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# Quantitatively Analyzing the Driving Factors of Urban Spatial Evolution in Lagos (2000-2020)

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## Abstract

Urban spatial evolution is shaped by a complex interplay of anthropogenic activities and environmental dynamics, influenced by physical, socioeconomic, and regulatory factors. This study focuses on understanding the driving forces behind urban spatial evolution in Lagos, Nigeria, between 2000 and 2020. Utilizing quantitative analysis methods, particularly Pearson correlation coefficients, the study investigates correlations between land use/land cover changes and various factors, including population, economic indicators (GDP, gross output value of road transport, gross output value of agriculture, gross industrial output value), transport infrastructure (road network expansion), demographic trends (immigrant population), climatic variables (temperature, rainfall), and urbanization rate. Pearson correlation coefficients were computed to analyze the correlation between LULC changes and the selected factors. Results indicate that population growth emerges as the primary driver of urban spatial evolution, followed by economic activities, particularly GDP and gross output values of various sectors. Population growth is strongly linked to urban development ($r = 0.982$) and reduction in natural habitats ($r = -0.942$). Additionally, transport infrastructure expansion and demographic shifts contribute significantly to the increase in built-up areas and decrease in vegetation. Also, climatic factors such as temperature and rainfall exhibit moderate to strong correlations with LULC changes. This study underlined the correlation between human activities and environmental dynamics in shaping urban spatial evolution; therefore, it is recommended that sustainable urban development policies be implemented, focusing on preserving green spaces, integrating nature-based solutions, and engaging stakeholders to balance population growth with environmental conservation.

## Subject Areas

Image Processing

**Keywords**

Land Use/Land Cover Change, Urban Expansion, Population Growth, Lagos, Remote Sensing Images, Coefficient Correlation, Sustainable Urban Growth

## 1. Introduction

Urban spatial evolution is a dynamic process driven by the complex interactions between human activities, environmental forces, and socioeconomic development [1]. Human activities, such as population growth, migration, and economic activities, influence land use patterns, infrastructure development, and spatial organization within cities [2] [3]. At the same time, environmental factors, including topography, climate, and natural resources, shape the spatial distribution of urban settlements and influence land use decisions [4]. Socioeconomic development, characterized by factors such as industrialization, globalization, and technological advancements, further influences urban spatial evolution by driving changes in economic activities, employment patterns, and urban form [5]. Globally, cities have been at the forefront of rapid urbanization, with more than half of the world's population residing in urban areas. A figure projected to rise to 68% by 2050, according to different publications [6] [7] [8] [9]. This phenomenon has reshaped landscapes, altered ecosystems, and redefined the spatial organization of human settlements. Urban areas worldwide, whether they're the sprawling metropolises of developed countries or the rapidly expanding megacities of developing nations, display a wide range of shapes and forms [10] [11] [12]. These variations are the result of a complex mix of factors, including historical influences, government policies, and present-day challenges. For instance, the layout of older European cities reflects centuries of urban development, while newer cities in developing regions often experience organic, unplanned growth [13] [14] [15]. Government decisions, like zoning laws and infrastructure projects, also play a significant role in shaping urban landscapes [16]. At the same time, modern issues such as population growth and climate change continuously reshape cities, prompting adaptation and innovation [17] [18]. Nigeria, Africa's most populous country, epitomizes the complexities of urbanization in the Global South [19] [20]. According to Worldometer statistics accessed February 7, 2024 (Worldometer, 2023), the urban population of Nigeria has seen significant growth over the past two decades, with figures surpassing 200 million and urbanization rates outpacing those of many other regions. From 2000 to 2023, the urban population experienced steady increases, as evidenced by the following intervals: from 42,627,440 in 2000 to 54,288,918 in 2005, marking a substantial growth of 11,661,478; from 54,288,918 in 2005 to 68,949,828 in 2010, reflecting a further increase of 14,660,910; from 68,949,828 in 2010 to 86,673,094 in 2015, indicating a continued upward trend with a change of 17,723,266; and from 86,673,094 in 2015 to 107,112,526 in 2020, depicting another notable increase of 20,439,432. With each interval showing a high increase in urban population, the demand for housing has intensified, leading to shortages and often informal settlements [21] [22]. Infrastructure deficits have also become more pronounced as urban areas struggle to keep pace with the burgeoning population, resulting in inadequate access to essential services such as water, sanitation, and transportation [22]. Furthermore, the rapid expansion of urban areas has put immense pressure on the environment, leading to degradation of natural resources, pollution, and loss of biodiversity [23]. Nowhere are these challenges more pronounced than in Lagos, the nation's economic nerve center and one of the fastest-growing megacities globally. Lagos characterizes the challenge in terms of urbanization, where rapid population invasions correspond with limited resources and inadequate infrastructure, exacerbating spatial inequalities and environmental vulnerabilities [24] [25] [26] [27]. The rapid increase in Lagos's population has triggered substantial urban growth. This growth is visible in the emergence of informal settlements spreading across the city, as well as in the construction of tall skyscrapers that stand out prominently against the city's skyline, shaping its modern appearance. However, beneath the appearance of progress in development, there exists a landscape dealing with a complex mix of development needs, demographic pressures, and climate vulnerabilities. The impact of development on the urban changes in Lagos is evident.

Various authors have conducted GIS analyses focusing on spatial integration and evaluating physical and environmental variables influencing urban environmental quality changes in Lagos [28] [29] [30] [31]. However, there remains a critical gap in scientific research: a lack of studies specifically delving into quantitative analysis of the driving factors behind urban spatial evolution in Lagos over the past two decades. Given the pressing challenges posed by rapid urbanization, it is imperative to comprehend the forces steering urban spatial dynamics in Lagos. Through a quantitative examination of the intricate interplay among developmental, demographic, and climatic factors, this study aims to unveil the dynamics shaping urban spatial evolution. By employing remote sensing, GIS and analytical techniques, the primary objective is to assess the spatial evolution of Lagos from 2000 to 2020, focusing on changes in natural surfaces. Additionally, this research seeks to quantitatively analyze the primary driving factors influencing urban spatial evolution among ten selected variables. This is achieved by examining correlation coefficients among these factors and Landsat classes spanning the years 2000 to 2020. Ultimately, the study aims to recommend sustainable measures necessary to achieve comprehensive development across all sectors of Lagos.

## 2. Materials and Methods

### 2.1. Study Area

Lagos, often referred to as Nigeria's "Centre of Excellence", was established on

May 27th, 1967, according to State Decree No. 14, and it was subdivided into sixteen urban and four rural distinct local government areas (**Figure 1**). It stands out as the most urbanized city in Nigeria, Africa's most populous nation, and ranks among the world's rapidly developing urban hubs. Geographically situated on the West Coast of Africa within Nigeria's southwestern geopolitical zone, Lagos boasts a prominent position [32]. In **Figure 1**, (a) represents the location of Nigeria in Africa, (b) represents the location of Lagos in Nigeria, and (c) represents Lagos state and its twenty distinct local government areas.

Lagos is known for its numerous slum areas, many of which have a notably high population density ranging from 790 to 1240 individuals per hectare [33].Due to the current population growth in Lagos, the city is poised to become the world's third-largest megacity by 2050, following Tokyo in Japan and Bombay in India. It is anticipated that the population of Lagos will surpass 35 million residents within the next three decades [32]. This expansion could be attributed to the city's socio-economic activities, which have significantly contributed to the rapid expansion of urban areas [34].

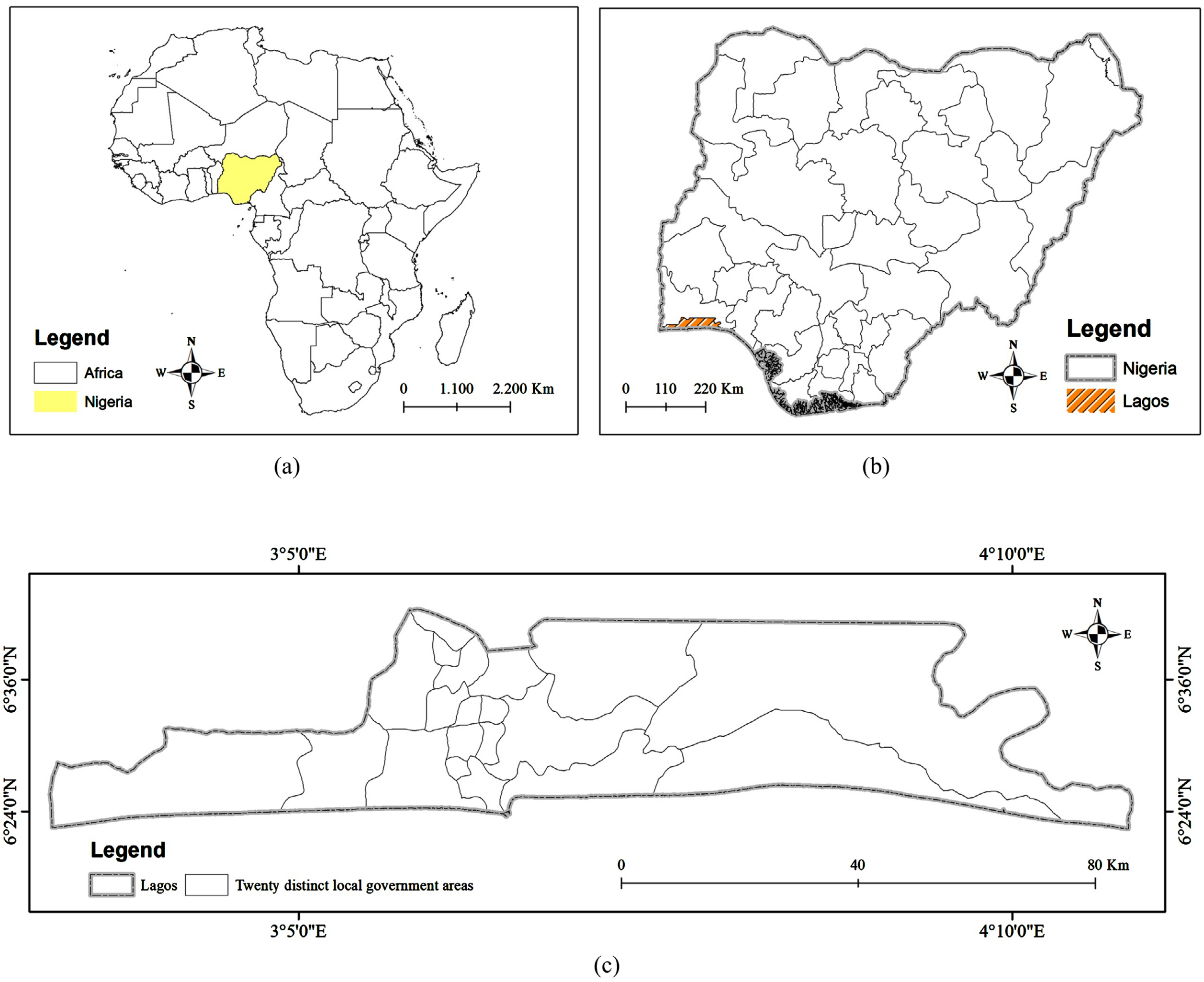


**Figure 1.** Geographical location of Lagos state.

## 2.2. Data

### 2.2.1. Source of the Used Data

Data for this study were gathered from multiple reputable sources to ensure comprehensive coverage across various dimensions. Specifically, population, transportation, socio-economic, and urbanization statistical data were sourced from the official websites of the Ministry of Economic Planning and Budget, as well as the Lagos State Government. These governmental sources were selected for their reliability and authority in providing accurate and up-to-date information relevant to the study area. Climate change parameters data were obtained from the WorldClim data website, a widely recognized repository for global climate data. This source was chosen for its extensive coverage and reliability in providing climatic information at different spatial and temporal scales, crucial for analyzing climate-related factors in the study. Furthermore, the assessment of urban spatial evolution was conducted using Land Use and Land Cover (LULC) change data derived from Landsat imagery. These data were acquired from the United States Geological Survey (USGS), a trusted source for satellite imagery and geospatial data (Table 1). EarthExplorer-Landsat imagery is renowned for its consistent quality and long-term availability, making it suitable for analyzing changes in land use and land cover over time.

### 2.2.2. The Selected Factors Affecting Urban Spatial Evolution

Physical factors are intrinsic determinants that profoundly influence the extent of urban spatial evolution. Climate conditions, specifically precipitation and temperature, exert a considerable influence on spatial dynamics by constraining water supply dynamics. As such, our examination incorporates annual precipitation and annual temperature as climatic factors, discerning their roles in elucidating the driving forces of urban spatial evolution in the context of Lagos City. Socioeconomic factors encompass a spectrum of temporal data, including population, urbanization rate, gross domestic product, gross industrial output value, and gross output value of agriculture. These historical datasets have been meticulously sourced from the Lagos Bureau of Statistics website. Representing dynamic indicators of population trends, urbanization rates, and economic structures, these factors are integral to understanding the potential influences they may exert on spatial changes within the confines of Lagos City. The chosen variables collectively serve as proxies for intricate societal dynamics, fostering a

**Table 1.** Types of data and the websites from which they were sourced.

| Data | Time Range | Resolution | Website |
|---|---|---|---|
| Statistical data | 2000 to 2020 | - | 1) https://mepb.lagosstate.gov.ng/lbs-publication/<br>2) https://lagosstate.gov.ng/ |
| Historical climate data | 2000 to 2020 | 2.5 minutes | https://worldclim.org/ |
| LULC change data | 2000 to 2020 | 30 m | https://earthexplorer.usgs.gov/ |

nuanced comprehension of the multifaceted relationships between socioeconomic factors and urban spatial evolution. These variables are as follows: 1) Annual urbanization rate, 2) GDP (billion USD), 3) Gross industrial output value (million USD), 4) Gross output value of agriculture (million USD), 5) Gross output value of road transport (billion USD), 6) Immigrant population (million), 7) Population (million), 8) Rainfall (mm), 9) Temperature (˚C), and 10) Transport (length of road network) (Table 2). The data are based on the influence of seven key contributors that drive spatial change. The percentage change for each driving factor was calculated using the following formula:

**Percentage change** = (final value − starting value)/(starting value) * 100%

### 2.3. Data Pre-Processing

#### 2.3.1. Climate Change Parameters

Historical climate data for the years 2000, 2010, and 2020 were obtained from reliable sources. The main climate change parameters of interest, namely rainfall (mm) and temperature (˚C), were extracted for analysis. A geographic information system (GIS) approach was employed to ensure spatial representativeness and minimize biases.

**1) Sampling Methodology:** GIS was utilized to select one sampling point within each distinct local government area, resulting in a total of 20 points sampled per month across the study period.

**2) Data Aggregation:** Monthly climate data for each parameter were averaged across all sampled points within a specific local government area for each respective year. This averaging process facilitated the creation of yearly datasets, providing a comprehensive overview of climate conditions at the local government area level for the years under consideration.

**Table 2.** Driving forces and their proportional change in Lagos.

| Variables | 2000 | 2010 | 2020 | 2000 (100%) | 2010 (100%) | 2020 (100%) | 2000-2010 (100%) | 2010-2020 (100%) | 2000-2020 (100%) |
|---|---|---|---|---|---|---|---|---|---|
| A | 4.2 | 4.8 | 4 | 32.31 | 36.92 | 30.77 | 4.62 | −6.15 | −1.54 |
| B | 20.751 | 80.61 | 152.11 | 8.19 | 31.80 | 60.01 | 23.62 | 28.21 | 51.82 |
| C | 517.11 | 1155.9 | 2432.16 | 12.60 | 28.16 | 59.25 | 15.56 | 31.09 | 46.65 |
| D | 66.5 | 178.88 | 255.76 | 13.27 | 35.69 | 51.04 | 22.42 | 15.34 | 37.77 |
| E | 4.85 | 21.34 | 44.51 | 6.86 | 30.18 | 62.96 | 23.32 | 32.77 | 56.10 |
| F | 0.6 | 0.71 | 1.1 | 24.88 | 29.51 | 45.61 | 4.63 | 16.11 | 20.73 |
| G | 13.4 | 19.8 | 26 | 22.64 | 33.45 | 43.92 | 10.81 | 10.47 | 21.28 |
| H | 2954.81 | 1960.93 | 1348.81 | 47.17 | 31.30 | 21.53 | −15.87 | −9.77 | −25.64 |
| I | 31.56 | 31.7 | 31.79 | 33.20 | 33.35 | 33.45 | 0.15 | 0.09 | 0.24 |
| J | 5180 | 5235.20 | 5314.38 | 32.93 | 33.28 | 33.79 | 0.35 | 0.50 | 0.85 |

### 2.3.2. Urban Spatial Evolution

For the assessment of urban spatial evolution across the years 2000, 2010, and 2020, Landsat satellite imagery was acquired. Specifically, Landsat imagery for the year 2010 underwent additional preprocessing steps due to the presence of image stripes, which are areas with missing or no data.

**1) Image Processing:** For the 2010 Landsat imagery with image stripes, the missing data were addressed using the "fill no data" tool available in QGIS software. This process involved interpolating or filling in the missing data within the image, thereby enhancing the completeness and usability of the dataset for subsequent analysis.

**2) Classification:** Following preprocessing, all Landsat images for the years 2000, 2010, and 2020 were classified into three distinct land cover classes: built-up areas, vegetation cover, and water bodies. A supervised classification method was employed to delineate and categorize land cover types within the study area (**Figures 2-4**).

**Figures 2-4** present LULC classes alongside their corresponding size for the two decades. The examination reveals a consistent rise in built-up areas, going up from 492.21 km$^2$ in 2000 to 993.1 km$^2$ in 2010 and further to 1271.94 km$^2$ in 2020. Conversely, vegetated land demonstrates a diminishing trend, decreasing from 2410.08 km$^2$ in 2000 to 1899.4 km$^2$ in 2010 and subsequently to 1756.36 km$^2$ in 2020. Notably, water bodies occupied 879.79 km$^2$, 889.58 km$^2$, and 753.94 km$^2$ in 2000, 2010, and 2020, respectively.

## 2.4. Method Used to Quantify the Analysis

The study focused on understanding the urban spatial evolution in Lagos over two decades, spanning from 2000 to 2010 and 2020. Ten (10) key factors influencing urban spatial evolution were selected for mathematical analysis (**Table 3**). These factors were chosen based on their potential influence on the changes observed in the built-up (representing the extent of urban development and infrastructure) and vegetation cover (indicating the coverage of natural vegetation and green spaces) of the area. Statistical analysis (Pearson correlation analysis) was performed using SPSS software. The first step of the process involved collecting data on ten chosen factors that influence the evolution of urban areas. The data also included the area of built-up areas and vegetation cover for each year over a period of two decades. These statistical and spatial data were then organized into an Excel spreadsheet, with columns dedicated to each variable and rows for specific years. The collected data was entered into the spreadsheet while ensuring accuracy and completeness. Later, the dataset was imported into SPSS for further analysis as SPSS can import data from Excel spreadsheets. Within SPSS, variables representing the ten factors, built-up area, and vegetation cover were chosen for analysis. Pearson correlation analysis was performed to correlate each factor independently with the built-up area and vegetation cover. This analysis allowed for assessing the strength and direction of their linear relationships over two decades.

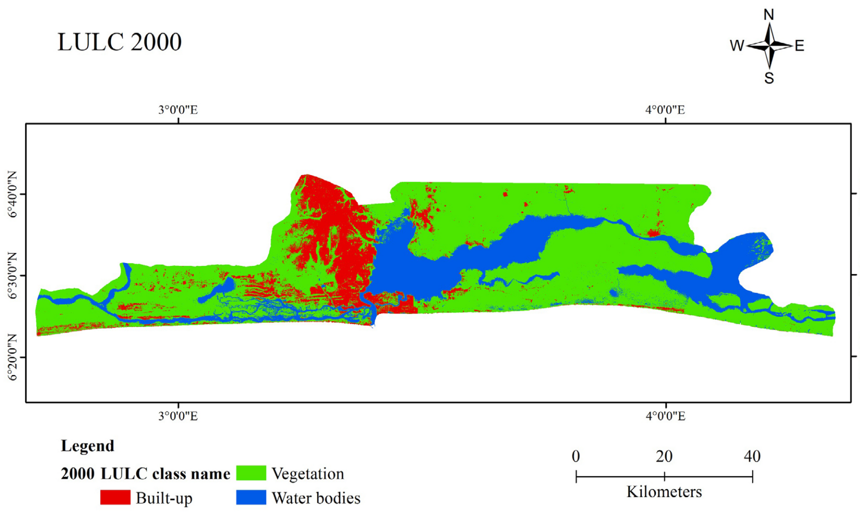


**Figure 2.** LULC change of Lagos for 2000.

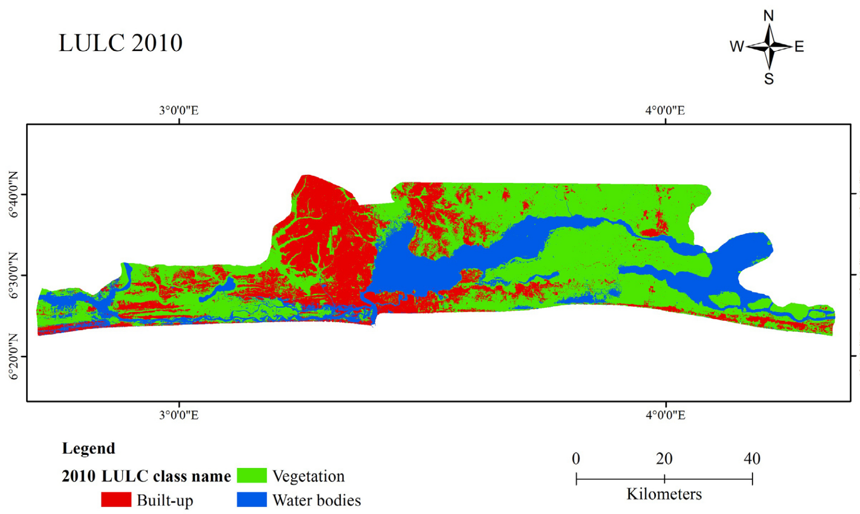


**Figure 3.** LULC change of Lagos for 2010.

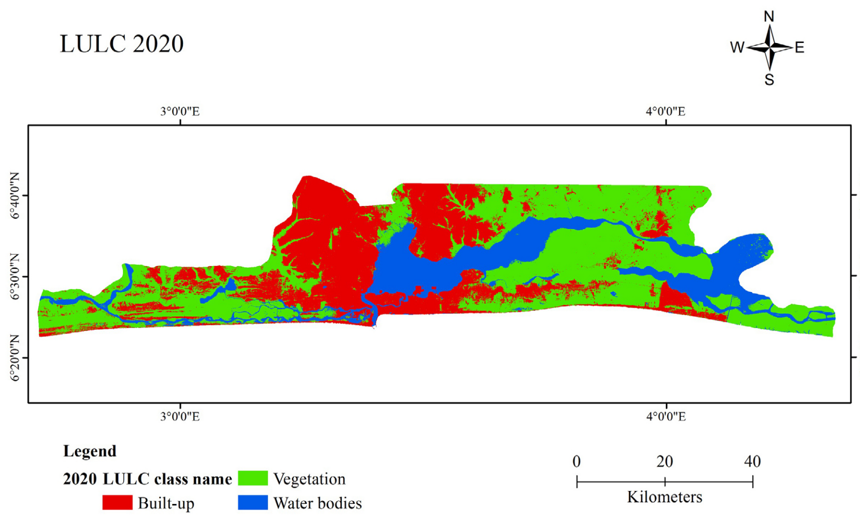


**Figure 4.** LULC change of Lagos for 2020.

**Table 3.** Pearson correlation between urban spatial evolution and driving factors.

| Driving factors | Built-up ($km^2$) | Vegetation ($km^2$) |
|---|---|---|
| Population | 0.982 | −0.942 |
| GDP (billion USD) | 0.977 | −0.934 |
| Gross output value of road transport (billion USD) | 0.966 | −0.917 |
| Transport (length of road network) | 0.965 | −0.914 |
| Gross industrial output value (Million USD) | 0.938 | −0.876 |
| Immigrants population | 0.891 | −0.812 |
| Gross output value of agriculture (Million USD) | 0.798 | −0.779 |
| Temperature (˚C) | 0.699 | −0.782 |
| Annual urbanization rate | 0.080 | −0.071 |
| Rainfall (mm) | −1.000 | 0.984 |

Annual urbanization rate represents the rate at which the urban area is expanding; GDP represents the economic output and development of the region; Gross industrial output value indicates the economic output from industrial activities; Gross output value of agriculture reflects the economic value of agricultural production; Gross output value of road transport represents economic output of road transport; Immigrants population refer to individuals who have moved to the city from other regions or countries, typically seeking better economic opportunities, improved living conditions, or, in some cases, fleeing conflict or persecution; Population reflects the demographic growth and distribution of people; Rainfall represents the amount of precipitation, a key climatic factor; Temperature represents the average temperature, another climatic factor; Transport (length of road network) indicates road transport network expansion.

## 3. Results

Urban spatial evolution results from intricate interactions between anthropogenic activities and environmental dynamics. These interactions encompass physical factors, socioeconomic influences, neighborhood considerations, and regulatory frameworks governing spatial development. While extant literature recognizes these factors, their nuanced impacts on urban spatial evolution necessitate detailed examination. In this quantitative analysis, ten chosen variables, spanning physical, economic, and social dimensions, are scrutinized to unravel their temporal effects on urban spatial evolution, focusing on neighborhood dynamics and spatial data. Notably, spatial development policy impacts were omitted due to limited extended temporal datasets. The study conducted on urban spatial evolution in Lagos from 2000 to 2020 has revealed that both natural and human activities, along with their interactions, have been the primary driving forces for changes in spatial development. Climatic conditions have played a role in determining the distribution and composition of spatial change classes by restraining land utilization. Human activities have had more concentrated and immediate impacts on urban spatial evolution than natural factors, but their effects often take a longer time to become noticeable.

### 3.1. Influence of Population, Transportation, and Urbanization

In the study area, population growth has been a driving force for urban spatial evolution, and the population dynamics have been a response to environmental changes. Lagos City's population was 13.4 million in 2000, 19.8 million in 2010, and 26.8 million in 2020 (Table 2), leading to an expansion of socio-economic related land uses. The growing population required more land for basic needs, including food and housing, and for economic development, resulting in increased production of commodities. Figure 5 shows the correlation between population growth and changes in built-up and vegetation land in Lagos City from 2000 to 2020. The correlation coefficient between population and vegetation land was −0.942, while the correlation between population and built-up land was 0.982 (Table 2). The built-up land increased rapidly by 101.76 $km^2$ from 2000 to 2010, followed by a slower rate of growth of 28.08 $km^2$ from 2010 to 2020. In contrast, the vegetation land decreased by −21.19 $km^2$ and −7.53 $km^2$, respectively. The area of vegetation land decreased by 28.72 $km^2$ from 2000 to 2020, while built-up land increased by 129.84 $km^2$. Despite these changes, the population remained on a rising trend over the same period.

The data reveals a notable trend in the immigrant population of Lagos over the years. In 2000, there were 600,000 immigrants, which increased to 711,600 in 2010, and further rose to 1,100,000 in 2020. These numbers signify a consistent growth in the immigrant community, indicating the city's continued appeal as a destination for people seeking new opportunities and experiences. The Pearson correlation coefficient of 0.891 between immigrants and built-up areas suggests a strong positive correlation. The positive correlation suggests a potential connection between immigration trends and urban development, possibly driven by the demand for housing and infrastructure to accommodate the growing population. On the other hand, the correlation coefficient of −0.812 between immigrants and vegetation indicates a strong negative correlation. This implies that as the immigrant population increased, there was a notable decrease in vegetation cover in Lagos.

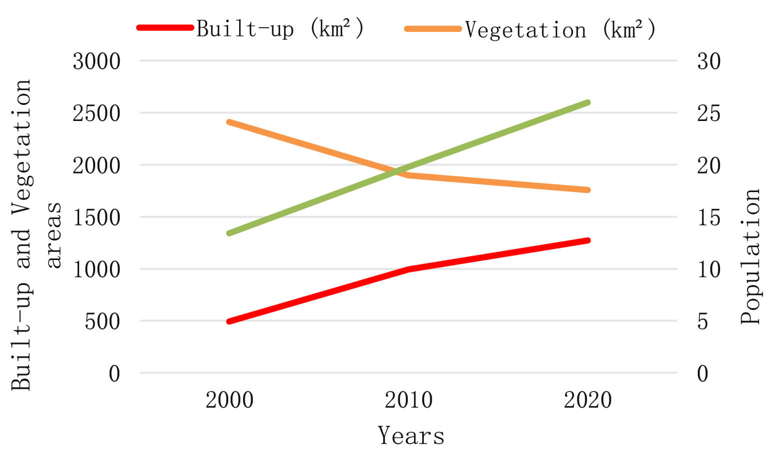


Figure 5. Changes of population, built-up, and vegetation land in Lagos during 2000-2020.

The quantitative analysis reveals a strong correlation (0.965) between the increase in road transport length in Lagos and changes in LULC. Specifically, the road network expansion is positively associated with a built-up area increase (0.965) and negatively correlated with vegetation decrease (−0.914). Over the years, the contribution of road transport length has steadily risen, measuring 5180 km in 2000, 5235.20 km in 2010, and 5314.38 km in 2020. Additionally, the gross output value of road transport in Lagos has shown a significant quantitative correlation to LULC changes, notably with a strong positive correlation of 0.966 to the increase in built-up areas and a notable negative correlation of −0.917 to the decrease in vegetation. The contribution to GDP has witnessed a substantial rise, escalating from 4.85 billion USD in 2000 to 21.34 billion USD in 2010 and further to 44.51 billion USD in 2020 (Figure 6).

On the other side, the annual urbanization rate analysis reveals interesting insights into its correlation with changes in both built-up and vegetation cover in Lagos. The R-squared values, which indicate the proportion of variance in the dependent variable explained by the independent variable, are 0.080 for built-up and −0.071 for vegetation cover.

### 3.2. Impact of Socio-Economic on Urban Spatial Evolution

The figures presented in Figure 7 showcase the notable growth of Gross Domestic Product in Lagos over the years 2000, 2010, and 2020. The study area has experienced a remarkable surge in GDP, particularly over the past two decades. The GDP exhibited a substantial increase, escalating from 20.75 billion USD in 2000 to 80.61 billion USD in 2010, and further soaring to 152.11 billion USD in 2020. This signifies a considerable growth of approximately 51.82% during the second decade (2000-2020). In terms of Pearson correlation, the analysis revealed significant relationships between built-up areas and economic indicators. The correlation coefficients between built-up areas and GDP, gross industrial output value, and gross output value of agriculture were found to be 0.977,

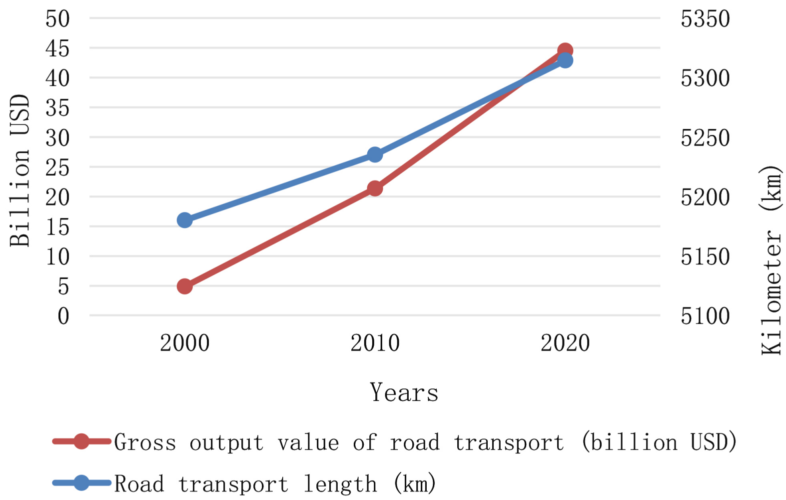


Figure 6. Changes of road transport length and gross output value of road transport.

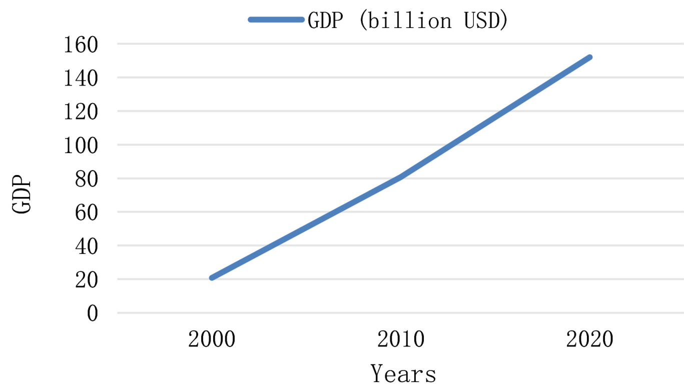


**Figure 7.** GDP during 2000-2020.

0.938, and 0.798, respectively. These strong positive correlations indicate that as the built-up areas expanded, there was a concurrent substantial increase in GDP, gross industrial output value, and gross output value of agriculture. Conversely, when examining the correlation between vegetation cover and economic indicators, negative correlations were observed. The correlation coefficients between vegetation cover and GDP, gross industrial output value, and gross output value of agriculture were found to be −0.934, −0.876, and −0.779, respectively. These negative correlations suggest that as vegetation cover decreased, there was a great role played by the development of the economy, as can be found in the increase of GDP, gross industrial output value, and gross output value of agriculture.

### 3.3. Impact of Climate Change Parameters on Urban Spatial Evolution

Climatic factors, such as temperature and precipitation, have significant effects on urban spatial evolution. In the case of Lagos, the average annual temperature during 2000-2010 was 31.68˚C, while during 2010-2020, it was slightly higher at 31.74˚C. Furthermore, precipitation also experienced a slight increase in the past two decades. The average annual precipitation for 2000-2010 was 2457.87 mm, whereas for 2010-2020, it was 1654.87 mm (**Table 2**, **Figure 8**). The increasing temperature in the study area has been detrimental to both the human system and natural vegetation in those areas. The warming trend has led to a decline in the quality of life for the people living there, and it has also negatively impacted the vegetation and wildlife. Moreover, the decreasing precipitation and the warming trend have negatively affected the expansion of vegetation land. Therefore, it is imperative to have more control over the use and allocation of land use to mitigate the effects of these climatic factors. The results indicate that alterations in land use and land cover in Lagos can be attributed to a blend of both human activities and climate-related influences. According to the Pearson correlation analysis, there is a substantial correlation between built-up areas and climatic factors, specifically 0.699 with temperature (˚C) and −1.000 with rainfall (mm). Additionally, vegetation cover demonstrates correlations of −0.782 with

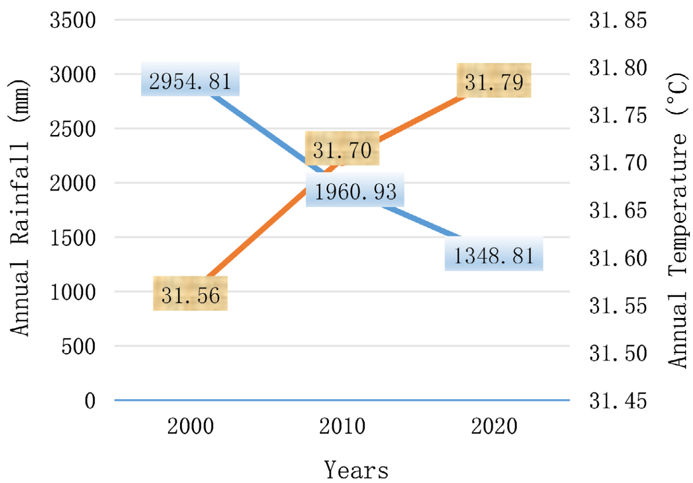


**Figure 8.** Comparison between temperature and rainfall.

temperature and 0.984 with rainfall, highlighting the interplay between these environmental and anthropogenic factors in shaping the observed changes in land use and cover.

## 4. Discussion

### 4.1. Temporal and Spatial Trends in Urban Spatial Evolution

In terms of time, the area of urban built-up areas in Lagos has been on the rise from 2000 to 2020, and the rate of increase in urban areas has persistently increased. Moreover, it was found that the growth rate reached the maximum in 2000-2020, indicating the fast urbanization process in 2000-2020. Between 2000 and 2020, the area of built-up land in the region has increased significantly, from 492.21 square kilometers to 1271.94 square kilometers, representing an increase of 779.73 square kilometers. This indicates rapid urbanization and expansion of human settlements. In contrast, the area of vegetated land has shown a continuous decline, decreasing from 2410.08 square kilometers in 2000 to 1756.36 square kilometers in 2020, representing a loss of 653.72 square kilometers. This suggests a potential reduction in biodiversity and ecosystem services. The area of water bodies has also fluctuated, with a slight increase from 879.79 square kilometers in 2000 to 889.58 square kilometers in 2010, followed by a decrease to 753.94 square kilometers in 2020. This pattern could be due to various factors, such as climate change or human water management practices as factors driving city growth and population growth in Lagos, job creation, factory development, modernization, and other social factors are central. Other urban "pull factors" attract the rural population to urban centers such as Lagos in Nigeria. These pull factors include better living conditions, infrastructures, and educational and hospital services. The main factor responsible for urban development in Nigeria is rural push combined with urban pull. In Nigeria's context, urbanization is primarily a result of economic growth due to industrialization and the movement of people from the countryside to the city. Similarly, it was said that global population growth contributes significantly to urban development and city growth. Some of these rural push factors include but are not limited to poor living conditions, poverty, political neglect, environmental degradation, poor healthcare, inadequate educational facilities, and lack of essential infrastructural services. Rural-urban migration has also increased as a result of better job opportunities in Lagos, which signifies the influence urban centers have on the rural hinterland and also conforms with the assertion that identified urbanization is a process that leads to the growth of urban centers due to economic development and industrialization. About 60 percent of the global population growth can be attributed to natural increase and maintains that such a population still continuously increases [24].

### 4.2. Drivers of City Expansion: Exploring the Forces Shaping Lagos

Exploring the forces shaping Lagos's rapid urban expansion, uniquely for this study, we investigated ten key factors potentially influencing the city's spatial evolution between 2000 and 2020. Using statistical analysis, primarily Pearson correlation, they quantified the relationships between these factors and observed changes in land use. The results unveiled "population growth" as the main driver, followed by socio-economic development. This is evident in the correlations between built-up areas, vegetation cover, and individual factors, providing a numerical measure of their influence on Lagos's transformation.

1) There is a very strong positive correlation between population and built-up area ($r = 0.982$), indicating that as the population increases, the built-up area also experiences a substantial increase. Conversely, there is a very strong negative correlation between population and vegetation area ($r = -0.942$), signifying that as the population rises, the vegetation area undergoes a significant decrease. 2) A strong positive correlation exists between GDP and built-up area ($r = 0.977$), suggesting that an increase in GDP corresponds to a notable expansion of the built-up area. Similarly, there is a strong negative correlation between GDP and vegetation area ($r = -0.934$), indicating that higher GDP is associated with a considerable reduction in vegetation area. 3) The road network expansion shows a strong positive correlation ($r = 0.966$) with built-up area increase and a notable negative correlation ($r = -0.917$) with vegetation decrease. 4) The transport (length of road network) exhibits a significant quantitative correlation with LULC changes, with ($r = 0.965$) for the increase in built-up areas and ($r = -0.914$) for the decrease in vegetation. 5) A strong positive correlation between gross industrial output value and built-up area ($r = 0.938$) implies that an upsurge in the industrial output value coincides with an increase in the built-up area. There is a moderate negative correlation between gross industrial output value and vegetation area ($r = -0.876$), suggesting that the vegetation area experiences a decrease, albeit to a lesser extent than with population or GDP. 6) The immigrant population in Lagos shows a strong positive correlation ($r = 0.891$) with built-up areas, indicating that as immigration increases, urban development grows concurrently. Conversely, there's a strong negative correlation ($r =$

−0.812) with vegetation, suggesting that as the immigrant population rises, there's a notable reduction in green spaces, potentially reflecting the environmental impact of urbanization associated with immigration. 7) A moderate positive correlation is observed between the gross output value of agriculture and built-up area (r = 0.798), indicating a proportional increase in built-up area with higher agricultural output. Similarly, there is a moderate negative correlation between the gross output value of agriculture and vegetation area (r = −0.779), suggesting a concurrent decrease in vegetation area, though less pronounced than with population or GDP. 8) There is a moderate positive correlation between temperature and built-up area (r = 0.699), indicating that the built-up area increases, albeit to a lesser extent than with some other factors, as temperature rises. A moderate negative correlation between temperature and vegetation area (r = −0.782) suggests a decrease in vegetation area similar in magnitude to that observed with the gross output value of agriculture. 9) A very weak positive correlation exists between the annual urbanization rate and built-up area (r = 0.080), suggesting an almost negligible relationship between the two variables. Likewise, there is a very weak negative correlation between the annual urbanization rate and vegetation area (r = −0.071), indicating a minimal association between the annual urbanization rate and vegetation area. 10) There is a very strong negative correlation between rainfall and built-up areas (r = −1.000), signifying that as rainfall increases, it negatively affects the growth of built-up areas. Conversely, there is a very strong positive correlation between rainfall and vegetation area (r = 0.984), indicating a substantial increase in vegetation area with higher rainfall.

### 4.3. Exploring Characteristics of Common Urban Models

Examining common urban models unveils key factors influencing the spatial expansion of cities across the globe. The following four examples highlight how diverse factors like economic forces, population dynamics, government policies, and geographical constraints interact to drive spatial expansion in different cities. Let's explore them: 1) Tokyo's urban area is the world's largest, expanding rapidly throughout the 1900s. High population and traffic are reshaping the city's landscape and transportation systems quickly. This growth is driven by its global economic importance, drawing in businesses and individuals seeking opportunities [35].

However, surrounded by mountains and water, available land for horizontal expansion is limited. In response to its limitations in land, Tokyo has opted for height, with towering buildings now defining its skyline. This shift upwards is further facilitated by government policies that encourage development and by substantial investments in infrastructure projects [36]. 2) Similar to Tokyo, Seoul grapples with limited land availability due to its mountainous terrain. Despite this, its urban area has grown, and innovation has become the key driver [37]. Seoul focuses on smart city initiatives, promoting efficient land use and sustainable development. Technological advancements in public transportation and housing solutions minimize sprawl while accommodating population growth [38]. Furthermore, investments in research and development attract talent and businesses, fueling economic growth and further urban expansion. 3) Dubai's story is one of dramatic transformation, fueled initially by oil wealth. This translated into ambitious development projects, attracting investments and tourism [39]. However, recognizing the limitations of oil dependence, Dubai embarked on a strategic diversification plan, focusing on finance, logistics, and tourism. Mega-projects like Palm Jumeirah became symbols of this ambition [40], further attracting global attention and investment and leading to significant spatial expansion. 4) São Paulo's historical role as Brazil's industrial hub fueled its urban expansion. This industrial legacy attracted businesses and workers, leading to the development of industrial zones and subsequent residential sprawl [41] [42]. However, challenges emerged due to unequal development. Limited opportunities in rural areas pushed people toward São Paulo, contributing to the rise of informal settlements and social disparities [43]. While investments in highways and metro systems facilitated suburban development, they also inadvertently fueled sprawl [42] [44]. Today, São Paulo navigates the complexities of its past, seeking sustainable solutions to manage its continued growth.

Despite their individual stories and driving forces, several key similarities bind these cities to Lagos: 1) All the mentioned cities experienced explosive population growth, driving demand for housing and infrastructure, putting pressure on available land and contributing to spatial expansion. 2) Each city, like Lagos, possesses economic prowess, attracting businesses, investments, and talent. This economic activity fuels development projects and construction, contributing to urban expansion. 3) Similar to Lagos, each city faces limitations in available land for horizontal expansion due to geographical constraints like mountains and water bodies. This pushes them towards vertical growth or denser development patterns. 4) Each city actively invests in infrastructure projects like transportation networks, public facilities, and utilities to accommodate the growing population and support urban expansion. 5) Similar to Lagos, these cities grapple with challenges like managing sprawl, ensuring inclusive development, and addressing social inequalities amidst rapid growth. However, these challenges also present opportunities for innovation, sustainable practices, and improved urban planning. While their specific narratives differ, these cities and Lagos share common threads driven by population growth, economic forces, geographical constraints, infrastructure development, and the balancing act between managing challenges and harnessing opportunities associated with rapid urban expansion.

## 5. Conclusion

In this study, the main objective was to identify the dominant driving factor among ten (10) selected variables influencing urban spatial evolution in Lagos, including Population, GDP, Gross output value of road transport, Transport (length of road network), Gross industrial output value, Immigrants population, Gross output value of agriculture, Temperature, Annual urbanization rate, and Rainfall. Through rigorous statistical analysis, particularly Pearson correlation analysis conducted using SPSS software, we aimed to quantify the strength and direction of relationships between these factors and observed changes in land use patterns. Our findings revealed that population emerged as the predominant driving force, with a positive correlation (r = 0.982) between population and built-up area, indicating a substantial increase in urban development with population growth. Conversely, a strong negative correlation (r = −0.942) was found between population and vegetation area, suggesting a considerable decrease in natural habitats as population increases. These results underscore the pivotal role of demographic shifts in shaping the urban landscape of Lagos, emphasizing the need for sustainable urban planning strategies to mitigate adverse environmental impacts while promoting balanced urban growth.

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## Author Contributions

**K.M.G.:** Conceptualization, methodology, formal analysis, visualization, and draft writing. **Y.S.:** Supervision, fund acquisition and draft review and editing. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of Interest

The authors declare no conflicts of interest.

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