Examining Patterns and Trends of Change in Greater Yola, Adamawa State, Nigeria: A 10 Years Spatio-temporal Investigation

Abstract: This research paper explores the dynamics of land cover and land use in Greater Yola, Adamawa State, Nigeria, spanning the years 2013 to 2023. Through comprehensive analysis, including remote sensing techniques and spatial modeling, the study examines the temporal trends and implications of urbanization on ecosystem diversity and resilience within the region. The findings reveal a significant trend of rapid urbanization, characterized by the expansion of built-up areas at the expense of natural vegetation, which poses challenges to ecosystem integrity. Furthermore, the analysis highlights the implications of these changes for ecosystem diversity, including the loss of natural habitats and fragmentation of ecosystems, threatening biodiversity and essential ecosystem services. The study underscores the critical need for a balanced approach to urban development and environmental conservation to achieve sustainable development goals. Recommendations are provided to guide policymakers and stakeholders in fostering ecosystem conservation, promoting sustainable land use practices, and mitigating the adverse impacts of urbanization on ecosystem health. By implementing these recommendations, Greater Yola can strive towards achieving a harmonious balance between urban growth and environmental stewardship, ensuring the long-term sustainability of ecosystems and the well-being of its residents.

Keywords:Adamawa State; Biodiversity conservation; Ecosystem diversity; Greater Yola; Land cover dynamics;Land use change.

1. Introduction

Urbanization is a global phenomenon reshaping landscapes and ecosystems at an unprecedented pace, with profound implications for biodiversity, ecosystem services, and human well-being (McGranahan & Satterthwaite, 2014; Seto et al., 2017; Sedghi et al., 2021). In sub-Saharan Africa, rapid urban growth is particularly pronounced, fueled by demographic shifts, rural-to-urban migration, and economic development (UN DESA, 2018; United Nations, 2019). As urban centers expand, they exert pressure on surrounding landscapes, leading to land cover and land use changes that can have far-reaching environmental consequences (Foley et al., 2005; McDonald et al., 2010; Vivekananda et al., 2021).

Adamawa State, located in northeastern Nigeria, exemplifies this dynamic urbanization process, with Greater Yola emerging as a prominent urban agglomeration experiencing rapid transformation (Eludoyin et al., 2015; Mafimisebi& Adam, 2016). The Greater Yola region, encompassing the capital city of Yola and its surrounding areas, has witnessed significant shifts in land cover and land use patterns over recent years, driven by urban expansion, infrastructure development, and agricultural intensification (Adejuwon& Abdullahi, 2017; Ayoade et al., 2019).

Understanding the dynamics of land cover and land use in Greater Yola is essential for informing sustainable development strategies, conservation initiatives, and urban planning efforts in the region. This research paper

aims to investigate the temporal trends and implications of land cover changes on ecosystem diversity and resilience in Greater Yola, Adamawa State, Nigeria, spanning the years 2013 to 2023.

Using a combination of remote sensing techniques, geographic information systems (GIS) analysis, and spatial modeling approaches, this study examines the spatiotemporal dynamics of land cover and land use in Greater Yola. By analyzing satellite imagery and land cover maps, we assess changes in the distribution and extent of various land cover classes, including built-up areas, vegetation, water bodies, open spaces, and sand dunes.

The findings of this research provide insights into the drivers and consequences of urbanization on ecosystem dynamics in Greater Yola. Specifically, we examine the extent to which urban expansion has impacted natural habitats, biodiversity, and ecosystem services within the region. Furthermore, we assess the implications of these changes for sustainable development goals, environmental management, and conservation efforts in Greater Yola and beyond.

This paper contributes to the existing literature by offering a comprehensive analysis of land cover dynamics in a rapidly urbanizing region of sub-Saharan Africa. By synthesizing remote sensing data, spatial analysis techniques, and ecological principles, we elucidate the complex interactions between urbanization and ecosystem dynamics, highlighting the need for integrated approaches to urban planning and environmental management.

2. Materials and Methods

2.1. Study Area

The study area is Greater Yola, the administrative capital of Adamawa State of Nigeria. It is a twin settlement consisting of Jimeta -administrative and commercial center, and Yola Town -the traditional settlement. Yola is located within latitudes 9°11’N to 9°20’N and longitudes 12°23’E to 12°33’E. It has total land coverage of 662.47 square kilometers and a population of 395,871 persons (National Bureau of Statistics, 2006). 2012 projection gives the population as 410,598 persons. The study area comprises of twenty-two (22) administrative wards from three (3) local government areas (Yola North, Yola South, and Girei).

The study area is underlain by the Albian-Aptian Bima sandstone and recent river alluvium. The Bima sandstone is the oldest formation in the Upper Benue trough and unconformable overlies the basement complex. The Bima sandstone occurs in the South-western, south-eastern and north-eastern parts of the study area. The river alluvium (recent) belongs to the quaternary age and is found along the main course of the Benue River, and

extends towards the northeast and southern parts of the study area. The river alluvium consists of poorly sorted sands, clays, siltstones and pebbly sand.

2.2. Methodology

2.2.1. Processing Techniques

a. **Image Classification:** Before image classification, a systematic classification scheme inspired by Anderson et al. (1976) was devised for the study area. "Classification Scheme 1" was chosen for its intricate capture and delineation of urban areas, facilitating a detailed analysis of spatial transformations. Support Vector Machine (SVM) algorithm was then applied for classification due to its effectiveness in handling complex datasets and discerning subtle patterns. SVM's ability to navigate multidimensional feature space was deemed suitable for mapping and classifying different land cover types, particularly for discerning urban changes from satellite imagery (Mohamed et al., 2020; Okwuashi and Ndehedehe, 2020).

b. **Trend Analysis**: The methodology employed involved adapting the approach proposed by (Long et al., 2007) to calculate and compare the areas associated with different land cover/land use types over the years. This comparative analysis aimed to unveil the percentage change, identify trends, and determine the rate of change from 2013 to 2023. To facilitate this, a table was constructed, presenting the areas and percentage changes for each year relative to one another.To assess the rate of change, the time span from 2013 to 2023 was divided into two distinct sub-periods: 2013–2018 and 2018–2023. A meticulous comparison was then conducted between these sub-periods to discern patterns and variations in land cover/land use changes. This comparative analysis, as advocated by (Long et al., 2007) to, not only focused on the two sub-periods but also considered the spatial distribution of the average (annual) rate of land cover/land use change across all three periods.The determination of the trend of change involved calculating the percentage change, where the observed change was divided by the sum of the area of a specific land cover/land use type in that period, multiplied by 100. The formula for calculating the trend percentage change is as follows: $Trend\ \%\ change = Observed\ change \times 100 / Total\ Area$.

   Here, the observed change represents the difference between the area before and after a particular year, while the total area is the sum of the total area for both years. To obtain the annual percentage rate, the trend percentage was divided by the number of years (N). A positive trend percentage indicates an increase in the respective land cover/land use type over the specified time frame, whereas a negative

value signifies a decrease in the land cover/land use type. This analytical framework provides a robust method for comprehensively evaluating trends and changes in land cover/land use over the examined period.

3. Results

3.1. Landcover/landuse mapping of Greater Yola in 2013

The landcover/landuse distribution of Greater Yola in 2013 as shown in Figure 1 and Table 1 revealed five class features namely: Built up area, Waterbody, Vegetation, Open Space, and Sand Dunes. Built up Area covered 9.35% of the study area with an area of 103.73 km^2, waterbody covered 1.31% with an area of 14.50 km^2, vegetation covered 75.70% with an area of 839.60 km^2, open space covered 13.17 % with an area of 146.03 km^2, and lastly, sand dunes covered 0.47% with an area of 5.23 km^2.

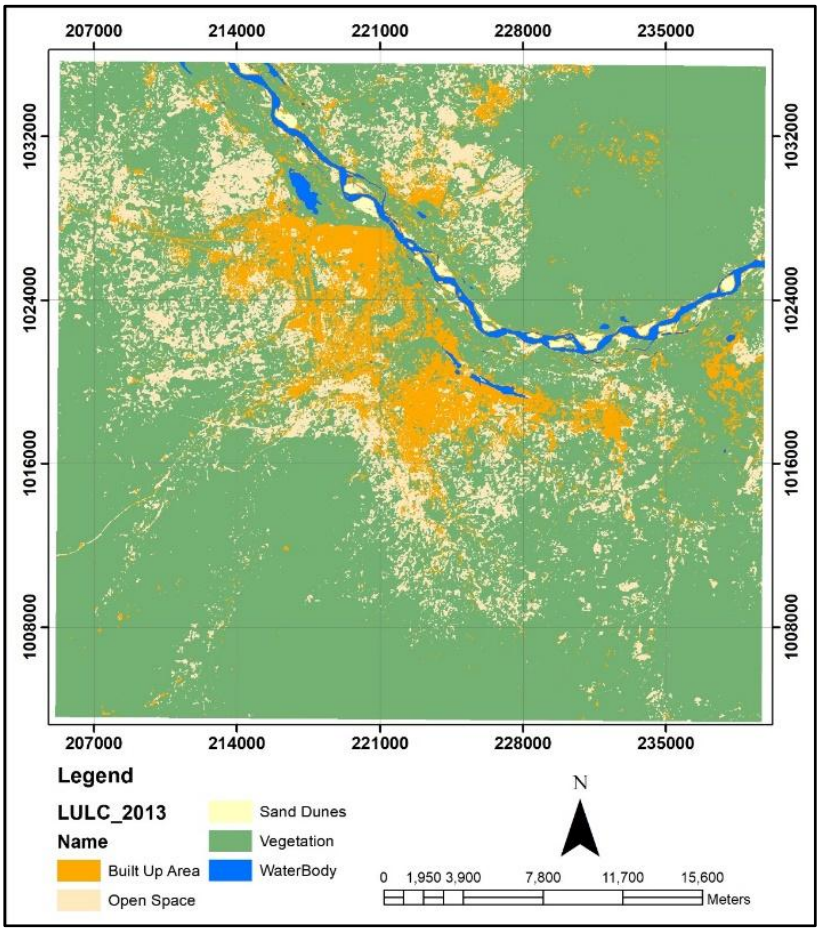


Figure 1: Landcover/landuse map of Greater Yola in 2013

Table 1: Landcover/Landuse distribution for 2013

S/N	*Class Name*	*Area(km^2)*	*Percentage (%)*
1	*Built Up Area*	*103.73*	*9.35*
2	*Water Body*	*14.50*	*1.31*
3	*Vegetation*	*839.60*	*75.70*
4	*Open Space*	*146.03*	*13.17*
5	*Sand Dunes*	*5.23*	*0.47*
6	*Total*	*1109.09*	*100.00*

3.2. Landcover/landuse mapping of Greater Yola in 2018

The landcover/landuse distribution of Greater Yola in 2018 as shown in Figure 2 and Table 2 indicated that Built up Area covered 17.43% of the study area with an area of 193.35 km^2, waterbody covered 1.29% with an area of 14.36 km^2, vegetation covered 47.66% with an area of 528.64 km^2, open space covered 33.12 % with an area of 367.35 km^2, and lastly, sand dunes covered 0.49% with an area of 5.42 km^2.

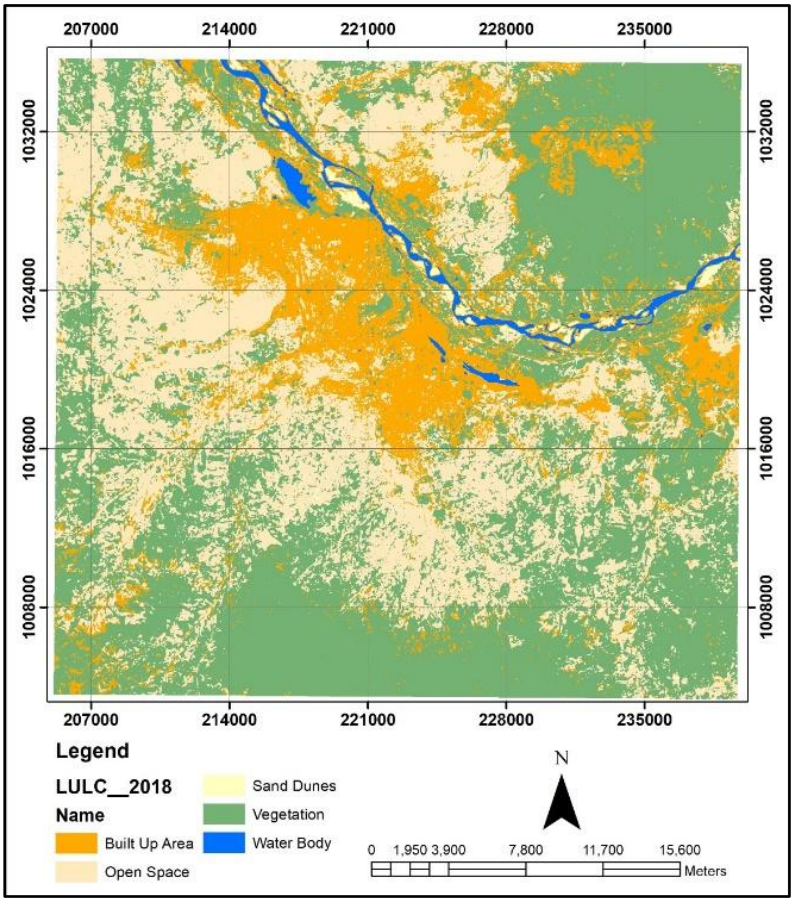


Figure 2: Landcover/landuse map of Greater Yola in 2018

Table 2: Landcover/Landuse distribution for 2018

S/N	*Class Name*	*Area(km^2)*	*Percentage (%)*
1	*Built Up Area*	*193.35*	*17.43*
2	*Water Body*	*14.36*	*1.29*
3	*Vegetation*	*528.64*	*47.66*
4	*Open Space*	*367.35*	*33.12*
5	*Sand Dunes*	*5.42*	*0.49*

3.3. Landcover/landuse mapping of Greater Yola in 2023

The landcover/landuse distribution of Greater Yola in 2023 as shown in Figure 3 and Table 3 indicated that Built up Area covered 23.97% of the study area with an area of 265.86 km^2, waterbody covered 1.32% with an area of 14.64 km^2, vegetation covered 41.43% with an area of 459.51 km^2, open space covered 32.90 % with an area of 364.84 km^2, and lastly, sand dunes covered 0.38% with an area of 4.25 km^2.

Table 3: Landcover/Landuse distribution for 2023

S/N	*Class Name*	*Area(km^2)*	*Percentage (%)*
1	*Built Up Area*	*265.86*	*23.97*
2	*Waterbody*	*14.64*	*1.32*
3	*Vegetation*	*459.51*	*41.43*
4	*Open Space*	*364.84*	*32.90*
5	*Sand Dunes*	*4.25*	*0.38*
6	*Total*	*1109.09*	*100*

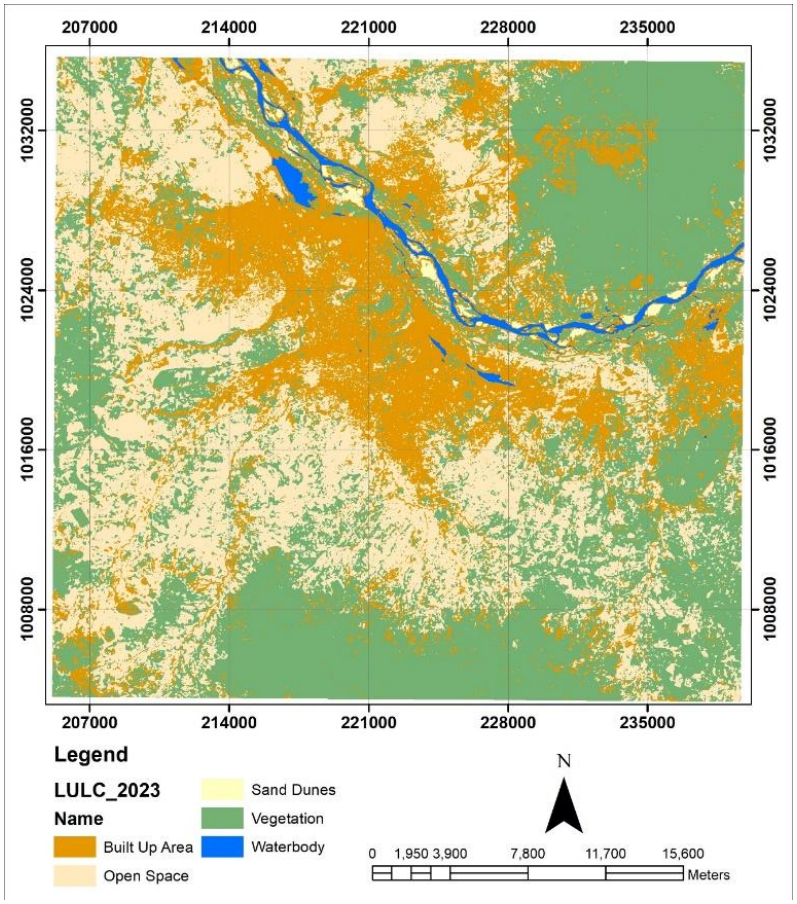


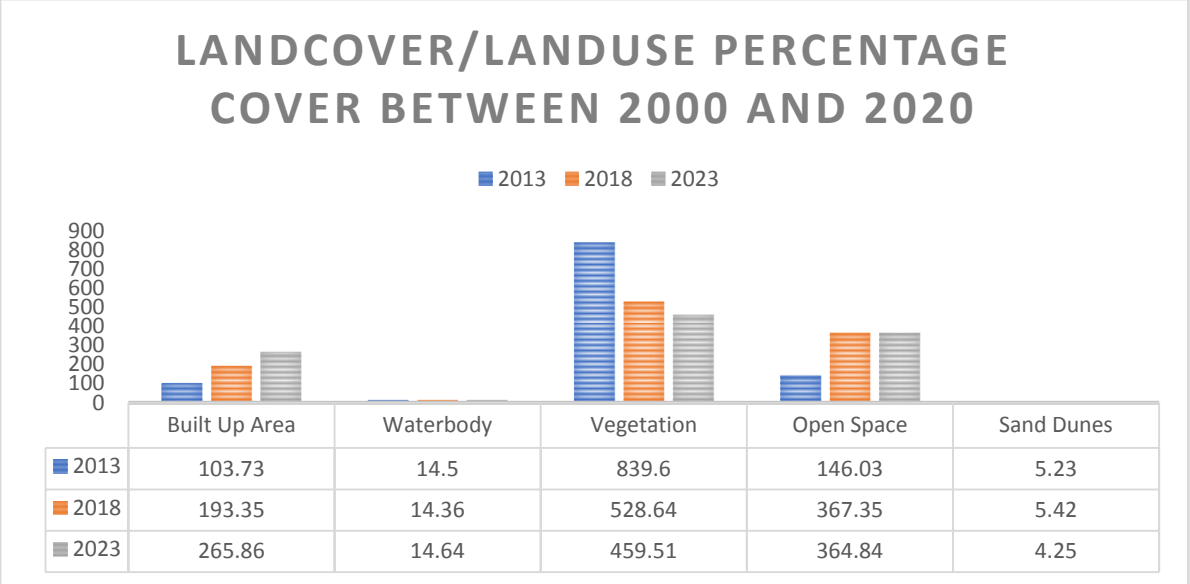
Figure 3: Landcover/landuse map of Greater Yola 2023

3.4. Summary of Landcover/landuse mapping of Greater Yola, Between 2013 to 2023

The summary of landcover/landuse analysis of Greater Yola is displayed in Table 4 and Figure 4 and summarily discussed below.

Table 4: Landcover/landuse distribution of Greater Yola from 2013 to 2023

S/N	*Year*	*2013*	*2018*	*2023*
	Class Name	*Landcover/Landuse Percentage Cover*		
1	*Built Up Area*	*103.73*	*193.35*	*265.86*
2	*Waterbody*	*14.50*	*14.36*	*14.64*
3	*Vegetation*	*839.60*	*528.64*	*459.51*
4	*Open Space*	*146.03*	*367.35*	*364.84*
	Sand Dunes	*5.23*	*5.42*	*4.25*



	Built Up Area	Waterbody	Vegetation	Open Space	Sand Dunes
2013	103.73	14.5	839.6	146.03	5.23
2018	193.35	14.36	528.64	367.35	5.42
2023	265.86	14.64	459.51	364.84	4.25

Figure 4: Histogram of landcover/landuse distribution of Greater Yola Between 2013 and 2023

The land cover and land use distribution in Greater Yola underwent discernible changes between the years 2013, 2018, and 2023, as depicted in Table 4 and Figures 4.

In 2013, the study area exhibited a land cover characterized by five distinct classes, namely Built-up Area, Waterbody, Vegetation, Open Space, and Sand Dunes. Built-up Area occupied 9.35% of the total area, equivalent to 103.73 km², while Waterbody accounted for 1.31% (14.50 km²). Vegetation dominated the landscape, covering 75.70% (839.60 km²), followed by Open Space at 13.17% (146.03 km²) and Sand Dunes at 0.47% (5.23 km²).

By 2018, there was a notable transformation in land cover dynamics. Built-up Area expanded to encompass 17.43% of the study area, corresponding to 193.35 km², indicating a significant increase. Waterbody and Vegetation experienced slight reductions, covering 1.29% (14.36 km²) and 47.66% (528.64 km²), respectively. Open Space witnessed a substantial rise to 33.12% (367.35 km²), while Sand Dunes remained relatively stable at 0.49% (5.42 km²).

The most recent data from 2023 highlights further shifts in land cover patterns. Built-up Area continued its upward trend, covering 23.97% (265.86 km²) of the study area, demonstrating continued urbanization. Waterbody and Vegetation experienced marginal changes, representing 1.32% (14.64 km²) and 41.43% (459.51 km²), respectively. Open Space maintained its prominence at 32.90% (364.84 km²), while Sand Dunes slightly decreased to 0.38% (4.25 km²).

This temporal analysis underscores the dynamic nature of land cover in Greater Yola, emphasizing the expansion of built-up areas and alterations in open spaces over the studied period, potentially indicative of urban development trends and environmental changes in the region.

3.5. Trend Analysis and Development Pattern

3.5.1 Trend Analysis

The comprehensive analysis of land cover and land use dynamics in Greater Yola, spanning the periods 2013 to 2018 and 2018 to 2023, reveals an intricate narrative of spatial and temporal trends. This examination not only delves into the percentages of land cover classes but also provides insights into the annual rates of change, shedding light on the multifaceted dynamics shaping the region's landscape.

3.5.1.1 Trend Dynamics between 2013 and 2018

Between 2013 and 2018, the spatial expansion of Built-up Areas was pronounced, witnessing an 88.3% increase. This surge signifies targeted urban development zones, indicating specific regions experiencing substantial transformation.

The temporal analysis highlights the sustained and accelerating pace of urbanization during this period, with a significant annual average increase of approximately 8.8%. This rapid transformation is likely driven by factors such as population growth, economic activities, and strategic infrastructural investments.

Waterbody coverage remained relatively stable, reflecting a resilient environmental feature. In contrast, Vegetation experienced a notable 34.8% decrease, suggesting potential anthropogenic impacts or variations in land management practices.

The annual average change in Vegetation coverage was approximately -3.6%, indicating nuanced responses to environmental changes. Meanwhile, stable Waterbody coverage suggests a degree of environmental resilience during this period.

Open Spaces saw a significant 150.4% increase between 2013 and 2018, This signifies the unintended consequence of urban development, where open spaces emerged due to the removal of vegetation.

The average annual change in Open Space coverage during this initial period was approximately +30.0%, emphasizing the region's commitment to maintaining open areas amidst urban expansion.

Sand Dunes exhibited minor percentage fluctuations with a 2.1% decrease, maintaining a relative constancy in the landscape. This stability indicates resilience to significant anthropogenic impacts during this period.

The minimal average annual change of approximately -0.2% emphasizes the continued stability and potential adaptability of Sand Dunes to environmental factors and human activities.

3.5.1.2 Trend Dynamics between 2018 and 2023

Between 2018 and 2023, there was an additional 37.2% increase in Built-up Area, signifying a continued targeted urban development trajectory. Specific regions experienced sustained transformations, contributing to the ongoing evolution of urban landscapes.

The annual average increase of approximately 7.7% underscores the region's consistent and accelerating pace of urbanization during this latter period.

Waterbody coverage remained stable, indicating continued environmental resilience. Vegetation experienced a minor 0.8% decrease, suggesting ongoing responses to environmental changes and potential stabilization.

The stabilized average annual change in Vegetation coverage at approximately -0.08% implies potential stabilization or adaptation to land management practices during this latter period.

Open Spaces experienced a slight 0.2% decrease between 2018 and 2023. This reflects an attempt to strike a balance between urban development and conservation, perhaps addressing the unintended consequence observed in the earlier period.

The nuanced average annual decrease of about -0.04% underscores the complexity of balancing urban development with open space conservation during this latter period.

Sand Dunes maintained their stability with minor percentage fluctuations, experiencing a 2.1% decrease during this period. This continued constancy highlights the resilience of Sand Dunes to environmental factors and human activities.

The minimal average annual change of approximately -0.2% emphasizes the ongoing stability and potential adaptability of Sand Dunes, contributing to the overall landscape constancy observed in this land cover class.

The findings from the comprehensive analysis of land cover and land use dynamics in Greater Yola between the periods 2013 to 2018 and 2018 to 2023 carry significant implications for urban planning, environmental management, and sustainable development in the region.

The pronounced spatial expansion of Built-up Areas between 2013 and 2018, coupled with a sustained and accelerating pace of urbanization, signifies a transformative phase in the region. This trend suggests a response to factors such as population growth, economic activities, and strategic infrastructure investments, pointing towards a rapidly evolving urban landscape.

The additional 37.2% increase in Built-up Area between 2018 and 2023 indicates a continued trajectory of targeted urban development. This sustained transformation highlights the region's commitment to urban growth, potentially influenced by ongoing economic and demographic changes.

The stability of Waterbody coverage during both periods indicates environmental resilience. This resilience may be attributed to effective water management practices, natural features, or a combination of both. Understanding this stability is crucial for sustainable water resource management in the face of urban expansion.

The Vegetation's notable decrease indicates great anthropogenic impacts or variations in land management practices between 2013 and 2018. However, the stabilization and minor decrease in Vegetation coverage between 2018 and 2023 imply adaptive responses to environmental changes or stabilization of land management practices.

The stability of Sand Dunes with minor percentage fluctuations underscores their resilience to environmental factors and human activities. The minimal annual change emphasizes ongoing stability, highlighting the potential adaptability of Sand Dunes in the face of changing conditions.

The significant increase in Open Spaces between 2013 and 2018 *is* as a result of the loss of vegetation during this period. This signifies the unintended consequence of urban development, where open spaces emerged due to the removal of vegetation. The annual average change of +30.0% underscores a proactive approach in maintaining open areas amidst rapid urban growth but highlights the ecological cost.

The slight 0.2% decrease in Open Spaces signifies evolving strategies in urban planning and open space preservation. The nuanced annual average decrease of about -0.04% reflects an attempt to strike a balance between urban development and conservation, perhaps addressing the unintended consequence observed in the earlier period.

The complexities in balancing urban development, vegetated areas and open space conservation are evident. The region faces challenges in maintaining vegetated areas amidst urban expansion, as seen in the fluctuations and decrease in Vegetation and increase in Open Spaces over time.

The nuanced average annual decrease of about -0.04% in Open Space coverage between 2018 and 2023 emphasizes the ongoing challenges in achieving a delicate equilibrium between urban development and the preservation of open areas.

3.6. Discussion of Results

The findings regarding the land cover and land use dynamics in Greater Yola between 2013, 2018, and 2023 provide critical insights into the region's environmental changes and their implications for ecosystem diversity. Analysing these results reveals significant trends and raises important considerations for sustainable development goals.

Expansion of Built-up Areas and Urbanization: The substantial increase in Built-up Areas over the studied period underscores the rapid pace of urbanization in Greater Yola. This trend signifies a transformation in the landscape, driven by factors such as population growth and economic development. However, the expansion of built-up areas comes at the expense of natural habitats, potentially leading to habitat loss and fragmentation, which can negatively impact ecosystem diversity.

Implications for Sustainable Development Goals (SDGs): This trend aligns with SDG 11 (Sustainable Cities and Communities), which aims to make cities inclusive, safe, resilient, and sustainable. However, it also highlights the need to balance urban development with environmental conservation to achieve SDG 15 (Life on Land), which aims to protect, restore, and promote the sustainable use of terrestrial ecosystems.

Changes in Vegetation Cover: The decrease in Vegetation cover observed between 2013 and 2018 raises concerns about the loss of natural vegetation and its implications for biodiversity. While the stabilization of Vegetation cover between 2018 and 2023 suggests potential adaptive responses or stabilization in land management practices, continued monitoring and conservation efforts are necessary to ensure the resilience of vegetated ecosystems.

Implications for Sustainable Development Goals (SDGs): The decline in Vegetation cover emphasizes the importance of SDG 15, particularly target 15.1, which aims to ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems. Efforts to halt deforestation and promote sustainable land management practices are essential to achieve this goal.

Conservation of Open Spaces: The increase in Open Spaces between 2013 and 2018, followed by a slight decrease between 2018 and 2023, highlights the complex relationship between urban development and open space conservation. While the initial rise in Open Spaces may indicate efforts to preserve green areas amidst urban expansion, the subsequent decrease underscores the challenges in maintaining this balance over time.

Implications for Sustainable Development Goals (SDGs): Balancing urbanization with the preservation of open spaces is essential for achieving multiple SDGs. It contributes to SDG 11 by ensuring sustainable urban development and SDG 15 by preserving ecosystems and biodiversity. Additionally, access to green spaces promotes health and well-being, aligning with SDG 3 (Good Health and Well-being).

Stability of Waterbodies and Sand Dunes: The stability observed in Waterbody and Sand Dune coverage throughout the studied period reflects the resilience of these ecosystems to environmental changes and human

activities. Preserving these natural features is crucial for maintaining ecosystem functions, supporting biodiversity, and mitigating the impacts of climate change.

Implications for Sustainable Development Goals (SDGs): Protecting waterbodies and natural landscapes aligns with various SDGs, including SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15. Conservation efforts should focus on preserving these ecosystems and ensuring their sustainable management to achieve these goals effectively.

4. Conclusion

The examination of land cover and land use dynamics in Greater Yola underscores a pronounced trend of rapid urbanization and habitat transformation throughout the analyzed period. The expansion of built-up areas, often at the expense of natural vegetation, highlights the substantial challenges posed by urban development to both ecosystem diversity and resilience.

Moreover, the observed alterations in land cover, such as the decline in vegetation cover and fluctuations in open space conservation, carry significant implications for ecosystem diversity within Greater Yola. The loss of natural habitats and the resulting fragmentation of ecosystems pose substantial threats to biodiversity and essential ecosystem services, emphasizing the critical need for conservation efforts.

Achieving a delicate equilibrium between urban development and environmental conservation emerges as a pivotal aspect for sustainable development in Greater Yola. While urbanization serves as a catalyst for economic growth and societal advancement, it must be carefully managed to mitigate adverse impacts on ecosystems and ensure long-term environmental sustainability.

The insights gleaned from this study offer valuable guidance for policymakers and stakeholders engaged in urban planning, environmental management, and sustainable development initiatives in Greater Yola. It is imperative that policies and strategies prioritize ecosystem conservation, advocate for the implementation of green infrastructure, and integrate principles of sustainable land use planning to counteract the detrimental effects of urbanization on ecosystem diversity.

Lastly, continual monitoring of land cover dynamics and ecosystem health is imperative to monitor temporal changes and facilitate adaptive management strategies. This necessitates the implementation of measures aimed at conserving critical habitats, rehabilitating degraded landscapes, and fostering sustainable land management practices to bolster ecosystem resilience and safeguard biodiversity conservation efforts.

Based on the findings and conclusions drawn from the analysis, the following recommendations are proposed to guide policymakers and stakeholders in fostering sustainable development and conserving ecosystem diversity:

1. Incorporate principles of ecosystem conservation into urban planning processes to ensure that development initiatives prioritize the preservation of natural habitats and green spaces. This can be achieved through the establishment of protected areas, green corridors, and zoning regulations that safeguard ecologically sensitive areas from encroachment.

2. Encourage the implementation of green infrastructure projects, such as urban parks, green roofs, and permeable pavements, to enhance ecosystem services, mitigate urban heat island effects, and promote biodiversity within urban areas. Green infrastructure initiatives can also provide recreational opportunities for residents and improve overall quality of life.

3. Raise awareness among the local community about the importance of ecosystem conservation and the benefits of sustainable land use practices. Implement educational programs, workshops, and outreach activities to engage residents, schools, and community groups in environmental stewardship efforts.

4. Promote sustainable agriculture practices that minimize habitat destruction, soil erosion, and water pollution. Encourage the adoption of agroecological approaches, such as organic farming, agroforestry, and integrated pest management, to enhance biodiversity, soil fertility, and resilience to climate change.

5. Develop and implement comprehensive land use planning and management strategies that balance urban development with the protection of natural ecosystems. This may involve land zoning, land-use regulations, and incentive-based programs to encourage sustainable land management practices and discourage habitat destruction.

6. Allocate resources for the continual monitoring of land cover dynamics, ecosystem health, and biodiversity trends within Greater Yola. Support research initiatives that focus on understanding the impacts of urbanization on ecosystems and identifying effective conservation strategies to mitigate negative effects.

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