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Assessment of Green Space Dynamics Under Urban Expansion of Senegalese Cities: The Case of Dakar

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Abstract: Senegalese cities have experienced rapid urbanisation, leading to profound landscape changes. Dakar, one of Senegalese's fastest-growing cities, is experiencing rapid urban expansion, significantly reducing green spaces. These green spaces, essential for urban sustainability and resilience, have become increasingly scarce, affecting the city's environment and the quality of life for its residents. This study aims to assess the spatiotemporal changes in Dakar's green spaces from 1990 to 2022. Using satellite imagery, this study produces land use maps to quantify green space coverage over the years. The results show a gradual decline in green spaces in Dakar between 1990 and 2022. In 1990, green spaces covered an estimated 13.36% of Dakar's area, which decreased significantly to 9.54% by 2022. In contrast, other land uses, such as built-up areas, increased significantly over this period, rising from 19.23% in 1990 to 39.34% in 2022. Moreover, built-up areas are not the sole contributor to the reduction of green spaces in Dakar. The study revealed that, between 1990 and 2022, 5.49% of green spaces were converted into bare soil due to excessive tree cutting. This pattern highlights the growing challenge of green space availability as built-up areas expand rapidly, particularly when growth is unplanned. This study underscores the importance of sustainable urban planning that integrates the protection and conservation of Dakar's vegetation to preserve vital ecosystem services.

Keywords: urbanisation; urban expansion; green space; ecosystem services; Dakar

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1. Introduction

Urbanisation is a worldwide complex phenomenon resulting from the rapid increase of the urban population. Since 2008, more than half the world's population has lived in cities [1], which has led to rapid urban expansion. Urban expansion is reshaping landscapes worldwide, becoming one of the key factors of the land use system [2]. The rapid growth of the urban population and the expansion of urbanised areas affect natural and human systems at all geographical scales. Today, studies have shown the immeasurable speed of conversion of forests and agricultural lands during the decades of urbanisation, which has led to a dramatic expansion of impervious surfaces at the cost of natural ecosystems and urban green spaces [3]. For instance, in Shanghai, a study showed that, under the impact of urbanisation, green spaces drastically decreased between 1990 and 2015 from 84.8% to 61.9%, while, at the same time, built-up areas increased from 15% to 36.5% [4].

Urban green spaces are generally defined as any area naturally and artificially vegetated and located inside or at the periphery of cities [5]. These spaces are structural components of the urban fabric and are necessary for the liveability of cities [6,7]. Since the nineteenth century, the importance of urban green spaces has been increasingly recognised worldwide, as they serve not only to simulate urban beauty but also to promote the resilience and health of city dwellers [8]. These spaces include parks, forest gardens, allotments, wetlands, and urban trees and can be public or private and are directly or indirectly available for uses such as active or passive recreation and a positive influence on the urban environment [9]. The importance of urban green spaces lies in the range of functions, services and benefits they provide that contribute to the quality of life and sustainability of cities [10]. These benefits, better known as ecosystem services, are classified into four great categories such as support services, provisioning services, regulating services and cultural services [11]. Their role in maintaining ecological balance and supporting urban resilience can be summarised as carbon sequestration and storage, air purification, temperature regulation, noise reduction, flood regulation and habitat for biodiversity [12–19]. For example, a study conducted in Kumasi, Ghana, demonstrated that green spaces have a carbon storage capacity of 211.28 tonnes per hectare, highlighting their role in mitigating carbon dioxide emissions [20]. Similarly, they can reduce temperatures by up to 2.23 °C, extending their cooling effects up to 2 km beyond their boundaries, creating cooling islands that reduce urban heat islands [21]. Among other benefits, green spaces can contribute to the well-being of residents and improve their health [22] by enhancing mental health, physical fitness, cognitive and immune function and by reducing overall mortality rates [23]. In other terms, urban green spaces improve the quality of life in cities [24].

Despite their importance and the services provided, green spaces are increasingly disappearing from urban areas due to the rapid development of cities caused by a growing population [25]. Indeed, natural areas are frequently converted into built-up environments. This leads to the degradation of vegetation, which provides essential ecosystem services [26]. Urban vegetation loss due to expansion has wide-ranging implications. Studies indicate that the decline in vegetation cover not only reduces biodiversity but also exacerbates urban heat island effects, leading to elevated local temperatures and increased energy demands, air and water pollution, increased flood risk and increased carbon emissions from cities, exacerbating climate change [27,28]. Among other consequences, given the importance of green spaces for health [29], the reduction of green spaces must harm residents' mental and physical health, as access to nature within urban areas is increasingly limited. In densely populated cities, where concrete dominates the landscape, green spaces provide havens of peace and serve as areas for recreational and social activities. This is especially evident in rapidly urbanising regions, where the pace of development outstrips efforts to preserve and restore green spaces [30].

Generally, in Senegal, the degradation of the vegetal resources has become an undeniable reality [31,32], particularly in urban areas. Urban expansion in Senegal is accelerating as cities grow to accommodate rapidly increasing populations, especially in metropolitan areas like Dakar. While crucial for economic development and housing, this expansion often comes at the expense of natural landscapes and green spaces, leading to significant urban vegetation degradation [33,34]. Dakar, the capital of Senegal, is a rapidly expanding conurbation with an urbanisation rate of 97.2%, growing in an unplanned manner and facing the gradual occupation of its natural and agricultural land mainly in peri-urban areas [35]. Once known as the Cape Verde Peninsula for its natural greenery, Dakar has experienced a gradual decline in green spaces, increasingly replaced by grey infrastructures [36], contributing to a lower quality of urban life. Despite, the important role of urban vegetation in Dakar, limited research has focused on understanding the extent of its degradation under urban expansion. From this perspective, this study seeks to address the question: How does urban expansion affect the dynamics of green spaces in Dakar? Based on previous research, this work hypothesises that the loss of green spaces in Dakar is directly linked to the development of the city. To test this hypothesis, this article aims to assess the dynamics of green spaces in the city of Dakar and explore the extent and impacts of urban expansion on the city's environmental resources. By analysing land use changes over several decades, the study provides insights into urban planning policies that protect and restore green spaces, promoting a sustainable balance between development and ecological preservation in Dakar City.

2. Materials and Methods

2.1. Study Area

Called the Cape Verde Peninsula, Dakar, the capital of Senegal, is located in the extreme west of Senegal (West Africa) between longitude 17°10 and 17°32 west and latitude 14°53 and 14°35 north. It is bounded to the east by the region of Thies and by the Atlantic Ocean to the north, west and south (Figure 1). One of Senegal's 14 regions, Dakar, the smallest region, covers an area of 550 km^2 or 0.28% of the national territory [37]. The region of Dakar is divided into departments, arrondissements and districts. Dakar belongs to the Sahelian domain of Senegal with a hot semi-arid climate (BSh) according to the Koppen-Geiger climate classification [38]. Its climate is strongly influenced by its proximity to the Atlantic Ocean. The temperature varies between 17 and 25 °C from December to April and 27 to 30 °C from May to November. The region of Dakar is generally situated between isohyets 300 and 600 mm [39]. The main green spaces found in Dakar are specifically composed of parks, forests, small gardens, green façades, grassed areas, trees, cemeteries and car park façades [40].

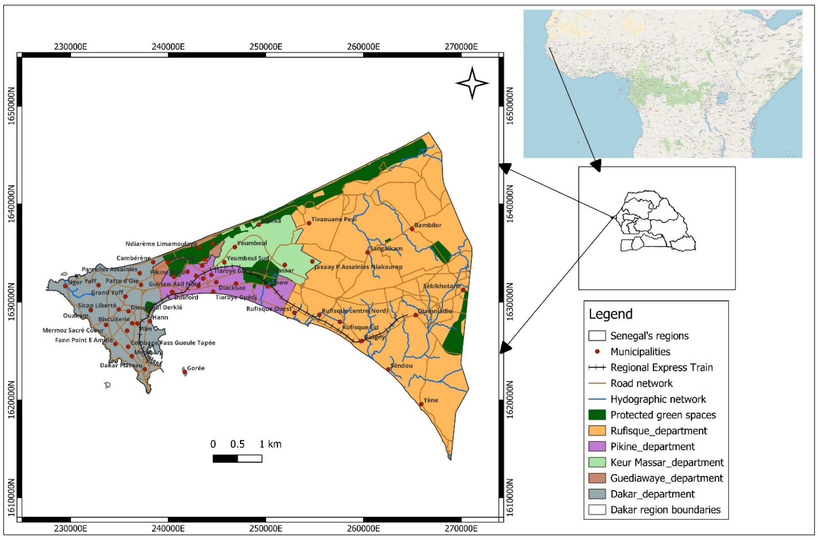


Figure 1. Location map of the study area.

2.2. Data Collection

The Landsat images (Path 205, Row 50) were collected to analyse the spatiotemporal evolution of the vegetation of the study areas from 1990 to 2022. For this analysis, images from the same period of the year, the dry season, were used to minimise high cloud cover and to ensure the consideration of permanent green spaces without the influence of rainfall. The images were downloaded from the United States Geological Survey (USGS) data portal. The following table (Table 1) describes the data used.

Table 1. Satellite images chosen for the spatiotemporal dynamics analysis.

Satellite	Path/Row	Sensor	Spectral Bands	Acquisition Date
Landsat 9	205/50	OLI_TIRS	11	9 April 2022
Landsat 7	205/50	ETM	8	31 May 2012
Landsat 7	205/50	ETM	8	18 April 2002
Landsat 5	205/50	TM	7	5 December 1990

2.3. Methods

In remote sensing, significant progress has been made to produce land use and land cover maps. Numerous initiatives have been undertaken to facilitate remote sensing practices through open-source software. In this context, the classification of Landsat images was conducted using Qgis 3.36.0 software with the Semi-automatic Classification plugin (SCP) [41]. The SCP plugin, integrated into mapping software, enables supervised land use and land cover classification from remotely sensed images [42,43]. The image classification followed several steps within the SCP plugin (Figure 2).

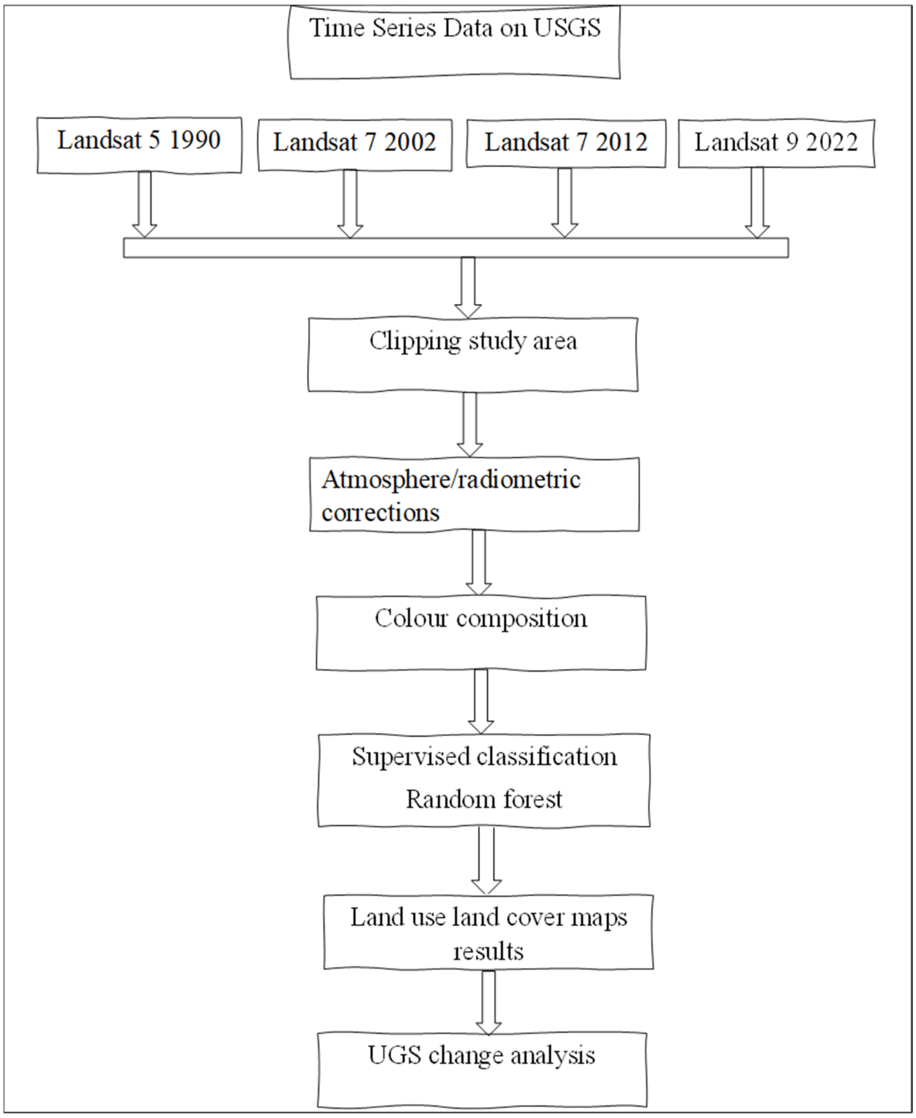


Figure 2. Flowchart of processing Landsat data.

The first step involves image preprocessing, which includes atmospheric and radiometric correction to enhance the image quality for accurate interpretation. This was achieved using the plugin's image conversion option, enabling both atmospheric and radiometric corrections. Next, the study was extracted using the "Clip Raster Bands" option. The supervised classification method was then employed to produce land use and land cover maps with the help of the SCP plugin's "Band Processing" option. Following image preprocessing and study area extraction, a false colour composition was created using selected bands. This colour composition identified five land cover classes in the Dakar region (Table 2).

Table 2. Land cover class description.

Land Use and Land Cover Types	Description
Green space	All areas of vegetation, including public and private green spaces.
Water	Areas of water like lakes, rivers and ponds.
Agriculture land	Cultivated areas such as fields and market gardens area.
Bare land	Areas devoid of vegetation or bare soil, rocks and tannins.
Built-up	Impervious areas including buildings and roads.

In the SCP dock, training inputs were assigned to each class, and the classification was then performed using the Random Forest algorithm, a machine learning algorithm consisting of multiple decision trees [44]. After classification, an accuracy assessment was conducted using overall accuracy and Kappa coefficients, which are widely applied in remote sensing.

Changes in land use and land cover were done using the SCP plugin's "Cross-classification option". The maps were cross-tabulated two by two, covering 1990–2002, 2002–2012, 2012–2022 and 1990–2022. Following this step, the matrix tables were analysed to illustrate the changes.

3. Results

3.1. Land Use/Cover of the Dakar City from 1990 to 2022

The analysis of land use and land cover in the Dakar region from 1990 to 2022 reveals a strong spatial dynamic, with a general dominance of two main classes, which are bare land and built-up area (Figures 3 and 4). The vegetation scattered around the city has experienced major changes over the years, with both decreases and increases. The overall accuracy and Kappa coefficients are 99.9% and 0.99 in 1990, 98.22% and 0.96 in 2002, 75.15% and 0.66 in 2012 and 96.99% and 0.95 in 2022, respectively.

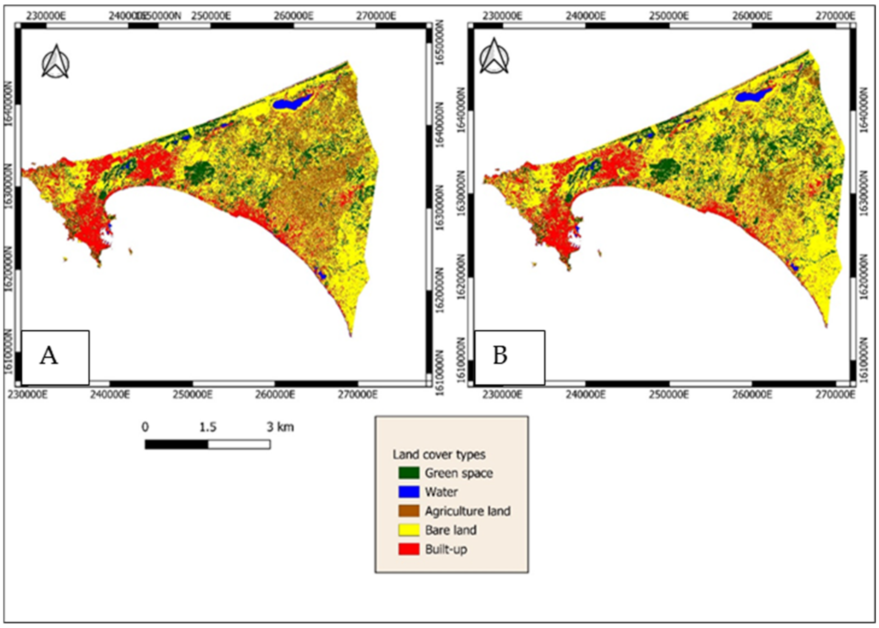


Figure 3. Land cover classes of Dakar from 1990 (**A**) and 2002 (**B**).

The reference year for this study is 1990. Figure 5 shows that, in that year, bare land was the dominant class, covering 46.34% of the total area, or 25,116.39 ha, followed by agriculture land at 19.35% (10,486.35 ha) and built-up area at 19.23% (10,424.52 ha). Green space and water bodies occupied lower proportions at 13.36% (7242.84 ha) and 1.72%

(931.32 ha), respectively. Twelve years later, in 2002, green spaces declined considerably, with 5% of their spatial cover disappearing, causing a huge loss of vegetation in an area where greenery is less prevalent. Indeed, green space occupied only 7.88% of the total area of Dakar or 4269.6 ha. A similar trend was observed in the water body and agricultural land, which cover 0.97% (528.03 ha) and 15.19% (8232.93 ha), respectively. Conversely, bare land and built-up area expanded significantly, covering 52.26% (28,325.34 ha) and 23.7% (12,845.52 ha) with an increase of 3208.95 ha and 2421 ha, respectively.

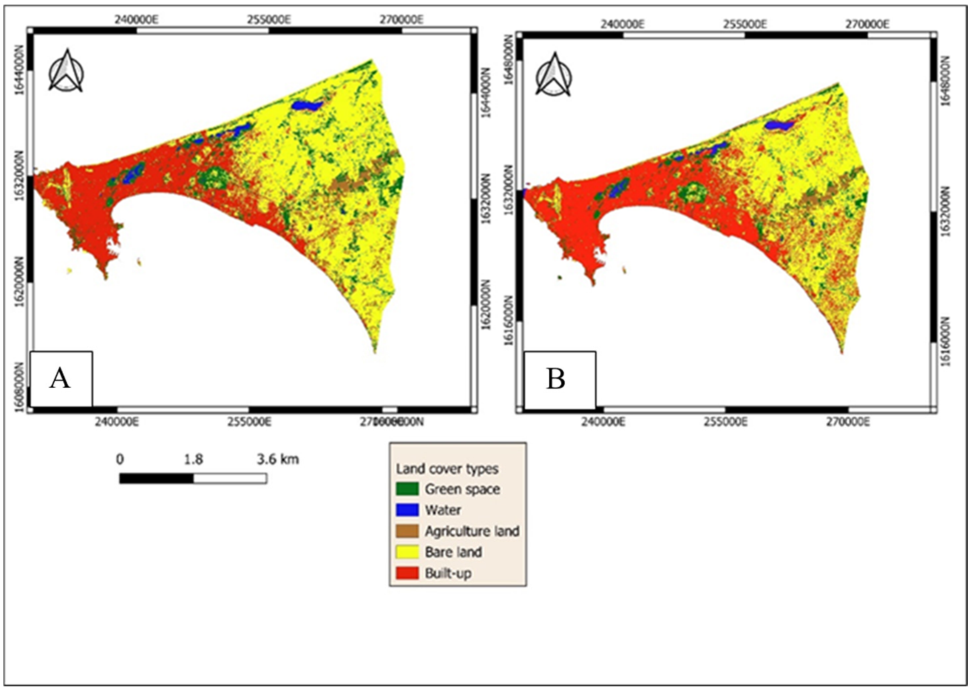


Figure 4. Land cover classes of Dakar from 2012 (**A**) and 2022 (**B**).

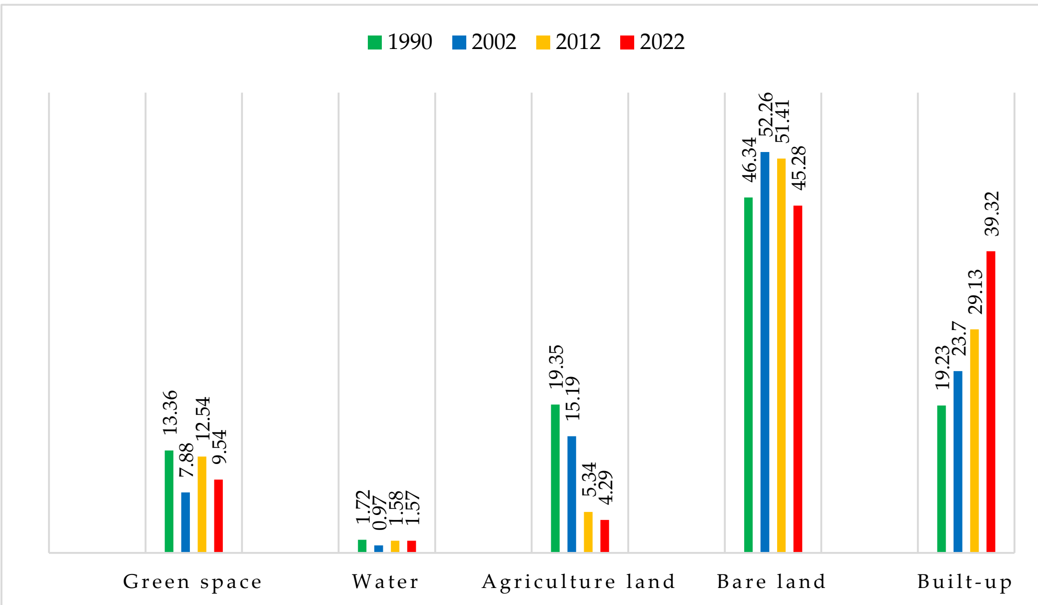


Figure 5. Percentage of land use types in the city of Dakar from 1990 to 2022.

The built-up area grew continuously in 2012, covering 29.13% (15,791.58 ha) of the Dakar region's land area, an increase of 2946.06 ha. Unlike previous years, an increase was observed in vegetation and water in Dakar in this same period. Indeed, green space rose slightly with 12.54% (6794.37 ha) of the area of Dakar, representing an increase of 2524.77 ha. A smaller increase was recorded in the water surface area, which climbed to 1.58% (855.72 ha). In contrast, agricultural land experienced a significant loss during this period, decreasing to 5.34% (2894.85 ha), a drastic reduction of 5338.08 ha. A similar declining trend was noted in the bare land class, which reduced by 460.44 ha, covering 52.41% (27,864.9 ha) in 2012.

The year 2022 was characterised by an overall reduction in all land cover types, except for the built-up area, which continued to grow rapidly. The built-up area reached 39.32% (21,311.28 ha) of the total area of Dakar, which increased by 10.19% (5519.7 ha) over just 10 years. In contrast, vegetation cover declined again to 9.54% (5170.59 ha), a loss of 3% (1620.75 ha). The water area, agriculture land and bare land classes accounted for 1.57% (853.02 ha), 4.29% (2324.61 ha) and 45.28% (24,541.92 ha), respectively.

3.2. Land Cover Changes in the Dakar Region from 1990 to 2022

The results reveal a significant shift in land cover in Dakar from 1990 to 2022, with these changes substantially impacting vegetation cover. The matrix tables illustrate the transformation of land cover classes over the years studied. The matrix results indicate a high instability level in Dakar green spaces, marked by their conversion into other land use types. Between 1990 and 2002, only 11.14% of green spaces remained stable (Table 3). Additionally, a considerable portion of vegetation cover was lost, with 3.07% converted to agricultural land and another 1.77% to bare land, highlighting the extent of vegetation cover degradation and a total loss of 5.2%. Agriculture land expanded, with 9.25% of bare land converted to agricultural use. Conversely, bare land decreased as it transitioned to agricultural land and built-up areas. Built-up areas grew by 5.14% at the expense of bare land, representing an overall increase of 5.4% in built-up areas.

Table 3. Land use and land cover matrix from 1990 to 2002 in percentage.

	Land Cover Types	**1990**					
		Green Space	**Water**	**Agriculture Land**	**Bare Land**	**Built-Up**	**Total**
2002	Green space	11.14	0.19	3.07	1.77	0.17	16.34
	Water	0.09	1.11	0	0.03	0.03	1.26
	Agriculture land	0.09	0.01	6.45	1.64	0.06	8.25
	Bare land	1.43	0.08	9.25	39.08	5.14	54.98
	Built-up	0.62	0.33	0.57	3.82	13.84	19.18
	Total	13.37	1.72	19.34	46.34	19.24	100

Between 2002 and 2012, significant changes continued, with vegetation cover decreasing sharply, leaving only 5% relatively stable (Table 4). Meanwhile, 7.93% of bare land and 2.63% of built-up areas were converted to green space, leading to a 4.07% increase in green areas. However, this period also experienced the greatest vegetation loss, with 4.75% of green space converted to bare land, while agricultural land and the built-up regions expanded by 1.18% and 1.22% of vegetation, respectively. The built-up areas notably decreased, losing over 10% of its surface to bare land, though it saw a slight increase elsewhere. Similarly, agricultural land expanded, claiming 4.94% of bare land.

Green spaces showed much greater stability between 2012 and 2022 (Table 5). Indeed, the vegetation cover increased by 8.41%, with only minor changes observed. During this period, the matrix table reveals that small portions of green spaces were converted to water (0.02%), agricultural land (0.07%), bare land (0.85%) and built-up (0.18%). Additionally, green spaces expanded as 3.05% of bare land was transformed into green space, reflecting efforts to develop green areas and reforest the city. In contrast, the water surface area continued to decline significantly, as did built-up areas, which decreased slightly by 10.16%. Specifically, the built-up areas declined by 10.19% in favour of the bare land category, resulting in a 6.51% increase in bare land.

Table 4. Land use and land cover matrix from 2002 to 2012 in percentage.

	Land Cover Types	**2002**					
		Green Space	**Water**	**Agriculture Land**	**Bare Land**	**Built-Up**	**Total**
2012	Green space	5	0.12	1.18	4.75	1.22	12.27
	Water	0.3	0.74	0.02	0.25	0.26	1.57
	Agriculture land	0.48	0.02	1.33	3	0.39	5.22
	Bare land	7.93	0.16	4.94	33.86	4.9	51.79
	Built-up	2.63	0.22	0.78	13.11	12.41	29.15
	Total	16.34	1.26	8.25	54.97	19.18	100

Table 5. Land use and land cover matrix from 2012 to 2022 in percentage.

	Land Cover Types	**2012**					
		Green Space	**Water**	**Agriculture Land**	**Bare Land**	**Built-Up**	**Total**
2022	Green space	8.41	0.02	0.07	0.85	0.18	9.53
	Water	0	1.55		0.01	0.02	1.58
	Agriculture land	0.09	0	4	0.2	0	4.29
	Bare land	3.05	0	0.98	40.54	0.71	45.28
	Built-up	0.72	0	0.16	10.19	28.24	39.31
	Total	12.27	1.57	5.21	51.79	29.15	99.99

The overall class transfer matrix from 1990 to 2022 shows very low stability for the green space class (Table 6), with only 3.66% of the area remaining as green spaces over this period. However, there were some positive changes in favour of green space, with 5.49% of bare land converted to green space and 3.62% of the built-up area also becoming vegetation. The water and agricultural land classes contributed smaller amounts to vegetation, 0.31% and 0.28%, respectively. Conversely, green space experienced significant losses, with 3% of its space converted to bare land, 1.76% to agricultural land, 0.97% to built-up areas and 0.14% to water. The water class saw the greatest decline, losing 7.8% of its surface area between 1990 and 2022. In contrast, agriculture land, bare land and built-up areas experienced substantial expansion, with agriculture land increasing by 15.06%, bare land by 1.05% and built-up areas by 20.09%. Built-up areas, in particular, have become increasingly sprawling over the years.

Table 6. Land use and land cover matrix from 1990 to 2022 in percentage.

	Land Cover Types	**1990**					
		Green Space	**Water**	**Agriculture Land**	**Bare Land**	**Built-Up**	**Total**
2022	Green space	3.66	0.14	1.76	3	0.97	9.53
	Water	0.31	0.77	0.04	0.19	0.27	1.58
	Agriculture land	0.28	0.03	2.01	1.78	0.19	4.29
	Bare land	5.49	0.18	11.85	24.31	3.45	45.28
	Built-up	3.62	0.61	3.69	17.05	14.36	39.33
	Total	13.36	1.73	19.35	46.33	19.24	100

4. Discussion

This study consisted of assessing changes in green spaces in the city of Dakar from 1990 to 2022. This work was based on satellite images to determine the green space coverage rate. The results obtained showed great instability in the coverage area of Dakar's vegetation. Various factors, including socioeconomic and environmental contexts, influence changes in land use [45]. From this perspective, the landscape of Dakar has undergone considerable transformations over the years, with all land use categories undergoing significant changes during the study period (Figure 6). Except for built-up areas, classes such as green spaces, water, agricultural land and bare land have shown a downward trend between 1990 and 2022. As green spaces were gradually converted into other land use types, their spatial coverage diminished substantially, with the largest losses occurring between 1990 and 2002, where 3.07% was converted to agricultural land, and between 2002 and 2012, where 4.75% of vegetation became bare soil. These declines result from intense human pressures.

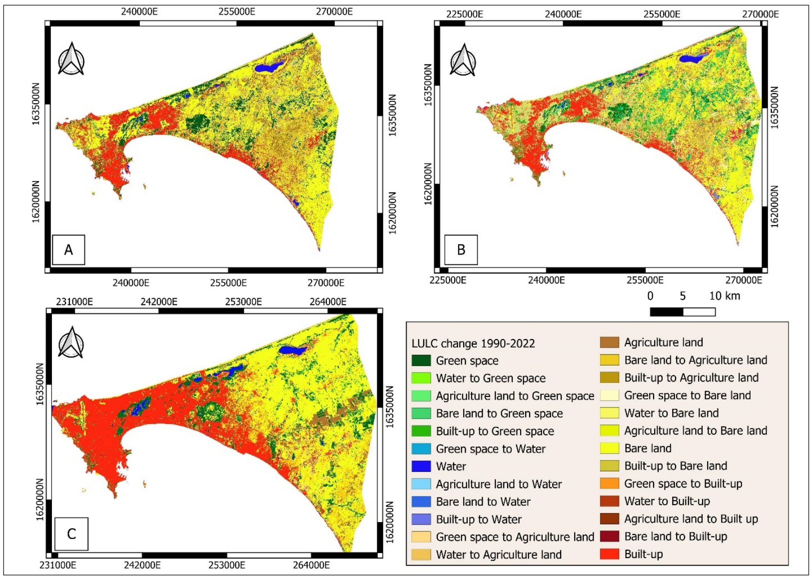
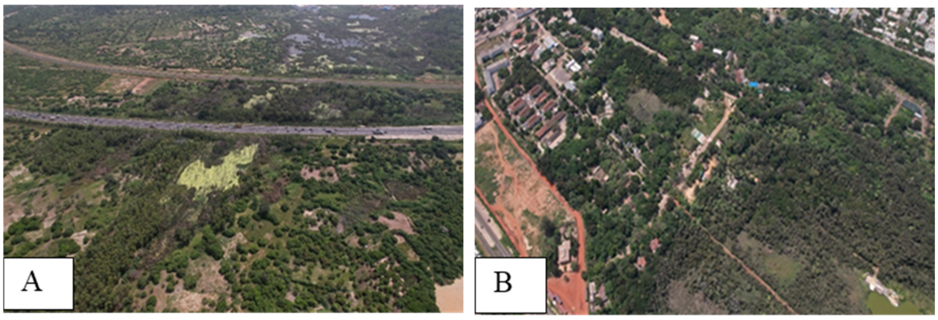


Figure 6. Land use/cover change in Dakar from 1990 to 2002 (**A**), from 2002 to 2012 (**B**) and from 2012 to 2022 (**C**).

Conversely, Dakar's built-up areas have expanded rapidly, driven by the rising demand for housing and infrastructure to meet the population's needs. Rapid demographic growth and migratory flows have increased the number of built-up areas. Urban expansion became especially evident from 2012 onwards as development shifted from the city's west to its east. This trend has been confirmed by another study, which found that, between 1989 and 2014, Dakar's built-up areas expanded at the expense of other land uses, with built-up area changes ranging from 30.6 to 118.6 km^2 out of a total surface of 550 km^2 [46]. Comparing these results to those found in this current study confirms Dakar's rapid urban growth, with built-up areas reaching 213.11 km^2 in 2022 compared to 104.24 km^2 in 1990. In this study, the relationship between green spaces and built-up areas was not significant (p-value equal to 0.66). In other words, the expansion of built-up areas is not only responsible for the depletion of green spaces in Dakar. This demonstrates that other factors must be taken into account. These different causes include the abusive cutting of trees for firewood, traditional medicine or future constructions. In addition, the climatic conditions of the area, which is located in the Sahelian zone with pronounced aridity, can cause the disappearance of green spaces. The lack of maintenance of green spaces also appears to be a significant factor in the loss of vegetation. All these factors contribute to the transformation of green spaces.

Changes in green spaces are most pronounced in unprotected peripheral green areas, which have gradually disappeared, becoming either built-up or bare soil. However, protected green spaces are also not immune to this trend. Dakar has three major public green spaces, which are the city's main green lungs. These areas are protected by presidential decree. These green spaces, the Hann Forest and Zoological Park, the Mbao Classified Forest and the Great Niaye and Dependence Urban Natural Reserve, have experienced decreasing plant cover over the years. A gradual decline in vegetation cover of these three large green spaces has been observed from 902.07 ha in 1990 to 820.71 ha in 2022, a decrease of 81.36 ha. This reduction is due to multiple declassifications permitting the construction of road infrastructure, such as the motorway that crosses the reserve and classified forest, as well as administrative buildings, as seen in Hann Park (Scheme 1).



Scheme 1. Photos illustrating the fragmentation of green spaces in Dakar: (**A**) motorway crossing the Mbao Classified Forest and (**B**) buildings located in Hann Forest and Zoological Park.

Globally, urban green spaces have significantly declined, as documented by several studies [47,48]. In Africa, for example, in Kumasi, Ghana, green spaces are often replaced by buildings and bare soil [49]. In Ethiopia, a similar pattern was observed, with green spaces transformed into open unvegetated areas due to urban development [50]. Green spaces are also shrinking in parts of Asia due to extensive urbanisation. For instance, a spatiotemporal study of Mumbai, India, revealed significant changes from 1988 to 2018 driven by urban expansion, increased built-up areas and, notably, migratory flows [51].

5. Conclusions

This study investigated the dynamics of Dakar's green spaces between 1990 and 2022. Landsat imageries, land use and land cover were used to quantify green spaces over time. The results showed a downward trend in Dakar's green spaces over time and space. The study revealed that Dakar's urban expansion has contributed to the significant reduction in green spaces, both qualitatively and qualitatively. Dakar's development has proceeded at an exponential rate, destroying plant cover and, at the same, a redistribution of open spaces where other green spaces could be developed. Moreover, the reduction in green spaces would not be without consequences, mainly an increase in urban heat islands, flooding and air quality, which is a recurring environmental problem in the city. This would impact the quality of life of the inhabitants. Hence, there is a need for sustainable urban planning that would take into account the development aspects and the conservation of Dakar's environment.

To address this issue, it is crucial to implement policies that actively preserve green spaces in the city, which is urgently needed to prevent further loss. Additionally, expanding green space development with community participation, such as reforestation days held during the rainy season, is essential. To fully understand the implications of the spatial changes in Dakar, continued monitoring of plant resources and assessing the impact on ecosystem services in this rapidly growing city are both critical. With the urbanisation of Dakar, protecting green spaces is essential to ensure sustainability, enhance resilience to climate change and improve the quality of life in the Senegalese capital.

This study is a contribution to the knowledge of the dynamics of green spaces in Senegal's most urbanised city, which is Dakar. However, this dynamic is not without consequences on the ecosystem services provided by green spaces of the city of Dakar. Future research could therefore be directed towards this perspective to ensure a better understanding of the impacts of the loss of urban vegetation. Furthermore, this study contributes to the wide awareness of the use of remote sensing procedures integrated into geographic information systems tools for spatial analysis using satellite images.

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Data Availability Statement: The satellite data used in this study are free and available on the website Earth Explorer via https://earthexplorer.usgs.gov (accessed on 10 September 2023).

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Conflicts of Interest: The authors declare no conflicts of interest.

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