was also stated during the survey:

Mangrove vegetation along the coast is declining due to increased saltwater intrusion from rising sea levels and human activities such as firewood collection and land development. The vegetation cover within the community is disappearing as increased residential infrastructure claimed most of the environment. The rice fields that were cultivated by women have all been converted to building infrastructure as the population continues to increase (Focus Group Discussion, 2021).

Since most of the coastal communities are located within the vicinity of water bodies such as estuaries, rivers and streams, the increase in built-up has resulted in shrinking the water bodies and wetlands over the last 30 years. This is perceived to be a consequence of land and water use systems that are not only limited to settlements but also for agriculture, mining, aquaculture, manufacturing industries, trade, tourism and transport infrastructure purposes. These occurrences put pressure on water bodies and wetlands along coastal areas [23,42]. For Tiando et al. [23]. Communities are grappling with the challenges of rapid unplanned urbanisation, which results in the shrinking of water bodies and wetlands, pollution from waste disposal, encroachments, illegal mining activities, and unplanned tourism activities. Also, the reduction of wetlands along the coast, which was negatively associated with an increase in barren land and built-up from 1990 to 2020, indicates that environmental degradation exposes the coastal environment of The Gambia to the impact of erosion and eutrophication. As a result, sediments from the eroded areas, when deposited in water bodies, may also contribute to the shrinking of the aquatic ecosystems. For the community members, sand mining and other infrastructural development activities occurring along the shores are causing their water bodies to shrink, which also causes the erosion of the coast and leads to the loss of the essential benefits they used to obtain from these ecosystems in the past. For instance, some community members stated the following:

The sand mining activities and uncontrolled dumping occurring in other parts of the coast are causing their water bodies to shrink, which leads to the loss of essential benefits such as the availability of shellfish, crabs and other seafood they obtained from these ecosystems over the past 30 years (Key informant interview, 2021).

The transformation of the beach has impacted us negatively by limiting our livelihood options and the economic activities that people engaged in along the beach. These include weaving fishing nets, fish smoking, and many different businesses because of the erosion and sea level rise we observed. Even some residential houses along the beach are affected. All this destruction started with the various projects, from the building of the bridge to sand mining activities around other parts of the coastal zone (Focus Group Discussion, 2021).

5. Limitations of the Study

The qualitative data, gathered through focus group discussions and key informant interviews, were collected during the COVID-19 pandemic, which posed significant challenges. Despite assurances of proper health protocols, many participants were hesitant to join gatherings, resulting in a time-consuming data collection process that may have limited the diversity of perspectives captured. Additionally, the study primarily focuses on long-term trends, potentially overlooking short-term events such as flash floods, windstorms, or policy interventions that could significantly influence land cover dynamics. Furthermore, community members did not explicitly identify climate change as a result of LULC, though the effects of hot weather and stronger winds, often seen as consequences of LULC changes, were noted. This gap could be linked to varying levels of understanding of climate change within communities. Therefore, further research should explore the role of governance and policy frameworks in addressing land cover transformations and incorporate a more thorough investigation of local perceptions of climate change. This will

enhance the understanding and sustainable management of coastal environmental changes in The Gambia.

6. Conclusions and Recommendations

The Gambia's coastal landscape provides various socioeconomic activities, including tourism, artisanal fishing, and cultural, aesthetic, and religious, for the coastal residents. These activities contribute 36% of the country's GDP [10]. In addition, this environment also provides important ecosystem services, including habitats and breeding grounds for aquatic animals, plants, and migratory birds. However, the coastal zone experiences extreme weather events with negative consequences on the inhabitants and the environment. The latter are intensified due to substantial modification of LULC, which corresponds with population growth along the 10–25 km coastline. The extent of transformation for each of the LULC characteristics indicated an increase in the barren land by 46% and built-up areas by 680%, and a decrease in vegetation cover by 35%, water bodies by 31%, and wetlands by 14%, from 1990 to 2020. As the population increases along the coast, it exerts strong pressure on the coastal land by increasing the need for urbanisation, which, in turn, increases the demand for infrastructure such as housing, health and education amenities, transport, and utility infrastructure to serve the needs of the growing population. This, along with land and water use systems along the coast, have all put considerable pressure on the coastal landscape, thereby increasing the vulnerability of coastal zones to climate change.

This study highlights that several human-oriented activities in the coastal habitats require further understanding in their socioeconomic and ecological processes, specifically, through research into coastal vulnerability to climate change, the building capacities of coastal inhabitants, and their adaptation and mitigation approaches. It is prudent for the government of The Gambia and relevant stakeholders to take population issues into account when formulating well defined management goals and objectives, which are derived from a deep understanding of the level of land transformation along the coast. This requires a rigorous, data-driven assessment of land transformation patterns along the coastline, utilising geospatial analysis, remote sensing, and ecological modelling to quantify changes in LULC. Therefore, there is a need to understand the interactions between population growth, land transformation, and coastal resource utilisation in order to better predict future pressures on these ecosystems. This will help ensure that the long-term sustainability of the coastal ecosystems is not compromised.

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