

Urban Expansion and Green Space Dynamics in Niamey, Niger (1990–2023)

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Abstract

The study examines the factors driving the development of green spaces in Niamey and its environs between 1990 and 2023. The paper investigates land use and land cover changes over the study period by analyzing important land uses, including agricultural land, bare soil, residential areas, vegetation cover, and water bodies, which were selected to represent the diversity of landscape features. The Maximum Likelihood Classifier was applied using 30 validation points per class to improve ground truthing accuracy. Pixel-based classification was performed using spectral similarity algorithms, calculating the probability of pixel affiliation with each LULC category. A high level of reliability in distinguishing land cover classes was determined with a Kappa coefficient ranging from 90.19% in 1990 to 95.36% in 2023. The study equally concluded that climatic pressures, particularly water deficits during dry years, exacerbate vegetation degradation and inadequate vegetation maintenance in less strategic zones, urban expansion and unsustainable practices on ecological stability further contribute to green space loss and are termed as key factors influencing green space transformation in Niamey, indicating the increasing vulnerability to climate challenges that posed rising temperatures and flood risks in the study area. Therefore, the study offers actionable insights for formulating adaptive strategies that support urban resilience and promote sustainable land management in Sahelian cities.

Keywords: Green Spaces, Identification, Vulnerability, LULC Urbanization

1. Introduction

Green spaces can be termed as a plant cover zone in a given geographical area (a clearly defined zone), including plants, agricultural land, grasslands, and forest cover, depending on the configuration of the terrain and their abundance. Among the threats posed by climate change, which constitutes a major uncertainty for the balance of terrestrial ecosystems, particularly in the Sahel, and for sustainable development, West Africa between 1990 and 2010 was characterized by global warming, heat waves, and increased rainfall [1]. The concept of sustainable development in urban areas is widely debated by both national and international authorities and experts, often within the broader discourse on urban resilience to the impacts of climate change [2] and [3].

A growing body of literature advocates for the decolonisation of urban planning, highlighting the

need to recalibrate master planning processes to better reflect local socio-cultural realities [4]. Institutions such as the African Centre for Cities play a pivotal role in advancing these perspectives by promoting a more nuanced understanding of sustainability in African cities [5]. There should be an emphasis on the integration of indigenous knowledge systems and locally driven strategies as essential components of urban planning, whereby balancing global insights with region-specific priorities can support achieving resilient and inclusive urban growth. Ultimately, this reorientation seeks to establish planning approaches that are both locally relevant and globally recognized. A household-based study in Niamey found that residents recognise urban green spaces as essential for strengthening urban resilience.

Green spaces are perceived as essential zones for improving environmental quality, heat stress regulators, and importantly supporting community well-being in the face of climate change [6]. Niamey government and relevant stakeholders launched a tree planting and green spaces maintenance campaign to enhance ecological urban well-being and to improve environmental quality, provide shaded areas, and beautify the city. The program contributes toward making Niamey a cleaner, more attractive, and healthier urban environment [7].

However, the importance of green spaces in cities as a new urban approach remains to be discovered, depending on their contribution and management [8] and [9]. From this point of view, a sustainable city is a mosaic of spaces open to different uses [10] and [2]. Consequently, its varied spaces must be associated with the green network with differentiated management according to the spaces and uses [11].

Indeed, green spaces were an integral part of the city of Niamey before Niger's independence [12] and [13]. During the post-colonial period, a large semi-circular green belt surrounding the city of Niamey over a length of 25 km and several green spaces within the city were created to provide an ideal living environment and protection from the elements, but also to beautify the city with green vegetation [12]. Chosen for the sanitary condition of its space, but also for its political history, the capital of Niger is undergoing an exceptional transformation in terms of space and demography [14] and [13]. The demographic and spatial explosion poses urban management problems, as does the lack of financial resources and good technical support for development [15]. It is in this context that a Master Plan for Urban and Rural Development (SDAU) and various redistribution solutions were implemented for decentralisation in 1984 [13]; this was considered a solution for better development in Africa in general and Niger in particular. Ecological processes have not excluded symbiosis with urban areas [15]. From a conservation and development perspective, this involves the planning and creation of recreational and protected areas, natural parks, and the reintroduction, reforestation, restoration, and rehabilitation of degraded environments [16] and [3]. Vulnerability depends on the nature, extent, and rate of climate change to which a system is exposed, its sensitivity, and its ability to adapt to new climatic conditions [14]. Adaptation is considered to assess the extent to which they can moderate or reduce negative impacts, or have positive effects, in order to avoid danger. Indeed, low adaptive capacity automatically implies vulnerability [17] and [18]. The contribution and management of green spaces in

Niamey, whether informal or developed, are of great ecological importance and provide enormous benefits for humans and animals due to the many services they provide [10]. In other words, their controlled implications in the urban context of life [19] and [20] are highly beneficial in social [10] and [9], and climate [2]. This research aims to contribute to the identification of the factors responsible for the change in the dynamics of green spaces in Niamey.

2. Materials and Methods

2.1 Study Area Description

Niamey city is located in the south-western part of Niger (Figure 1) between 13°28 and 13°35 north latitude and 2°03 and 2°10 east longitude. It is completely submerged by the department of Kollo [21]. With administrative boundaries of 255 km², of which about 185 Km² is urbanised, and an altitude of between 160 metres and 250 metres. Niamey is located on an alluvial plain characterised by predominantly flat topography, punctuated by a few hills, with soils of sandy-loam composition [21]. The city experiences a semi-arid climate, featuring a brief rainy season and a prolonged dry period. The Niger River traverses the urban area, serving as a natural boundary and creating a distinct microclimate. This environment supports both natural Sahelian-Sudanian vegetation and strategically planned artificial green spaces, which are distributed throughout the city to enhance urban livability. Collectively, these green areas contribute to the well-being of residents while bolstering the city's resilience against the adverse impacts of climate change [15] and [21].

According to the World Population Review, the population of Niamey is expected to rise to 1,496,000 in 2024, a considerable leap from the 24,370 inhabitants the city had in 1950 and is projected to reach an estimated 2,461,000 in 2034 [14]. Moreover, given that the population is set to grow to almost 1 million in 10 years (2034) and given that Niamey's residents prefer individual houses with spacious rooms, if possible, the city's surface area, which is 225 km² [22], could unsurprisingly double. As far as green spaces in the city of Niamey have almost doubled in size in less than ten years, which was attributed to the effort of the former President Mahamadou Issoufou by initiating a Nyala Project initiative development policy [23] and [24]. Currently, there are around thirty green spaces established over 10 years period. By 2034, green spaces will have tripled, as seen in the recent policies designed to combat global warming and improve people's well-being in the city of Niamey.

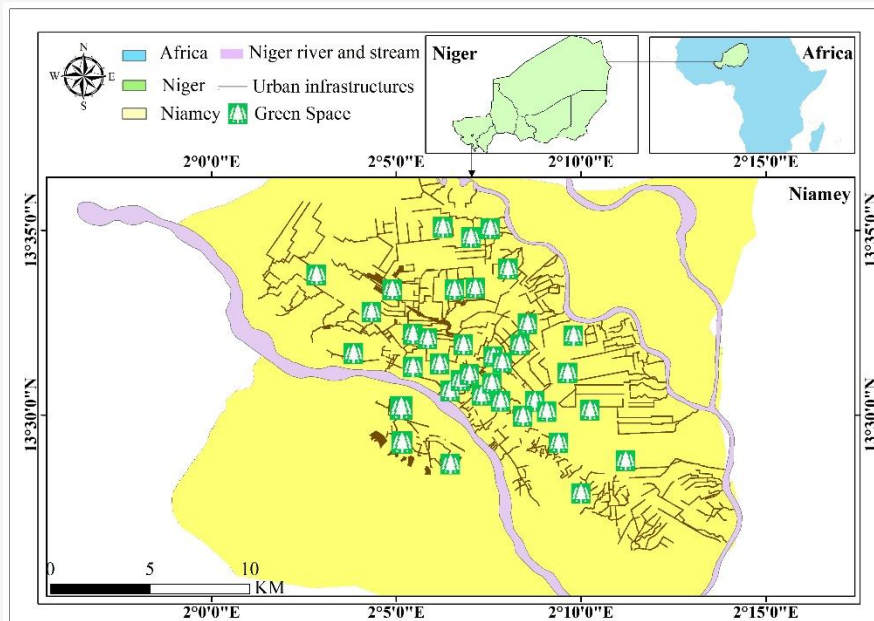


Figure 1: Study area map (Niamey - Niger)

The Commune Urbaine de Niamey (CUN) is composed of a president of the municipal council who manages a city subdivided into five communes, each headed by a mayor elected by the municipal council [22]. This green belt has been significantly encroached upon due to increasing urbanisation, which led to the sale of plots within the area [12]. These land sales within the green belt were orchestrated under the autonomous authority of the five local councils that make up the city of Niamey, during a period of around ten years, before the central municipality eventually regained control of land management [16] and [13]. In Niamey, land cover and land use dynamics, particularly green space changes, are driven by rapid urbanisation resulting from a demographic boom and land development. The city's plant diversity is shaped by the presence of the Niger River and the Gountou-Yéna valley, which together form a varied ecosystem featuring irrigated crops along the riverbanks. Public parks and gardens, meanwhile, are municipal initiatives aimed at improving the well-being of Niamey's residents [15]. In collaboration with the Ministry of Urban Planning, the Nigerien government in 2000, faced with financial constraints, implemented a policy to clear salary arrears owed to civil servants by granting them residential land plots. This policy resulted in the loss of 400 hectares from the city's green belt to make way for housing developments [12] and [13].

As shown in Figure 1, the city of Niamey is divided into two parts by the Niger River over a distance of 15 km, with a few valleys surrounding it

that feed the river during the rainy season. The green spaces are characterised by a green belt, trees along the waterways, and trees along the roads through the city. However, nurseries, public and private green spaces, and residential gardens are artificial creations of nursery owners, municipalities, and the population to improve the urban landscape for the citizens of Niamey. The soils are tropical ferruginous plateau soils and sandy terraces, with the most dominant plant species being: *Azadirachta indica*, *Khaya senegalensis*, *Terminalia mentalis*, *Eucalyptus camaldulensis*, *Faidherbia aldida*, *Prosopis juliflora*, *Combretum micranthum*, *Combretum nigricans*, *Combretum glutinosum*, *Balanites aegyptiaca*, *Phoenix dactylifera*, etc. [25]. There is a high concentration of green spaces on the left bank of the Niger River due to asymmetrical spatial development compared to the right bank of the city. These green spaces were identified through a thorough understanding of the terrain, namely the city of Niamey, and through documentation on the development of green spaces throughout the city [25] and [15]. These green spaces were carefully visited and catalogued through field visits, from municipality to municipality and neighbourhood to neighbourhood, in order to confirm their presence in the Nigerien capital.

A study in Niamey and Maradi [26], shows that school yards with trees help create microclimates, enhance ambient cooling, support biodiversity, and provide opportunities for ecological education.

Also, annual tree-planting campaigns during the National Tree Day on 3 August have contributed to restoring green spaces, a trend that can be monitored using NDVI-based research [27]. But the green belt, established in the 1960s as an ecological buffer, has been affected by illegal dumping, unauthorised housing developments, and informal land-use practices [25]. The reduction of green spaces across Niamey reflects deeper socio-economic pressures, particularly population growth, high demand for fuel wood, and unplanned urban expansion, highlighting the city's ecological vulnerability [28].

2.2 Methodology

The methods used to carry out this study were cartography, statistical analysis, such as correlation tests of the different variables through a matrix, and ground truthing observations with photographs, whereby a structured multi-step approach was employed to analyze the spatiotemporal evolution of green spaces in Niamey from 1990 to 2023. The methodology is illustrated in Figure 2. Landsat imagery (TM, ETM+, and OLI) was acquired for the study area, with selection restricted to the dry season (February-May) to minimize cloud interference and enhance vegetation detection [29]. The images with good spectral resolution and minimal cloud cover were selected, underwent layer stacking, image enhancement, and extraction of the study corrections to ensure temporal consistency across the dataset; land use and land cover classification was performed using a supervised Maximum Likelihood Classifier, assigning each pixel to one of five categories: agricultural land, bare soil, built-up areas, tree cover, and water bodies [30]. To ensure the reliability of the results, an accuracy assessment was carried out using 30 validation points per class, collected during field surveys and cross-referenced with municipal green space records [31] and [32]. The classification performance was quantified using the Kappa coefficient (Equation 2), which provided an objective measure of the algorithm's ability to differentiate between land cover classes [33].

The first method consisted of using different land-use and land cover (LULC) maps at different time scales as used by [11] and [34], for a period of 33 years, in order to observe the changes in the green spaces of Niamey. Satellite images were downloaded from the USGS website accessed via (<https://earthexplorer.usgs.gov/>). These are Landsat 5, 7 and 8 images carefully chosen for their quality to ensure reliable analysis between February and May, in order to better visualize the different land cover classes for the years 1990, 2000, 2010 and 2023, chosen based on the quality of the images for each decade between 1990 and 2023, the preference was

given to images with minimal cloud cover, complete spectral information, and adequate resolution to clearly distinguish vegetation from other land cover types and these steps provided a consistent and robust dataset for examining changes in green spaces in Niamey. The data acquisition dates are presented in Table 1. These images were processed and classified using ArcGIS to produce land use maps with all the variables necessary to show the dynamics of the city [35] and [36] over a period of 33 years. However, transition matrices have been produced to better demonstrate the gains and losses of the different classes [37] and [25]. Also, the research employed the use of the kappa coefficient (Equation 2), through the ArcGIS software mask on LULC maps to assess the accuracy of my LULC maps of the city of Niamey [37]. Regarding the components depicted on the maps, agricultural land encompasses solely the densely populated regions where cereals and vegetables are cultivated. Bare soil delineates the plateaus and soil areas, and built-up areas represent the infrastructure. Trees encompass all concentrations of trees, including fruit-bearing trees, whether in gardens or parks. Water bodies encompass all ponds, rivers, lakes, or marshes present [29]. The following years, 1990, 2000, 2010, and 2023 were chosen due to the availability of reliable satellite imagery, which allows for an accurate assessment of the evolution of green spaces within Niamey. To bridge potential gaps across these periods, additional information was gathered from municipal records and complemented by direct field observations. This combination of sources provides a more comprehensive understanding of trends over the past three decades, ensuring that changes in urban green spaces are interpreted with greater accuracy and context.

The second method consists of producing transition matrices using the ArcGIS software mask. These matrices, subdivided into several tables, are produced based on the map data to create a global matrix (1990-2023) and others by slice in relation to the periods to which the maps belong [25]. These matrices show the transition periods of the land classes over time and space [33]. The sum of these classes represents the city's green spaces, reflecting both natural vegetation and cultivated areas that contribute to ecological functions. The temperature data obtained from the Global Weather Archive database offers historical records by country (Niger, Niamey). It also includes population data derived from the Global Statistical Database [13], along with the total area of LULC zones in hectares and the corresponding percentages, calculated after processing satellite imagery in ArcGIS.

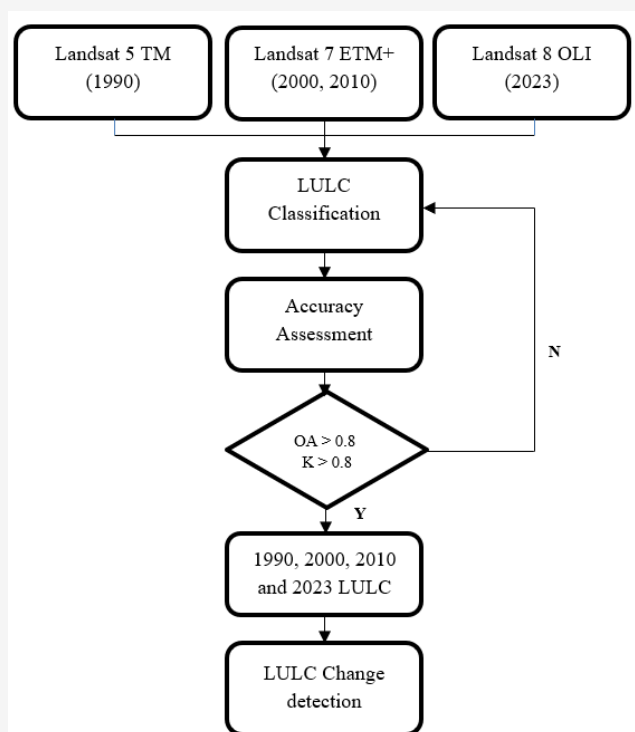


Figure 2: LULC Change detection

Table 1: Aerial and satellite data for the analysis of LULC change in the city of Niamey from 1990 to 2023

Study area	Satellite data used	Sensor type	Resolution range (m)	Date of data acquisition
Niamey	Landsat 5	TM	30	24 February 1990
	Landsat 7	ETM+	30	23 March 2000
	Landsat 7	ETM+	30	7 February 2010
	Landsat 8	OLI	30	15 March 2023

These values concern the green space classes (trees and agricultural land), which were computed for each year [25]. The analysis consisted of processing the data to quantify the gains and losses [37] of green spaces in terms of class changes between 1990 and 2023.

The mapping was done by acquiring satellite images, then processing the images, and using ArcGIS to perform supervised classification. Next, Kappa coefficient (Equation 2) was used to inspect the accuracy and validate the mapping as a finished and credible product [36]. Landsat images with a resolution of 30 metres were selected based on almost zero or completely clear cloud cover and complete coverage of the study area. The images were processed by incorporating them into the ArcGIS mask for cutting, for example, with data such as the shapefile of the study area, before proceeding with classification [29] and [25].

2.2.1 Accuracy Assessment

When assessing the accuracy of satellite image classification, field data is of paramount importance. Thirty points per class [31] and [32] were randomly selected in order to calculate the Landsat image classification results for accuracy verification [38]. These 30 points per class, which were randomly selected, were used to characterise the different classes that make up the land use classes. The identification of each point is linked to a given class, which ultimately provides statistical information about the different classes that make up the map. However, it should be noted that behind this optional choice of 30 points per class, there are underlying terrain issues. The overall accuracy (OA) and Kappa coefficient (K) are defined in Equations 1 and 2, respectively:

$$OA = \frac{TC}{TP} \times 100$$

Equation 1

Where:

TC is the number of pixels in each LULC type that correctly classified.

TP is the total number of pixels in each LULC type (total in the column).

$$K = \frac{(TS \cdot TCS) - \sum (CT \cdot RT)}{TS^2 - \sum (CT - RT)} \times 100$$

Equation 2

Where:

TS is the total samples

TCS is the total corrected sample

CT is the total number of pixels in the column

RT is the total number of pixels in the line

Table 2 presents the assessment of the K value regarding the performance of the LULC classification [33].

Table 2: Kappa coefficient agreement

K	Rating criteria
0.81 – 1.00	Almost perfect agreement
0.61 – 0.80	Substantial agreement
0.41 – 0.60	Moderate agreement
0.21 – 0.40	Fair agreement
0.00 – 0.20	Slight agreement
< 0.00	Disagreement

3. Data Presentation and Analysis

3.1 Spatiotemporal Dynamics of the City

Land use and land cover maps are a series of maps covering the period 1990-2023 for the city of Niamey during the hot season between February and May (Figure 3), providing information on land cover [25]. This land use map of the city of Niamey during the hot season, dating from 1990 Figure 3(a), shows a relatively favourable green grid with trees (32%) and agricultural land (6%). At that time, only a small part of the map area was occupied by built-up areas (9%), proving that Niamey was less populated and exerted less pressure on plant resources. The visibility of green spaces is more pronounced in the northern part, which surrounds the city at the level of the four communes on the left bank. The built-up areas in red are clearly located in the centre of the map due to the low population at the time. Bare soil (52%) was less common at that time, due to the abundance of trees and herbaceous plants in the city. Water (2%) is represented in blue by the river and a number of lakes and koris around the city.

Trees and agricultural land were distinguished in the classification process to differentiate between areas of forest cover (trees) and areas of agricultural production (agricultural land). It should also be noted

that in the forest cover area (trees), green spaces serve purposes such as recreation, beautification, and protection, and the vegetation is almost permanent compared to agricultural land, which is generally used for food production and where vegetation is not necessarily permanent after the harvest period.

The land use and land cover map for the year 2000 (Figure 3(b)), compared to the previous map for the year 1990 (a), clearly shows an apparent reduction in the number of trees from 32% to 23%, followed by a decrease in arable land from 6% to 5%. With the increase in population, the proliferation of built-up areas is intensifying, putting a strain on plant resources due to the demand for space and wood. As a result, green spaces are decreasing, giving way to rising temperatures [40]. On the right side of the city, however, green spaces are disappearing, with a sharp increase in bare land from 52% to 61%, particularly in commune 5. In 2010 (Figure 3(c)), compared to 2000 (Figure 3(b)), the land use and land cover map of the city of Niamey underwent a real change, easily observable by the increasing colonisation of developed areas in the northern part, while threatening the green belt that can be seen in a semicircle on the left bank of the river. There has also been a marked reduction in arable land from 5% to 2%, most of which is concentrated along the river. On the left bank of the city, trees are heavily concentrated in the city centre, as shown on the map, due to the beginning of the city's modernisation and off-season cultivation around the city's water bodies. However, there were fewer trees, decreasing from 23% to 22%, and bare soil was more colonised in 2010 (Figure 3(c)) at 62% than in 2000 (Figure 3(b)) at 64%.

Indeed, on the 2023 land use map (Figure 3(d)), it is not surprising to see that trees have decreased significantly since 1990 (Figure 3(a)) 32% and are increasingly rare compared to the 2000 (Figure 3(b)) 23% and 2010 (Figure 3(c)) 22%. Trees have increased dramatically on the 2023 map (Figure 3(b)) by 33%, which represents a significant increase from 1990 (Figure 3(a)) to 2023 (Figure 3(d)). Furthermore, this increase was attributed to the city's green space policy (Niamey Nyala initiated by the Former President) [23] and [24], supported by municipal councils and the agency for the modernisation of cities in Niger [3], as a result of the development of green spaces throughout the city of Niamey and the protection of the green belt. Compared to other land use maps Figure 3(a), Figure 3(b), and Figure 3(c); the 2023 map (Figure 3(d)) shows a significant increase in red allocation areas, which are expanding more and more compared to previous years [25] and [28].

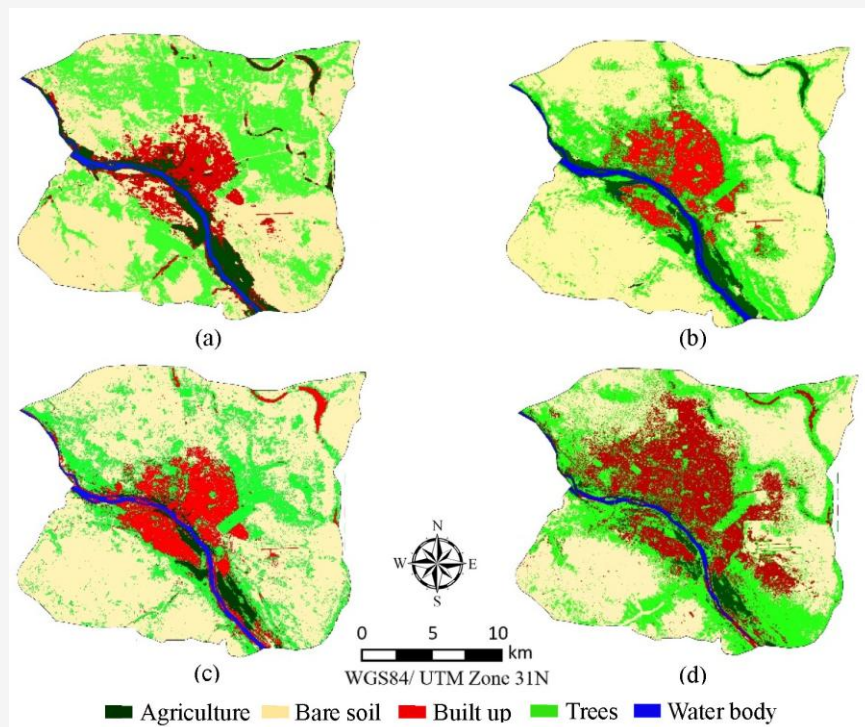


Figure 3: Land Use and Land Cover Map of Niamey (a) 1990, (b) 2000, (c) 2010, (d) 2023

On the other hand, there has been a significant expansion of agricultural land, which increased by 3% in 2023 (Figure 3(d)) compared to 4% in 2010 (Figure 3(c)), encouraged by the government as part of its "*Nigériens nourrissent nigériens*" (Nigériens Feed Nigériens) project, which supports the development of irrigated areas. Commune 5 is the most suitable for cultivation due to the availability of land and easy access to water, but this is also the case in the northern and central parts of the city due to the shallow water table and the availability of koris everywhere.

Between 2010 and 2023, Niamey experienced a marked transformation in its spatial configuration. A comparative analysis of the land cover maps from 2010 (Figure 3(c)) and 2023 (Figure 3(d)) reveals a sharp increase in built-up areas, which expanded from 12% in 2010 (Figure 3(c)) to 21% in 2023 (Figure 3(d)), representing a net growth rate of 10%. This expansion is largely attributable to a demographic boom, evidenced by the conversion of bare soil into built-up areas. Bare soil, which accounted for 62% of the land in 2010 (Figure 3(c)), decreased to 41% in 2023 (Figure 3(d)), primarily in favour of urban development. Part of the reduction in bare soil may also be explained by a slight increase in agricultural land, which grew from 2% in 2010 (Figure 3(c)) to 3% in 2023 (Figure 3(d)). There is also a noticeable expansion of tree-covered areas

(green spaces), rising from 22% in 2010 (Figure 3(c)) to 33% in 2023 (Figure 3(d)). Conversely, water bodies declined from a coverage of 2% in 2010 (Figure 3(c)) to just 1% in 2023 (Figure 3(d)). These fluctuations, whether in agricultural land, trees, or water bodies, are closely linked to the demographic pressure observed over the 13 years period. Overall, these shifts in land cover proportions reflect both spatial and temporal changes driven by a complex network of direct and indirect interactions between the variables in question.

Table 3 presents data on population [14], temperature records [22], and land use/land cover (LULC) surface areas derived from map design sessions conducted in ArcGIS. These surface values were subsequently converted into hectares using Excel. The analysis of green space dynamics, focusing on the *Trees* and *Agriculture Land* classes between 1990 and 2023, highlights significant transformations in the study area. In the year 1990, as presented in Table 3), agricultural land accounted for 3,185.28 ha, but a substantial portion of it was converted into bare soil and built-up areas [25]. Losses amounted to around 1,468.35 ha, while gains (1,256.31 ha) were insufficient to offset this decline, resulting in a net reduction of cultivated land. This trend in land use and land cover changes reflects a gradual shift from agricultural land use to urban development and infrastructural expansion [37].

Table 3: LULC and demographic data of Niamey (1990-2023)

Years	Population	Max. Temp. (°C)	Min. Temp. (°C)	Avg. Temp. (°C)	Agriculture (ha) [%]	Bare soil (ha) [%]	Built up (ha) [%]	Trees (ha) [%]	Water body (ha) [%]
1990	438,000	42	18	30	3,185.28 [6]	28,016.01 [52]	4,885.02 [9]	17,476.38 [32]	827.73 [2]
2000	696,000	43	16	29	2,824.92 [5]	33,817.14 [62]	4,821.48 [9]	12,254.76 [23]	1,083.24 [2]
2010	954,000	42	16	29	1,260.00 [2]	33,406.02 [61]	6,571.26 [12]	11,860.38 [22]	881.64 [2]
2023	1,437,000	42	19	31	1,716.93 [3]	22,905.81 [42]	11,248.02 [21]	17,938.53 [33]	581.13 [1]

Table 4: Global transition matrix (1990-2023) for the LULC classes

Land class	2023 LULC (ha)					Total (ha)
	Agriculture	Bare soil	Built up	Trees	Water body	
1990 LULC (ha)						
Agriculture land	1,256.31	21.15	832.5	1,060.38	14.94	3,185.28
Bare soil	155.07	14,512.23	4,598.46	8,750.25	0.00	28,016.01
Built up	194.67	62.01	3,128.4	1,499.94	0.00	4,885.02
Trees	54.54	8,296.47	2,521.98	6,603.39	0.00	17,476.38
Water body	56.34	13.95	166.68	24.57	566.19	827.73
Total (ha)	1,716.93	22,905.81	11,248.02	17,938.53	581.13	54,390.42

While in the year 1990 as indicated in (Table 3), tree cover spanned about 17,476.38 ha, yet substantial losses accounted to 10,873.00 ha and this is more in peri-urban areas affected by urban expansion and intensive firewood exploitation [41]. However, a gain of 6,603.39 ha was recorded, largely from localised natural regeneration or reforestation efforts, but still the overall balance remains negative. Therefore, the findings of this study reflect a gradual decline in both the density and extent of tree-covered areas in Niamey, which is evidence of the ongoing impact of human pressures and urban sprawl [25] and [29].

The transition matrix analysis from 1990 to 2023, as shown in Table 3 above, revealed major shifts in land use within the study area. The study shows that Agricultural land has shrunk dramatically, dropping from 6% in 1990 to 3% in 2023, a loss of roughly 46% largely converted into built-up zones and, to a lesser extent, tree-covered areas. Bare soil, which initially dominated at 52%, declined to 42%, reflecting about an 18% reduction. These changes are driven by both urban expansion and processes of natural regeneration or reforestation. Built-up areas experienced the most significant growth, rising from 9% to 21%, an increase of around 130%, directly linked to rapid population growth (from 438,000 to 1,437,000 inhabitants) and mounting development pressures. Tree-covered areas have remained fairly stable, with a slight rise from 32% to 33%, reflecting a delicate balance between deforestation, cultivation,

and natural regeneration. Water bodies, however, declined modestly from 2% to 1%, likely influenced by human pressures and climate variability. Overall, these shifts point to rapid and sustained urbanisation, a reduction in productive farmland, and contrasting trends between bare soil and vegetation cover. They highlight the need for integrated land use planning, sustainable urban development, and targeted conservation measures to curtail further degradation.

Figure 4 clearly illustrates the evolution of the different classes that make up the land use map in Table 4 for the period of 1990, 2000, 2010, and 2023. With regard to agricultural land, the study observed a clear improvement, with agricultural land increasing from 3,473.19 ha in 2023 to 1,418.31 ha in 1990, representing a positive gain of 2,054.88 ha. On the other hand, bare land has decreased from 4,277.34 ha in 1990 to 2,037.42 ha in 2023, representing a loss of 2,239.92 ha, or more than half of the bare land. For the built-up areas, there has been a striking change between 1990 and 2023, from 4,570.92 ha to 24,955.65 ha, respectively, which is equivalent to a gain of 20,384.73 ha. This huge gain can be explained by overpopulation in the city or a demographic boom, which indirectly leads to such a high level of construction. With regard to trees, a shortage is clearly evident in the decrease in the area of trees from 20,143.98 ha between 1990 and 2023, with the respective areas being 42,927.57 ha and 22,783.59 ha.

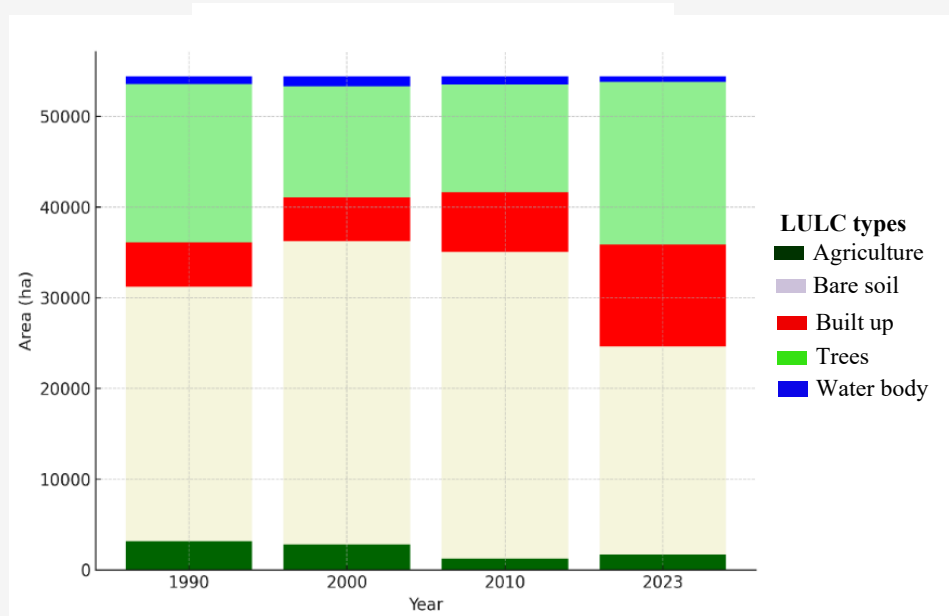


Figure 4: LULC area between 1990 and 2023

This decrease in trees is due to the expansion of built-up areas and agricultural land. Finally, water bodies, which have undergone a fairly minimal change, show a loss of 55.71 ha, from 1,196.28 ha in 1990 to 1,140.57 ha in 2023. The various land use classes have increased or decreased at the expense of other classes in relation to the development of the city and the activities that take place there.

3.2 Land Use and Land Cover Transition

The transition matrices for land use and land cover classes in the city of Niamey for the period between 1990 and 2023 (33 years) enable the various component classes to be displayed, viewed, and measured using the respective data for each year.

Table 4 highlights the major changes in land use and land cover for a period of 33 years. Agricultural land has fallen sharply by around 46%, from 3,185.28 ha to 1,716.93 ha, largely because of conversion into built-up areas (832.50 ha). While a tree-covered land shows (1,060.38 ha). Bare soil shows a more nuanced pattern with a value of 14,512.23 ha that remain uncultivated, while substantial portions have transitioned into tree-covered areas (8,750.25 ha) and built-up land (4,598.46 ha), indicating a mix of reforestation and urban growth. Built-up areas have doubled, increasing from 4,885.02 ha to 11,248.02 ha, driven mainly by the transformation of agricultural land, bare soil, and tree-covered areas, with a minor contribution from water bodies. Tree-covered land has also been reduced due to conversion into bare soil (8,296.47 ha), but has also gained from both bare soil

and agricultural land, reflecting both deforestation and regrowth. Water bodies have remained largely unchanged and represent only a small proportion of land transitions. Therefore, in summary (table 4), the most significant changes include bare soil and tree-covered areas, while urban expansion is considered as the main factor that results in the conversion of agricultural and uncultivated land into built-up areas. These results highlight increasing human pressures and underscore the need for careful urban planning and sustainable land management.

A fairly pronounced transition was observed based on the land classes highlighted in the transition matrix (Table 4). Indeed, depending on the classes, we can list their dynamics over time and space through the transition matrices [25], and more precisely for a period of 33 years (1990-2023) through the superimposition of the two maps (Table 4). From the year 1990 to 2000, as displayed in (Table 5), land use and land cover changes revealed a clear pattern driven by urban expansion, agricultural pressures, and forest dynamics. Agricultural land experienced a noticeable decline, partly converting into built-up areas and also tree zones, reflecting both urban encroachment and tree planting or natural regeneration. Bare soil underwent significant transitions toward forested areas and, to a lesser extent, urban land, indicating a combination of reforestation and city growth. Built-up areas expanded further, drawing from farmland, bare soil, and forests, highlighting the progressive spread of urban development over previously productive or vegetated land.

Table 5: Transition matrix by superposition of land classes from 1990 to 2000

Land class	2000 LULC (ha)					Total (ha)	
	Agriculture	Bare soil	Built up	Trees	Water body		
1990 LULC (ha)	Agriculture land	1,023.21	44.19	30.87	155.79	5.94	1,260.00
	Bare soil	102.78	28,343.97	778.95	4,585.77	5.67	33,817.14
	Built up	1,098.72	196.83	3,517.38	1,554.39	203.94	6,571.26
	Trees	583.47	4,821.03	493.65	5,958.81	3.42	11,860.38
	Water body	16.74	0.00	0.63	0.00	8,64.27	881.64
	Total (ha)	2,824.92	33,406.02	4,821.48	12,254.76	1,083.24	54,390.42

Table 6: Transition matrix by superposition land classes from 2000 to 2010 maps

Land class	2010 LULC (ha)					Total (ha)	
	Agriculture	Bare soil	Built up	Trees	Water body		
2000 LULC (ha)	Agriculture land	1,180.26	109.35	1,159.29	662.94	73.44	3,185.28
	Bare soil	3.06	21,023.01	1,651.50	5,338.44	0.00	28,016.01
	Built up	75.33	234.36	3,640.86	934.38	0.09	4,885.02
	Trees	0.27	12,449.61	101.88	4,924.62	0.00	17,476.38
	Water body	1.08	0.81	17.73	0.00	808.11	827.73
	Total (ha)	1260.00	33,817.14	6,571.26	11,860.38	881.64	54,390.42

Table 7: Transition matrix by superposition land classes from the 2010-2023 maps

Land class	2010 LULC (ha)					Total (ha)	
	Agriculture	Bare soil	Built up	Trees	Water body		
2000 LULC (ha)	Agriculture land	744	74.00	688.00	1048.00	10.00	2,564.00
	Bare soil	170	6,136.00	5,612.00	13,919.00	0.00	25,837.00
	Built up	268	62.00	1,887.12	3,085.	0.00	5,302.12
	Trees	941	4,540.00	5,494.00	8,818.30	0.00	19,793.30
	Water body	256	46.00	386.00	159.00	47.00	894.00
	Total (ha)	2,379	10,858.00	14,067.12	27,029.30	57.00	54,390.42

Tree-covered areas remained dynamic, with ongoing cycles of deforestation and regrowth, while water bodies stayed largely stable. Overall, the most significant changes occurred between bare soil and forested areas, with urban expansion clearly driving the conversion of farmland and uncultivated land into built-up spaces. These patterns highlight the increasing pressures of human activity on the landscape and emphasize the need for thoughtful land management and conservation measures to safeguard both agricultural lands and forested regions.

On the other hand, in the three tables (Table 5, Table 6 and Table 7), we observe a gradual transition of the built-up area category over the three periods studied (1990-2000, 2000-2010 and 2010-2023). This transition is due to environmental changes of a

climatic and human nature that impact the other categories. However, in recent years (Table 4), the unilateral transition from bare soil to built-up areas has been significant, although there has been continuity since 1990. A constant transition can be observed from 2010 to 2023 between the bare soil and water bodies classes and built-up areas. With regard to the bare soil class, a transition has been observed over the decades between 1990 and 2010 and another transition in recent years between 2010 and 2023, all depending on the classes with which the transitions are taking place [13] and [40]. The water bodies class underwent a marked and increasing transition with the built-up areas and agricultural land (green spaces) classes between 2000 and 2010 through the factor of anthropogenic pressure.

The 2000-2010 transition matrix shown in (Table 6) reveals notable patterns of land use changes, reflecting the combined influence of urban expansion, agricultural activities, and forest cover dynamics. Some agricultural land has been replaced by built-up areas and trees provided through afforestation programs, indicating both the encroachment of urban development on farmland and deliberate tree planting. Bare soil exhibits a highly dynamic pattern, with significant portions transforming into forested areas and a smaller fraction into urban land, highlighting the coexistence of reforestation and urban growth. built-up areas have increased further, encroaching on farmland, bare soil, and forested land, illustrating the gradual spread of cities over previously productive or vegetated areas. Tree-covered land continues to exchange with bare soil and other classes, demonstrating ongoing cycles of deforestation and natural regeneration. Water bodies, in contrast, have remained largely unchanged, showing minimal direct impact from human activities. In short, the most significant changes involve exchanges between bare soil and forested areas, with urban growth continuing to transform farmland and uncultivated land into built-up regions. These patterns highlight increasing human impacts on land cover and underscore the need for careful land management and sustainable urban planning.

In summary, the transition matrix for 2010-2023 shown in (Table 7) indicated that the most significant transformations occur between bare soil and forests, while urban growth remains the primary driver converting farmland and uncultivated land into built-up areas. These patterns underscore the increasing human impact on land cover and the importance of adopting sustainable land management and urban planning strategies. Over time, the dynamics of green spaces in the city of Niamey have undergone constant change due to various factors. According to their study in Ouagadougou « *Urbanisation, characterised by spatial expansion and population growth, is the main driver of changes in land use and green spaces cover in Niamey* » [25], this refers to the fact that the city's population growth is a determining factor in the dynamics of green spaces and also in the transition of the various variables that make up LULC, as is the case in our study on a temporal and spatial scale. However, in their article on green spaces in Bamako and Sikasso, explain that « *it is therefore also crucial to promote green spaces*

and their ecosystem services in the cities of Bamako and Sikasso, making them sustainable and resilient to climate change » [29], so that, through an exponential transition of green spaces, the city population can enjoy a climate with a comfortable ambient temperature and no bare soil.

3.3 LULC Maps Accuracy

In terms of accuracy, the Kappa index is a well-established classification for maps from different years [25] and [39]. The accuracy margin increases with time: 90.19% (1990), 94.80% (2000), 94.81% (2010), and 95.36% (2023). In other words, in 1990 there was more margin for error and imprecision with a percentage of (9.81%) than in 2023, which had the least margin for error and imprecision, at (4.64%), and the same scenario for changes in accuracy in 2000 and 2010. This analysis was based on the different LULC classes, which are as follows: Agriculture land (green spaces), bare soil, built up, Tree (green spaces) and water Body.

With a total sample size of 30 reference pixels for accuracy assessment of 30, it can be seen that in most cases, samples are correct (2000, 2010 and 2023), except in 1990. An accuracy of 100% samples was not achieved, even though all the sample accuracies are good and quite acceptable [39], given the very small margins of error, with an accuracy percentage of over 90% for all the results obtained.

The Kappa coefficient presented in Table 8 remained consistently high, ranging from 90.19% in 1990 to 95.36% in 2023, demonstrating a strong level of agreement between the classified maps and the reference data [33]. The Overall Accuracy in Table 8 displayed notable variation over the study period, reaching 93.33% in 1990, 96.67% in 2000, 96.71% in 2010, and 96.92% in 2023. These results suggest that OA tends to remain at a very high level even over longer time intervals or in landscapes experiencing significant changes, such as urban growth or alterations in vegetation cover [32]. Based on commonly applied classification standards, OA values above 70% indicate high accuracy, 50-70% moderate, and below 50% low [33]. Accordingly, the 1990, 2000, 2010, and 2023 classifications can all be regarded as highly accurate. The findings highlight the value of reporting both OA and the Kappa coefficient, as together they offer a clear and balanced view of classification performance while showing how landscape changes affect accuracy over time.

Table 8: The overall accuracy of the kappa coefficient

Years	1990	2000	2010	2023
K (%)	90.19	94.80	94.81	95.36
OA (%)	93.33	96.67	96.71	96.92

Table 2 indicates an almost perfect agreement level (0.81-1.00), as the Kappa coefficient results range between 81% and 100% [33]. Table 8 shows that the Kappa coefficient, remained consistently high throughout the study period, ranging from 90.19% in 1990 to 95.36% in 2023. This trend reflects a steady enhancement in classification accuracy over time, with the most notable improvement occurring between 1990 and 2000, where the coefficient increased by over 4%. Beyond 2000, the Kappa values remained relatively stable at around 94-95%, indicating that the classification process became more robust and dependable. This improvement is likely linked to advances in remote sensing data quality and more refined image processing techniques. The particularly high Kappa value achieved in 2023 (95.36%) further demonstrates the strong reliability of the classification and supports the credibility of the temporal assessment of land use and land cover changes.

The Kappa values are considered satisfactory based on the percentage range of accuracy (90.19% - 95.36%), and are relatively high [33] and [25]. Some degrees of uncertainty are expected in the various land use dynamics maps of Niamey, mainly due to the misclassification of certain variables such as rainfed crops, shrubs, grasslands, and trees, which were grouped under the 'trees' class. Nevertheless, the reliability of the findings remains acceptable, considering the thirty reference points assessed by [31], as well as the general high clarity and precision of the satellite imagery employed throughout the analysis. This is further supported by the well-documented evidence of deforestation, uncontrolled occupation of protected areas, construction activities, and demographic growth in Niamey.

4. Discussions of Findings

The various land use and land cover maps of Niamey city show an increase in built-up areas, which has resulted in a decrease in the number of trees, bare soil surfaces, and agricultural land. These maps show a certain dynamic in LULC classes, leading to a change in land use over the years [35] and [13]. This is due to its status as the capital city of the country. It offers a number of economic advantages that attract the rural migrants, civil servants, the construction of large infrastructures housing the administration and central services, and also the high birth rate, which makes the country one of the most active in terms of demographic growth. This territorial expansion of the city of Niamey is due to the demographic growth of its population, which is justified by the construction of infrastructures to constantly modernise the city, which is the image of the country. Demographic pressure is one of the significant

factors in the degradation of green spaces in Niamey [25] and [15].

Socio-economic pressures on land such as informal settlement development within the green belt, which severely degrades wooded areas [13], speculative land use, and weaknesses in the enforcement of planning regulations also play a major role in driving land-use changes [15]. Public opinion, as detailed in surveys, highlights that green spaces are considered essential for improving living conditions, enhancing the urban landscape, and providing protection against heatwaves [25]. Today, as Niamey stands as the country's leading city, it is experiencing rapid demographic growth [14], which in turn fuels urban expansion [12] and [13], creating heat islands that are compounded by its relatively dry climate [22]. Yet, residents also point out the scarcity of these green areas, despite their importance in daily life [41] and [28]. Land-use planning has been a decisive factor in shaping Niamey's land-use and land-cover (LULC) dynamics over the past 33 years [42] and [43]. Significant shifts, particularly between forested areas and bare soil, reflect both deliberate reforestation efforts and competing pressures such as agricultural expansion. The conversion of bare soil into built-up land is a clear marker of the city's relentless urban growth, driven by demographic pressure, infrastructure demands, and migration flows from surrounding regions [12], which also affect the availability of green spaces. Similar patterns have been reported in Bamako, Sikasso, and Ouagadougou [40], showing that demographic growth interacts with socio-economic and regulatory factors in shaping the urban landscapes of our cities [25].

Niamey, located in a predominantly Sahelian climate, lies in a zone with very low rainfall, where the dry season is considerably longer than the rainy season [25]. This limited precipitation creates a harsh climate, marked by highly variable drought conditions that fluctuate from year to year [22]. Such climatic instability, driven by long-term water scarcity, has severe impacts on vegetation, particularly on young plants that require care and regular watering, many of which are damaged by recurring water stress across the city [15]. Heatwaves are also increasingly felt in Niamey, prompting local communities to launch tree-planting initiatives in schools [26] as well as across the urban area [26], in an effort to mitigate heat islands that undermine the well-being of residents. Encouragingly, targeted programmes such as the *Niamey Nyala* initiative [15] have led to modest improvements in green space coverage within the study area. Nevertheless, progress remains uneven.

Around 58% of residents still lack access to a green space within a 15 minutes walk [28], while shortcomings in institutional coordination and weak enforcement of planning policies [25] continue to hinder wider success. Strengthening civic awareness and improving land governance mechanisms are therefore essential to consolidate and sustain these positive outcomes.

The issue of land-use planning is a fundamental factor in influencing the temporal and spatial changes in land use and land cover [43] and [44]. Indeed, planning practices demonstrate that a significant transition has taken place over the 33 years period, reflecting the influence of various policies implemented over the years. During this timeframe, a notable shift has been observed between tree cover and bare soil, largely due to the rebound effect associated with the creation of new green spaces. This transformation is also evident in the transition from tree cover to agricultural land, reflecting an increase in tree planting within the city. Conversely, the transition observed between built-up areas and tree cover is attributed to the relentless demographic growth experienced by the city of Niamey. This is further corroborated by the shift from bare soil to built-up areas, which clearly illustrates a continuous expansion of urban zones driven by indirect population pressure on land. Interestingly, a dynamic transition is also observed between the classes of bare soil, built-up areas, trees, and agricultural land in relation to water bodies, marked by an unprecedented evolution in the water body class [25].

The city of Niamey has undergone significant spatial and temporal changes, as observed through remote sensing. Remote sensing stands out as one of the most effective tools for monitoring, analysing, and assessing urban dynamic changes over both spatial and temporal scales [45] and [34]. Research shows as in Dakar [43] and Zinder [44] that Niamey has experienced a dramatic transformation in land use and land cover dynamics, primarily driven by changes in the built-up class in transition with various other land cover types. This transformation is largely due to demographic pressure, similarly observed in cities such as Bamako and Sikasso [29], Ouagadougou [40], Benin [46], and Niamey [25], demonstrating that urbanisation significantly contributes to the transformation of Niamey's urban landscape. Nevertheless, in recent years, an increase in the green spaces classes has been noted within the city's landscape dynamics, attributed to sustainable urban planning policies such as Niamey Nyala [15]. This ongoing dynamic and pressure can partly be explained by a lack of awareness among residents regarding the ecosystem services provided by green

spaces in Niamey [25]. However, this study is limited by the unavailability of high-quality historical images from the USGS (<https://earthexplorer.usgs.gov/>) for previous years, as well as by the lack of information on the accelerated expansion of urban areas. Also, assimilation through awareness raising, on the perception and understanding by the population [47] of the role of green spaces [8] in the city of Niamey is a key element for better integration of nature into urban life.

5. Conclusion and Recommendations

The study demonstrates that integrating indicators like remote sensing data and transition matrix analysis provides a robust framework for assessing the spatial and temporal dynamics of green spaces in Niamey. By combining LULC classification with evidence-based observations, the study realized substantial land use and land cover transformations driven by socioeconomic factors, including demographic pressures, urban expansion, and insufficient regulation in both strategic and non-strategic areas. It also indicates an overall expansion of built-up areas and a modest increase in tree-covered zones, mainly due to recent initiatives by the government to increase green spaces within the city center. Equally, the study revealed a significant reduction in agricultural land and persistent pressures such as uncontrolled wood harvesting, informal dumping sites, and recurrent fire outbreaks in key green belts. Contrary to earlier assumptions of widespread tree cover loss, the findings of the study indicated a more nuanced pattern.

Therefore, the study recommends the need for targeted urban greening strategies or initiatives to include equitable resource allocation to non-strategic neighbourhoods and the establishment of sustainable maintenance and investment mechanisms, as well as community-based awareness campaigns to enhance the public perception of green space benefits. Urban planning frameworks should also incorporate climate adaptation measures that account for hydrological variability and increasing land-use pressures.

Secondly, priority should be given to areas in need of restoration, alongside the ongoing protection and monitoring of existing green spaces. This framework should also address challenges such as informal settlements and illegal dumping, and engage local communities actively, particularly those living nearby, to ensure the long-term sustainability and effectiveness of urban green space management. Due to limited resources, machine learning approaches were not co-opted in the study. This factor should be considered when interpreting the findings and can inform future research directions.

Although Landsat data remains a key resource for monitoring land use and land cover, they do have some limitations when compared with Sentinel-2. Fewer dedicated products and indices are available for Landsat, and its atmospheric correction and radiometric calibration processes are generally less refined, which can introduce minor uncertainties. In addition, its cloud masking and shadow detection are not as effective as those provided by Sentinel-2, which can sometimes limit the usability of images in areas frequently affected by cloud cover.

Finally, the methodological approach developed can be extended to other Sahelian cities experiencing similar challenges, especially in terms of rapid urban growth and the changing role of green spaces, providing a framework to better understand and assess land use dynamics in these contexts. It is not only a replicable model for sustainable urban land management but also offers a basis for scenario-based planning and adaptive governance strategies that anticipate rapid demographic growth and climate-related stressors across the region.

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