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Advancing Social Science Teaching Through GIS-Based Mapping and Forecasting of LULC Changes of Recreational Parks in Durban Metropolis

Tolulope Ayodeji Olatoye*[a] & Raymond Nkwenti Fru[a]

* Corresponding author
Email: Tolulope.olatoye@spu.ac.za

a. Department of Human Science, Faculty of Education, Sol Plaatje University, Kimberley, Province of the Northern Cape, South Africa

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ABSTRACT

This study examines the spatio-temporal and projected dynamics of land use and land cover (LULC) changes in Durban Metropolis, South Africa. The research problem focuses on the growing tension between urban sprawl and the ecological sustainability of recreational parks in Durban Metropolis. As rapid urban expansion continues to encroach upon the recreational green spaces, it exacerbates degradation, threatening biodiversity and undermining ecosystem resilience. This study's significance extends to Higher Educational Institutions (HEIs) by demonstrating how GIS technology can be integrated into research, teaching, and learning to enhance environmental literacy and promote sustainable development principles. This research also contributes to bridging the gap between environmental research and pedagogy, empowering educators and students to engage actively in ecosystem conservation. The study adopts the Place-Based Education (PBE) Frameworks, providing a foundation for understanding the interconnectedness between societies and ecosystems, thereby aligning well with the study's emphasis on advancing environmental education. A quantitative research approach was employed, combining GIS-based spatial analysis of satellite imagery with quantitative data. Base maps from 2004, 2014, 2024 and projections for 2034 for 9 major parks were analyzed to project trends in vegetation loss and urban LULC for the study area in 2034, highlighting areas of significant ecological concern. Findings emphasize continued pressure on green spaces, underscoring the urgent need for conservation strategies. The study recommends integrating GIS-based tools in teaching sustainable urban development, fostering critical thinking, and promoting place-based learning to equip students with skills for analyzing and addressing real-world environmental challenges.

KEYWORDS

Ecological sustainability; ecosystem resilience; geo-spatial technology; social science teaching; recreational parks; urban sprawl.

INTRODUCTION

According to Olatoye, (2020), urbanization and rapid population growth have significantly transformed land use and land cover (LULC) patterns, often at the expense of natural ecosystems and green spaces such as recreational parks. Recreational parks play a crucial role in enhancing urban resilience by providing essential ecosystem services, promoting biodiversity, and improving the quality of life for urban residents (Wang et al., 2024). In addition, they serve as vital resources for advancing environmental education, fostering awareness of sustainable living, and cultivating a sense of environmental stewardship (Pandey & Ghosh, 2023).

The interaction between urbanization and land use changes, particularly in rapidly growing cities like Durban, South Africa, is an increasingly critical area of study. The global trend of urban expansion, driven by population growth and industrialization, has placed significant pressure on natural ecosystems, including essential green spaces like recreational parks (Olatoye, 2020). These parks, integral to maintaining biodiversity, enhancing urban resilience, and supporting public well-being, are facing unprecedented challenges from urban sprawl. The importance of such spaces cannot be overstated, as they offer invaluable ecosystem services—improving air quality, promoting recreational opportunities, and providing a sanctuary for both people and wildlife (Wang et al., 2024).

Internationally, the literature highlights a growing awareness of the role that urban green spaces play in fostering sustainable cities. According to Pandey and Ghosh (2023), these spaces not only support biodiversity but also serve as educational resources—teaching communities about sustainability and ecological stewardship. In rapidly urbanizing regions, this dual role of green spaces—preserving nature while serving educational purposes—has become a focal point for both urban planners and educators (Mahmoudi et al., 2022). Such findings are essential for understanding how land use and land cover (LULC) shifts impact urban parks and their potential as environmental education assets. Locally, Durban represents an ideal case study for understanding these dynamics. The city, marked by a combination of rapid urban growth and rich biodiversity, faces significant LULC changes that threaten the integrity and functionality of its green spaces (Mazeka et al., 2021). As noted by McLean et al. (2024), the increasing pressure on land resources in Durban, particularly within its recreational parks, poses substantial challenges to sustainability efforts. The city's green spaces, which provide vital services like carbon sequestration and recreational areas for urban residents, are being reduced in both size and quality due to urban expansion. Thus, this study builds on a growing body of international and regional research, aligning with the work of Li et al. (2021), who identified the necessity of reliable spatial data for managing LULC dynamics in urban settings. Their work emphasizes the critical role that spatially explicit data plays in preserving the functionality and accessibility of green spaces, particularly in cities like Durban, where urbanization is rampant. However, despite these findings, gaps remain in integrating spatial data with environmental education, an area this study seeks to address through GIS-based mapping and forecasting techniques.

A key gap identified in the literature is the lack of context-specific teaching resources linking environmental education to urban green spaces' actual conditions (Brudvig & Catano, 2024). Without robust and accessible data on the spatio-temporal dynamics of LULC changes, educators and urban planners are left with insufficient tools to address the loss of ecological services in urban parks. In addition, the difficulty in engaging communities through environmental education initiatives is compounded by limited access to green spaces and disconnection between educational programs and the lived experiences of urban dwellers (Krasny, 2020). This study, by incorporating GIS-based methods, not only addresses the spatial analysis of LULC but also enhances the relevance of environmental education by providing actionable insights for policymakers and educators alike. In synthesizing the international literature with regional specifics, this study applies the Place-Based Education (PBE) framework, which emphasizes the importance of using local environments, such as recreational parks, as active learning spaces. PBE is recognized for its ability to connect learners with their surroundings, fostering a deeper understanding of ecological issues through direct engagement with the local environment (Pamukcu-Albers et al., 2021). By examining LULC changes within the context of Durban's urban parks, this research links environmental education with urban planning, ensuring that learners and the broader community understand the importance of sustainable land use in the face of rapid urbanization.

The increasing pressure on land resources in urban centers, including Durban Metropolis, poses significant challenges to the sustainability and functionality of these green spaces. Durban, a rapidly urbanizing city in South Africa, boasts a unique mix of biodiversity and urban development (Mazeka et al., 2021), making it an ideal location to investigate the dynamics of LULC changes in recreational parks. Understanding how these changes occur over time is critical for implementing strategies to conserve green spaces, enhance urban ecosystem resilience, and ensure equitable access to recreational areas (McLean et al. 2024). This study is highly relevant to environmental education as it provides spatial insights into the state and dynamics of urban green spaces, enabling educators to design context-specific programs that foster ecological awareness and sustainable practices. Additionally, it contributes to social science teaching by highlighting the interconnectedness between urban development, ecosystem resilience, and societal well-being, equipping learners with practical knowledge to address environmental challenges in real-world contexts. Geographic Information System (GIS)-based mapping and forecasting techniques offer robust tools for analyzing spatiotemporal LULC dynamics, enabling policymakers, urban planners, and environmental educators to make informed decisions about land use management (Abraham & Kundapura, 2022; Olatoye et al., 2022). This study aims to employ GIS-based approaches to map and forecast LULC changes in Durban's recreational parks, with a particular focus on their implications for environmental education and ecosystem resilience. By analyzing historical trends and predicting future scenarios, this research seeks to underscore the importance of preserving recreational parks as critical urban assets. Furthermore, the study highlights the potential of environmental education in promoting

sustainable urban development and fostering community engagement in environmental conservation. Ultimately, the findings of this research will contribute to shaping policies and practices that balance urban growth with environmental sustainability in Durban Metropolis.

Urban recreational parks are critical assets for enhancing ecosystem resilience, biodiversity conservation, and the well-being of urban populations (Mahmoudi et al 2022). These green spaces provide invaluable opportunities for recreation, community engagement, and environmental education, fostering a deeper understanding of sustainable practices and ecological stewardship (Mkhize, 2023; Pamukcu-Albers et al., 2021). However, in Durban Metropolis, rapid urbanization, population growth, and competing land use demands are driving significant changes in LULC, threatening the availability and functionality of these vital urban green spaces. Despite their importance, there is limited comprehensive knowledge on how LULC changes are affecting the spatial extent, quality, and accessibility of recreational parks in Durban. According to Li et al. (2021), these LULC changes have far-reaching implications not only for urban ecosystems but also for the integration of environmental education into community and school programs. Challenges in environmental education, such as limited access to green spaces, lack of context-specific teaching resources, and insufficient stakeholder engagement, further exacerbate the difficulty of promoting ecological awareness and sustainable practices. In particular, the absence of reliable spatial data and forecasting models hinders effective planning and policymaking to preserve recreational parks (Brudvig & Catano, 2024), Durban inclusive. Without a clear understanding of the historical and future dynamics of LULC changes in these parks, urban planners and educators face significant obstacles in balancing urban development with ecological sustainability. Furthermore, the disconnect between environmental education initiatives and the lived experiences of urban communities limits the potential for fostering a culture of environmental stewardship and sustainability (Krasny, 2020). It is on this premise that this study addresses these critical gaps by employing GIS-based mapping and forecasting techniques to analyze LULC changes in Durban's recreational parks. It also seeks to explore how the degradation or loss of these parks undermines environmental education efforts, limiting their impact on urban communities.

Aim and Questions of the Study

This study aims to enhance social science teaching by utilizing GIS-based mapping and forecasting to examine land use and land cover changes in Durban's recreational parks, emphasizing their significance for environmental education and urban ecosystem sustainability.

Research Question of the Study: how can GIS-based mapping and forecasting be used to examine land use and land cover changes in Durban's recreational parks, with a particular emphasis on their role in enhancing social science teaching, environmental education, and promoting urban ecosystem sustainability?

Significance of Study

This study is significant for several reasons, particularly in its contribution to environmental education, social science teaching, and sustainable urban planning. By employing GIS-based

mapping and forecasting techniques to analyze land use and land cover (LULC) changes in recreational parks within Durban Metropolis, the research provides valuable insights into the spatial and temporal dynamics of urban green spaces. These insights are critical for fostering informed decision-making in urban planning, as they help policymakers and stakeholders understand the implications of LULC changes on ecosystem resilience, biodiversity conservation, and social well-being. In a rapidly urbanizing city like Durban, where green spaces face immense pressure from competing land uses, such knowledge is essential for designing sustainable development strategies that balance urban growth with environmental preservation. In the field of environmental education, this study highlights the role of recreational parks as critical learning environments for fostering ecological awareness and sustainability practices. Parks serve as living laboratories where communities and learners can engage with real-world environmental issues, deepening their understanding of the relationship between societies and nature. By uncovering the threats posed to these parks by LULC changes, the study emphasizes the need to integrate spatial data and forecasting tools into environmental education programs. This can enhance the effectiveness of teaching and inspire action-oriented solutions among learners, equipping them with the knowledge and skills needed to address contemporary environmental challenges. Moreover, the study makes a significant contribution to social science teaching by linking urban land dynamics to broader societal and ecological themes. According to Barth (2020), recreational parks provide a platform for exploring interdisciplinary concepts such as urban resilience, ecosystem services, and the social benefits of green spaces. By investigating the decline or transformation of these spaces, the research offers a practical case study that educators can use to illustrate the interconnectedness of environmental, social, and economic systems. This approach not only enriches the teaching of social science but also prepares learners to critically analyze and respond to the complexities of urbanization and environmental sustainability. Ultimately, this study has the potential to influence policies and practices of recreational parks, ensuring their continued role as vital urban assets. It underscores the importance of using advanced technologies such as GIS in urban management and education to promote a sustainable future.

THEORETICAL FRAMEWORK

The Place-Based Education (PBE) Theoretical Framework

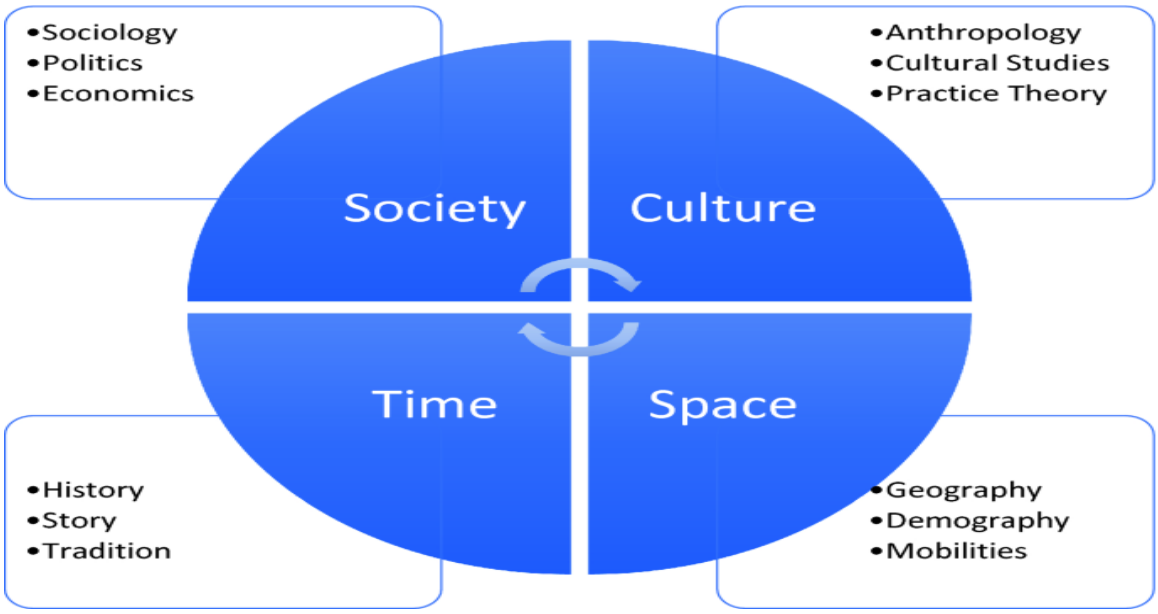
The Place-Based Education (PBE) Framework is a dynamic and context-rich approach to education that offers a compelling theoretical foundation for studies involving LULC and urban management. Rooted in the belief that learning should be connected to the local environment, PBE emphasizes the importance of immersive, real-world educational experiences that empower learners to engage directly with their surroundings. This framework places the local community, its geography, history, culture, and ecology at the heart of the educational experience. In doing so, it provides a powerful lens through which the complexities of urban development, land-use changes, and environmental sustainability can be explored. PBE does

not just focus on traditional classroom learning; it encourages students to analyze their immediate environment as both a classroom and a subject of study, particularly in the context of urban landscapes and ecological dynamics. At its core, PBE brings an interdisciplinary approach to understanding how local landscapes and ecosystems interact with human development. In the context of LULC studies and urban management, PBE offers a unique methodology that emphasizes contextual learning and sustainable urban planning. It encourages students and researchers to directly observe and interact with urban spaces, allowing them to study the dynamic relationships between land use, ecological processes, and urban growth. Through this framework, the focus shifts to hands-on engagement with local communities and environments, fostering an understanding of the real-world implications of urbanization, land-use change, and environmental sustainability. PBE encourages students to see urban parks, green spaces, and other local landscapes not just as isolated entities, but as integral parts of the larger urban ecosystem. It challenges traditional approaches to urban management by pushing for a more holistic view of land-use planning that includes both ecological health and community engagement. By immersing learners in real-world contexts, PBE cultivates an understanding of how land use patterns impact environmental resilience and the quality of urban life. This makes PBE especially relevant for studies investigating the interactions between urban development and natural resources, such as urban green spaces and recreational parks. Figure 1 depicts the PBE Framework.

Figure 1 depicts the PBE multidimensional framework integrating society, culture, space, and time to explore the dynamics of LULC changes in recreational parks within Durban Metropolis. Each dimension offers a critical lens for understanding how these parks evolve and their implications for urban development, environmental education, and ecosystem resilience. The societal dimension examines the influence of social structures, governance, and economic activities on park accessibility and preservation, shedding light on how inequalities and political decisions shape their utilization. The cultural dimension underscores the role of shared values, traditions, and practices in fostering environmental stewardship, highlighting how parks contribute to community identity and learning. The spatial dimension leverages GIS-based mapping and forecasting to reveal how urban expansion and demographic changes impact the spatial distribution and ecological health of these parks in the study area. Finally, the temporal dimension delves into historical trends, illustrating how decades of urbanization have reshaped green spaces while forecasting future scenarios for sustainable management. By interconnecting these dimensions, this study offers a comprehensive approach that moves beyond spatial analysis to address the social, cultural, and historical factors influencing park management. This integrative perspective not only enhances environmental education and social science teaching but also provides actionable insights for policymakers and urban planners striving to balance urban growth with the conservation of green spaces.

Figure 1.

The Place-Based Education (PBE) Framework (Source: Corbett, 2020).



The study of Durban's recreational parks offers a perfect example of how the PBE framework can be applied to LULC studies and urban sustainability. The parks in Durban, as both ecological and recreational assets, provide a rich context for investigating the intricate relationships between urban expansion, environmental sustainability, and community well-being. Using PBE as a theoretical lens, this study goes beyond analyzing parks as mere spaces for leisure; it positions them as living classrooms that serve as microcosms for larger urban dynamics. Through hands-on exploration of these parks, the study links land-use changes with ecological health, and shows how urban management practices can influence the quality and accessibility of urban green spaces. Hence, it is germane to state that Durban's recreational parks function as integral components of the urban landscape and thus ensuring that the theory aligns with the study, which also encourages learners and urban planners to engage directly with these spaces to understand the impact of urbanization on both the built and natural environment. The parks offer a unique opportunity to observe firsthand how land cover changes, such as increased urban sprawl or the expansion of built-up areas, can affect biodiversity, vegetation health, and ecosystem services. This direct engagement with the environment through PBE also enables a deeper understanding of sustainable land-use practices, showing how recreational areas can be preserved or enhanced amidst growing urban pressures.

The Connection Between PBE, LULC Changes, and Urban Sustainability: The PBE framework provides a robust theoretical foundation for exploring and understanding the complex interactions between land use and urban growth. By applying PBE to the study of LULC changes in Durban, this research taps into the framework's core principles of contextual learning, interdisciplinary exploration, and community engagement. The study highlights how sustainable urban management practices can be informed by local environmental knowledge, emphasizing

that educational systems and policy frameworks must engage directly with the lived realities of urban populations. Through the lens of PBE, the study also underscores the importance of community involvement in urban planning, showing how local residents, policymakers, and urban planners can work together to manage the urban landscape in a way that promotes sustainability, ecological health, and equitable access to green spaces. PBE's emphasis on hands-on, localized learning not only improves educational outcomes but also fosters environmental stewardship among residents and future urban planners. This approach aligns perfectly with the goals of LULC studies, which aim to assess and manage land resources in a way that balances developmental needs with environmental preservation. Hence, through this compelling framework, the study underscores the critical role of recreational parks in advancing sustainable urban development and fostering ecological awareness.

RESEARCH METHODOLOGY

The methodology for this study was designed to ensure a robust, data-driven approach to mapping, analyzing, and forecasting LULC changes in the major recreational parks within Durban Metropolis. By integrating advanced geospatial techniques with qualitative insights, the research aimed to provide actionable solutions that balance urban development with the conservation of green spaces. A duo mixed-methods approach was employed, combining GIS-based spatial analysis, and quantitative analysis to achieve the aim of study. The methodological steps followed in the study are the following:

Study Area Delimitation and Data Collection: The first phase involved delimiting the boundaries of the study area within Durban Metropolis, focusing specifically on recreational parks and surrounding urban zones. Landsat High-resolution satellite imageries were obtained online from the United States Geological Surveys (USGS) spanning the past two decades (2004–2024) were obtained to enable spatio-temporal analysis of changes.

GIS-Based Mapping of Recreational Parks: Using state-of-the-art GIS software (ArcGIS 10.8 version), the study mapped the spatial distribution of recreational parks in Durban Metropolis. Landsat 5 TM for 2004, Landsat 8 and 9 OLI/ TIRS for 2014 and 2024 with path 168 and row 81 82 were spatially georeferenced with a spatial resolution of 30m. The radiometric correction was done and then the raster was clipped to the extent of the study area. The multispectral composite was done to prepare the data for image classification. This process involved supervised classification techniques to identify distinct LULC categories, such as built-up areas, green spaces, and water bodies. The maps revealed historical trends in park expansion, contraction, or fragmentation, providing a visual representation of how urbanization had influenced green spaces over time. Special attention was paid to identifying hotspots of park degradation or encroachment.

Predictive Modeling and Forecasting: To predict future LULC changes, the study employed machine learning algorithms to simulate future scenarios, enabling the projection of green space availability and distribution by 2034. Forecasting results highlighted areas at risk of losing

recreational parks due to urban sprawl, guiding policymakers toward proactive interventions. The reliability of these models was tested through accuracy assessments using metrics such as the Kappa coefficient.

Field Surveys and Ground Truthing: Field surveys were conducted to validate the results of the GIS-based analysis. Ground truthing involved physically visiting selected recreational parks to verify their current status, assess levels of accessibility, and identify visible threats, such as illegal dumping or invasive species. These observations enhanced the accuracy of the spatial analysis and provided qualitative insights into the socio-ecological challenges faced by these parks.

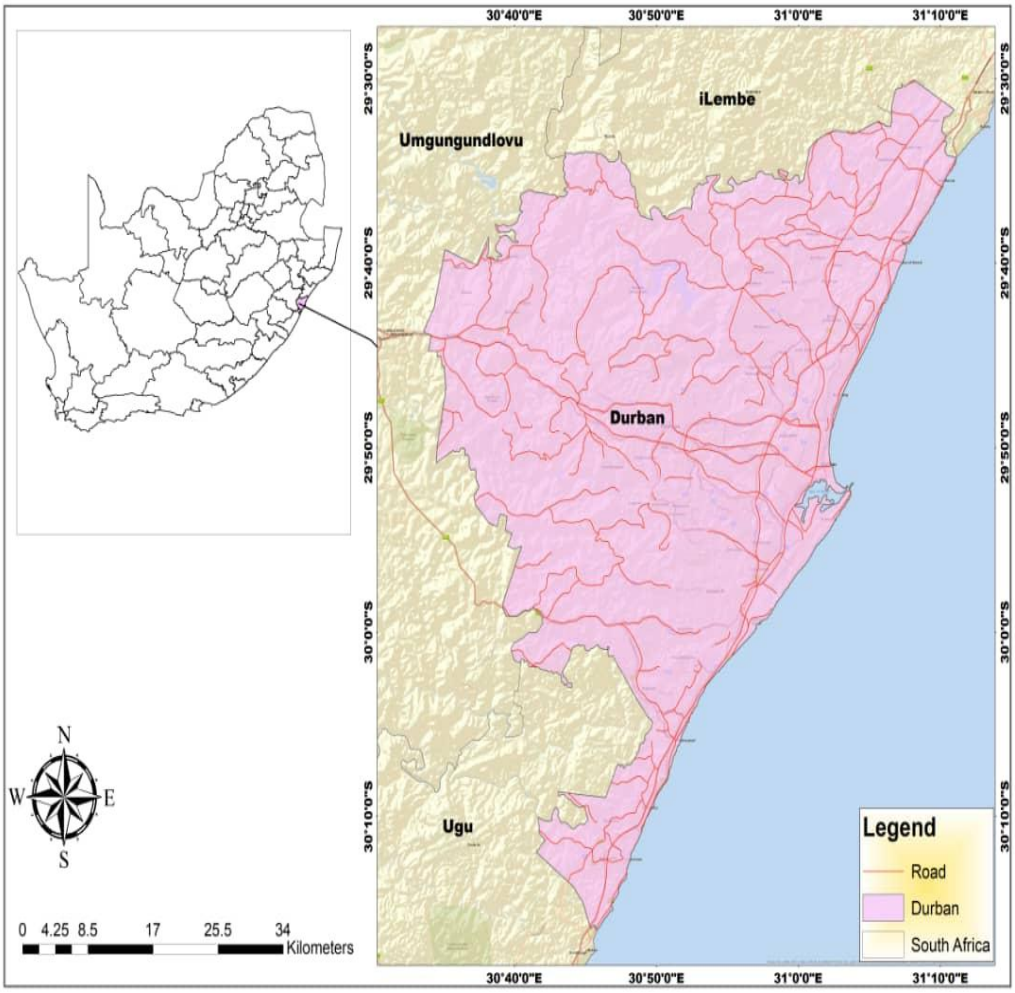
Integration with Environmental Education: A unique aspect of this study was its focus on integrating findings into environmental education. Based on spatial and qualitative insights, educational materials were developed to enrich social science teaching. These materials emphasized the significance of Durban's recreational parks as critical resources for learning and sustainability.

Data Analysis and Visualization: Quantitative data from GIS analyses were analyzed to ensure comprehensive insights. The results were presented using engaging maps, making the findings accessible to a wide audience. Comparative analyses highlighted variations in park management practices across Durban, identifying best practices and areas for improvement. To guarantee the accuracy and reliability of the LULC analysis, verification was performed using two essential indices: the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI).

The Study Area

The study focused on Durban Metropolis, the third-largest city in South Africa, known for its coastal location, rapid urbanization, and demographic diversity (McBride, 2022). Durban, located on the eastern coast of South Africa, has a subtropical climate, characterized by mild, wet winters and hot, humid summers. The city is known for its warm temperatures, high humidity, and rainfall, influenced by its proximity to the Indian Ocean (Bond and Galvin, 2023). Durban is situated at approximately 29.8587° S latitude and 31.0218° E longitude on the southeastern coast of South Africa (Ndlovu et al. 2021). This strategic location places it along the eastern seaboard, making it one of the country's most important port cities. Durban's geographical positioning contributes significantly to its tropical climate and its status as a major commercial hub. Durban's climate is classified as humid subtropical (Cfa) according to the Köppen climate classification system (Mgadle, 2022). This type of climate is characterized by warm, humid summers and average temperatures ranging from 24°C (75°F) to 30°C (86°F) during the summer months (November to March), with highs occasionally exceeding 30°C (86°F). The heat is often tempered by sea breezes from the Indian Ocean, providing some relief from the intense heat, while the winter season (June to August) are warm and pleasant, with average daytime temperatures ranging between 14°C (57°F) and 25°C (77°F) (Abel, 2022). Figure 2 depicts the Map of the Study Area.

Figure 2. *Map of the Study Area (Source: Authors)*



ANALYSIS OF RESULTS

LULC Processing of Satellite Imagery

Satellite imagery from Landsat 7 ETM (2004), alongside Landsat 8 and 9 OLI/TIRS (2014 and 2024), covering Path 168 Row 081 and Path 168 Row 080, was carefully georeferenced with a spatial resolution of 30 meters. The satellite data, spanning the study period (2004–2024), was collected in November 2024. To ensure optimal quality, radiometric corrections were applied, followed by clipping the raster datasets to conform precisely to the study area's boundaries. The imagery was further refined by resampling to a 5-meter pixel resolution, reducing potential distortions or errors, a practice validated by research from Mekasha et al. (2020) and Li et al. (2020). A multispectral composite was then constructed, preparing the data for advanced image classification techniques.

Image Classification

A supervised image classification technique was employed within the ArcGIS 10.8 software environment, a crucial tool for analyzing temporal LULC changes. This method leveraged training algorithms and labeled data to enhance the precision of identifying and mapping transformations. The imagery was classified into six unique land cover categories: built-up areas, agricultural land, grassland, dense vegetation, water bodies, and barren land, each

differentiated by their distinct spectral signatures. Training samples were meticulously drawn from the composite image to generate classification signatures. Using the maximum likelihood algorithm, pixel values were assigned to the most probable land cover class based on their spectral attributes, aligning with methodologies proposed by Adesina et al. (2024). The resulting classification, illustrated in Figure 3, presents a detailed representation of the LULC patterns for the study area in 2004. This workflow not only ensures data integrity but also enhances the reliability of detecting and analyzing LULC changes, making it a cornerstone of robust spatial analysis and environmental monitoring.

Recreational Parks Identified for the Study

The study identified 10 key recreational parks that stand out for their ecological, cultural, and recreational significance: Beachwood Mangroves Nature Reserve, Durban Botanical Gardens, Durban North Japanese Gardens, Jameson Park, Kenneth Stainbank Nature Reserve, Mitchell Park Zoo, Natal Sharks Board, Phezulu Safari Park, Queen Elizabeth Grassland, and Umgeni River Bird Park.

Beachwood Mangroves Nature Reserve (BMNR)

BMNR spans approximately 76 square hectares and serves as a sanctuary for one of Durban's rare mangrove ecosystems. This protected area is home to three distinct mangrove species, as well as an array of aquatic life, including crabs and fish thriving in its tidal estuaries. Visitors can traverse wooden walkways that wind through the reserve, offering a close-up view of this fragile coastal environment and its vibrant birdlife. The LULC distribution trends for BMNR over the study period are presented in Table 1.

Table 1 reveals that the BMNR has undergone notable LULC changes over the years, with projections indicating continued shifts up to 2034. Dense vegetation, which covered 18.45 Ha^2 in 2004, slightly declined by 2014 but rebounded significantly to 28.92 Ha^2 in 2024, with further growth projected to reach 29.92 Ha^2 in 2034, reflecting successful conservation and regrowth efforts. Grassland, on the other hand, has steadily declined from 19.28 Ha^2 in 2004 to 11.31 Ha^2 in 2024, with a minor reduction expected by 2034, likely due to natural succession and encroachment by dense vegetation. Waterbodies remained relatively stable from 2004 to 2014, with a slight increase to 18.30 Ha^2 in 2024, but are projected to decrease to 16.30 Ha^2 by 2034, potentially due to sedimentation or social activities. Barren land peaked at 24.05 Ha^2 in 2014 before decreasing to 16.11 Ha^2 in 2024, with a slight rise to 17.11 Ha^2 expected in 2034, signifying restoration efforts and urban impacts. The built-up area, initially minimal at 0.90 Ha^2 in 2004, declined in 2014 but increased significantly to 1.92 Ha^2 in 2024 and is projected to grow to 2.52 Ha^2 by 2034, indicating rising infrastructural development within the reserve. Figure 3 depicts the LULC classification for BMNR from 2004-2034.

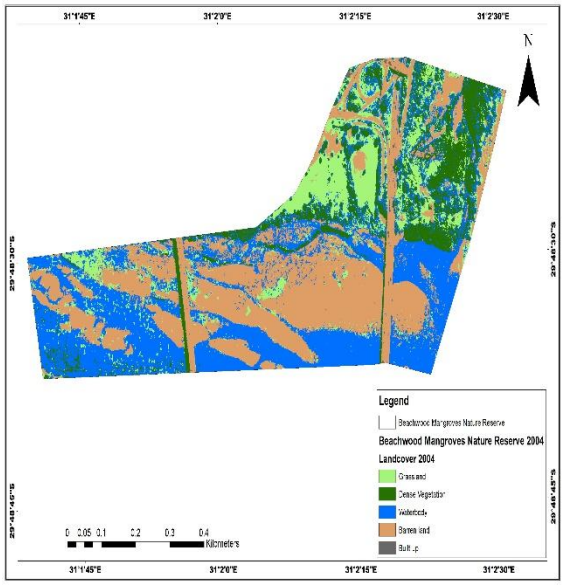
Table 1.

The Projected LULC Distribution-Beachwood Mangroves Nature Reserve (BMNR) 2004-2034.

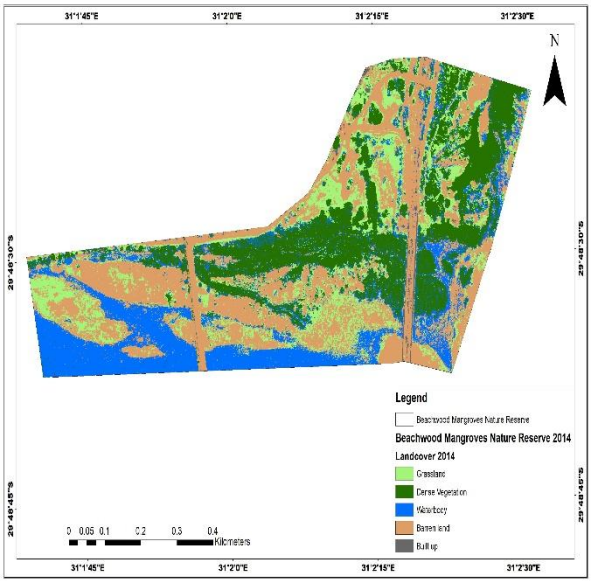
S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	18.4494	18.4326	28.9193	29.9193
2.	Grassland	19.2787	15.9809	11.3135	11.4135
3.	Waterbodies	17.3528	17.2933	18.2973	16.2973
4.	Barren Land	19.2784	24.0498	16.1092	17.1092
5.	Built-Up Area	0.9039	0.3156	1.9236	2.5236

Figure 3.

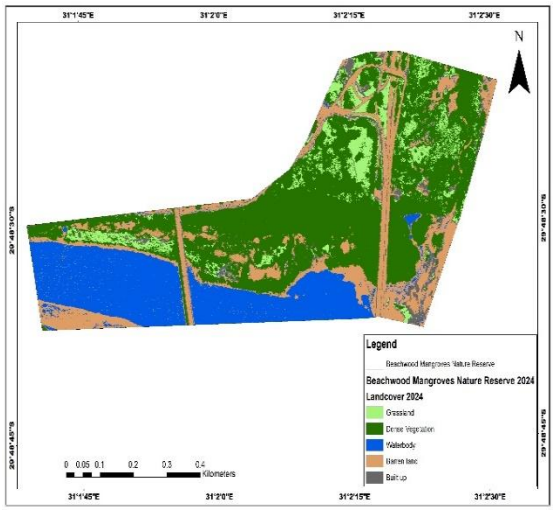
The LULC classification for BMNR from 2004-2034



2004



2014



2024

2034

Durban Botanical Gardens (DBG)

Founded in 1849, DBG stands as Africa's oldest botanical garden still in existence, embodying a rich legacy of biodiversity and heritage. Spanning an impressive 15 hectares, it boasts an

extraordinary array of flora, including rare cycads, exotic orchids, and towering palms. Its serene landscapes, complete with tranquil lawns, enchanting butterfly gardens, and the renowned Garden of the Senses, create a perfect retreat for picnics, gatherings, and moments of relaxation. Beyond its beauty, the gardens serve as a hub for cultural and ecological engagement, offering educational workshops, live concerts, and guided tours that immerse visitors in its splendor. Table 2 highlights the LULC distribution for DBG from 2004 to 2034.

Table 2.

The LULC distribution for Durban Botanical Gardens (DBG) 2004-2034.

S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	5.1189	5.1068	5.0305	5.0119
2.	Grassland	4.0670	5.1076	3.6055	4.9450
3.	Waterbodies	0.4302	0.3303	0.1861	0.1662
4.	Barren Land	1.1198	0.5979	0.2527	0.4529
5.	Built-Up Area	5.3190	5.7186	7.9803	8.9803

Figure 4.

LULC classification for Durban Botanical Gardens from 2004-2034

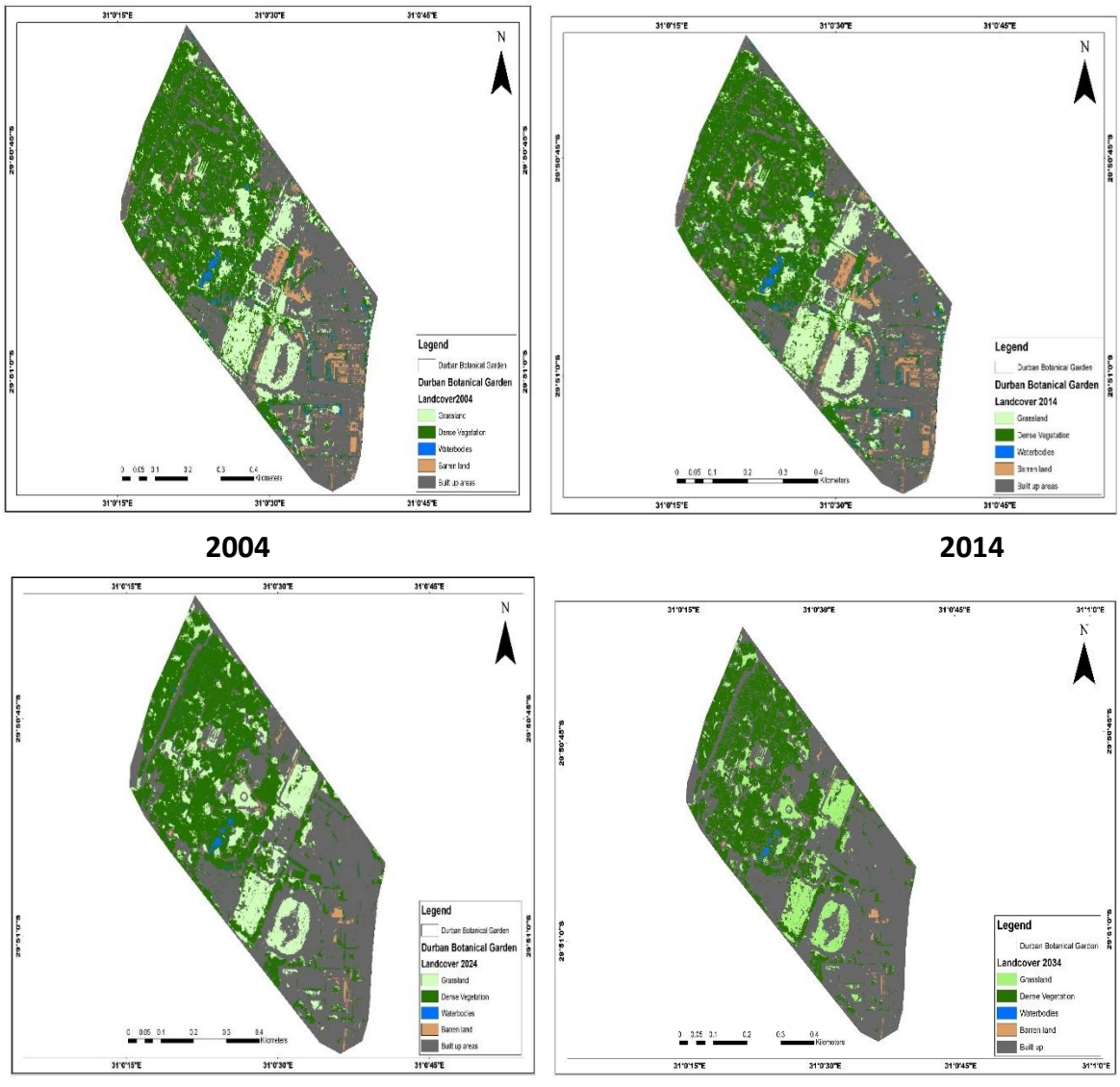


Table 2 reveals that DBG has experienced and is projected to continue undergoing significant LULC transformations from 2004 to 2034, reflecting shifts in land management priorities and urban development. Dense vegetation, a hallmark of the gardens, showed a slight decline from 5.12 Ha² in 2004 to 5.03 Ha² in 2024, with a projected reduction to 5.01 Ha² in 2034, likely due to encroachment by other land-use types or adjustments in landscaping practices. Grassland areas, which initially measured 4.07 Ha² in 2004, experienced fluctuations, peaking at 5.11 Ha² in 2014, before reducing to 3.61 Ha² in 2024. However, a recovery to 4.95 Ha² is anticipated by 2034, possibly due to restoration efforts aimed at enhancing green spaces. Waterbodies within the gardens have steadily diminished, shrinking from 0.43 Ha² in 2004 to 0.19 Ha² in 2024, with a further reduction to 0.17 Ha² projected for 2034, potentially due to infilling or water management challenges. Barren land has decreased significantly from 1.12 Ha² in 2004 to 0.25 Ha² in 2024, though it is expected to increase slightly to 0.45 Ha² by 2034, which may indicate ongoing land alterations for maintenance or infrastructure upgrades. Meanwhile, built-up areas have expanded substantially, growing from 5.32 Ha² in 2004 to 7.98 Ha² in 2024, with a further rise to 8.98 Ha² expected by 2034, reflecting increased infrastructural development to accommodate the gardens' evolving role as a hub for education, tourism, and events. These changes underscore the need for sustainable planning to balance DBG's ecological integrity with its urban and cultural functions. Figure 6 depicts the LULC classification for DBG from 2004-2034.

Durban North Japanese Gardens (DNJG)

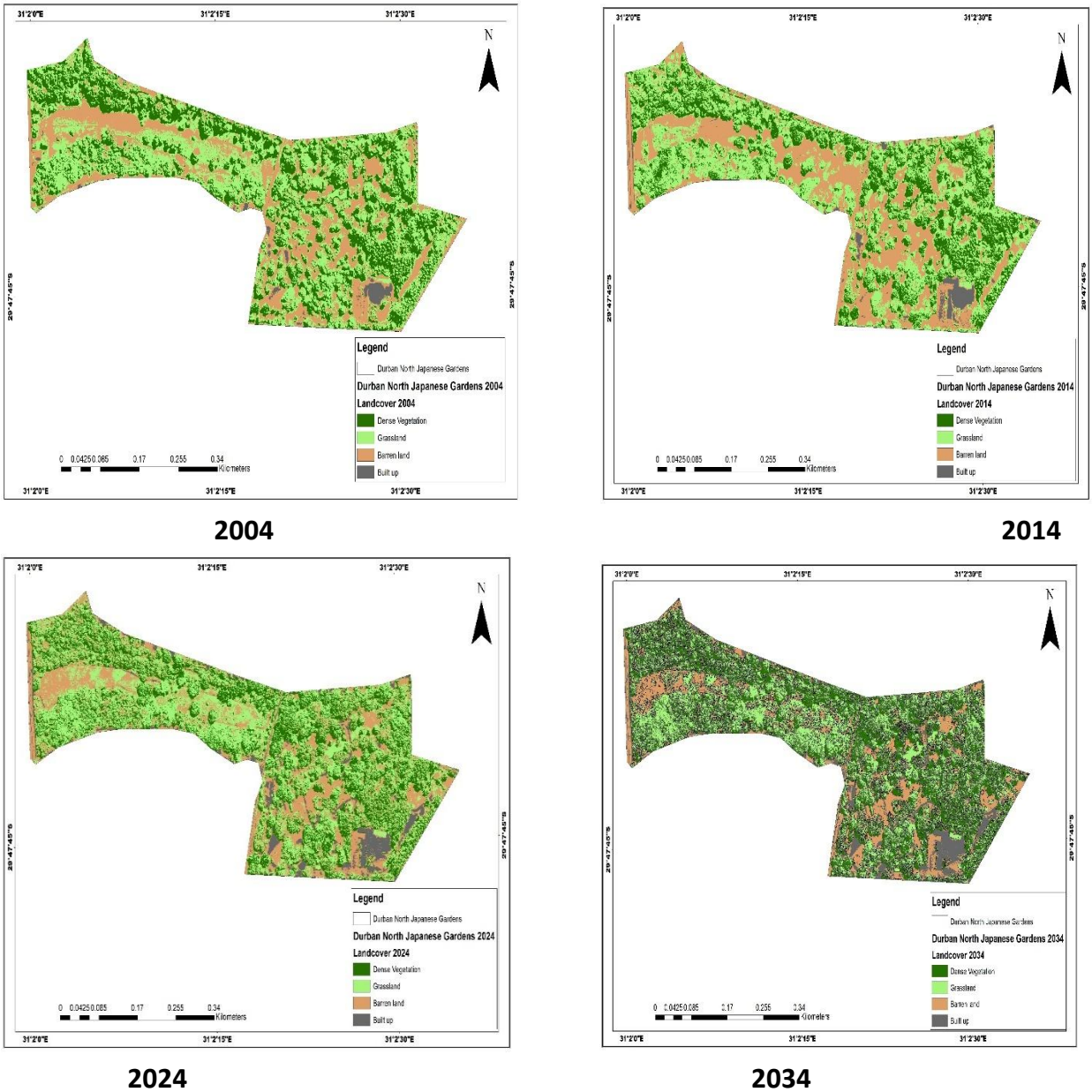
Embodying the tranquil elegance of traditional Japanese design, DNJG offers a serene escape from the city's energetic pace. Spanning an impressive 16 hectares, this enchanting haven features meticulously pruned bonsai trees, glistening koi ponds, and intricate stone lanterns, evoking the timeless beauty of Japanese harmony with nature. Meandering pathways lead visitors through an idyllic landscape enhanced by graceful bridges and charming gazebos, providing an atmosphere perfect for peaceful reflection or unhurried strolls. With its captivating blend of artistry and natural beauty, DNJG remains a treasured sanctuary in Durban. Table 3 illustrates the LULC distribution of the gardens from 2004 to 2034.

Table 3 reveals significant trends that reflect shifts in landscape management and utilization in DNJG. Dense Vegetation, which initially covered 5.64 Ha² in 2004, experienced a steady decline to 4.69 Ha² in 2024, with projections indicating a further reduction to 4.28 Ha² by 2034. This reduction could result from ongoing urban encroachment, adjustments to garden landscaping, or the reallocation of land for other purposes. Conversely, Grassland has remained relatively stable, with minor fluctuations. From 7.87 Ha² in 2004, it slightly decreased to 7.60 Ha² in 2024 but is projected to rise significantly to 8.61 Ha² by 2034. This increase may reflect restoration initiatives or a deliberate shift toward creating open, grassy areas for leisure and aesthetic appeal. Barren Land expanded from 2.84 Ha² in 2004 to 3.41 Ha² in 2024 and is expected to increase more significantly to 5.52 Ha² by 2034. This trend could signal ongoing construction, renovation projects, or areas temporarily cleared for future development or maintenance activities. The most dramatic growth is seen in Built-Up Areas, which expanded

from a mere 0.24 Ha² in 2004 to 1.09 Ha² in 2024, with a sharp rise projected to 1.89 Ha² by 2034. This reflects increased infrastructural developments, such as additional gazebos, pathways, or visitor facilities, aimed at enhancing the garden's functionality and visitor experience. Figure 5 depicts the LULC distribution of DNJG from 2004 to 2034.

Figure 5.

LULC classification for Durban North Japanese Gardens from 2004-2024.



2004 **2014**

2024 **2034**

Table 3.

The LULC distribution for DNJG from 2004-2024.

S/N	LULC Types	2004 (in Ha²)	2014 (in Ha²)	2024 (in Ha²)	2034 (in Ha²)
1.	Dense Vegetation	5.6435	4.8352	4.6916	4.2837
2.	Grassland	7.8699	7.7638	7.6042	8.6065
3.	Waterbodies	0	0	0	0
4.	Barren Land	2.8416	3.5379	3.4118	5.5177
5.	Built-Up Area	0.2425	0.6089	1.0924	1.8898

Source: Authors, (2024)

Kenneth Stainbank Nature Reserve (KSNR)

KNSR spans an impressive 253 Ha^2, showcasing a harmonious blend of coastal forests and expansive grasslands. This pristine sanctuary serves as a refuge for diverse wildlife, including zebras, impalas, and playful monkeys, thriving within its lush ecosystems. Visitors are invited to explore its well-maintained hiking trails, unwind at serene picnic spots, and marvel at the historical charm of Coedmore Castle, a colonial-era landmark that adds a touch of history to the natural splendor. Renowned for its rich biodiversity and tranquil ambiance, KSNR offers an exceptional escape for nature enthusiasts, birdwatchers, and those seeking to connect with Durban's remarkable natural heritage. Table 4 illustrates the LULC distribution for KSNR from 2004 to 2034.

Table 4.

The LULC distribution for KSNR from 2004-2024.

S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	135.6966	137.0963	148.3376	151.8508
2.	Grassland	104.7968	109.2686	81.3713	79.6210
3.	Waterbodies	1.5174	0.5523	2.3004	0.6781
4.	Barren Land	0.8764	0.6164	0.6681	0.697
5.	Built-Up Area	10.1131	14.3508	20.1925	21.6681

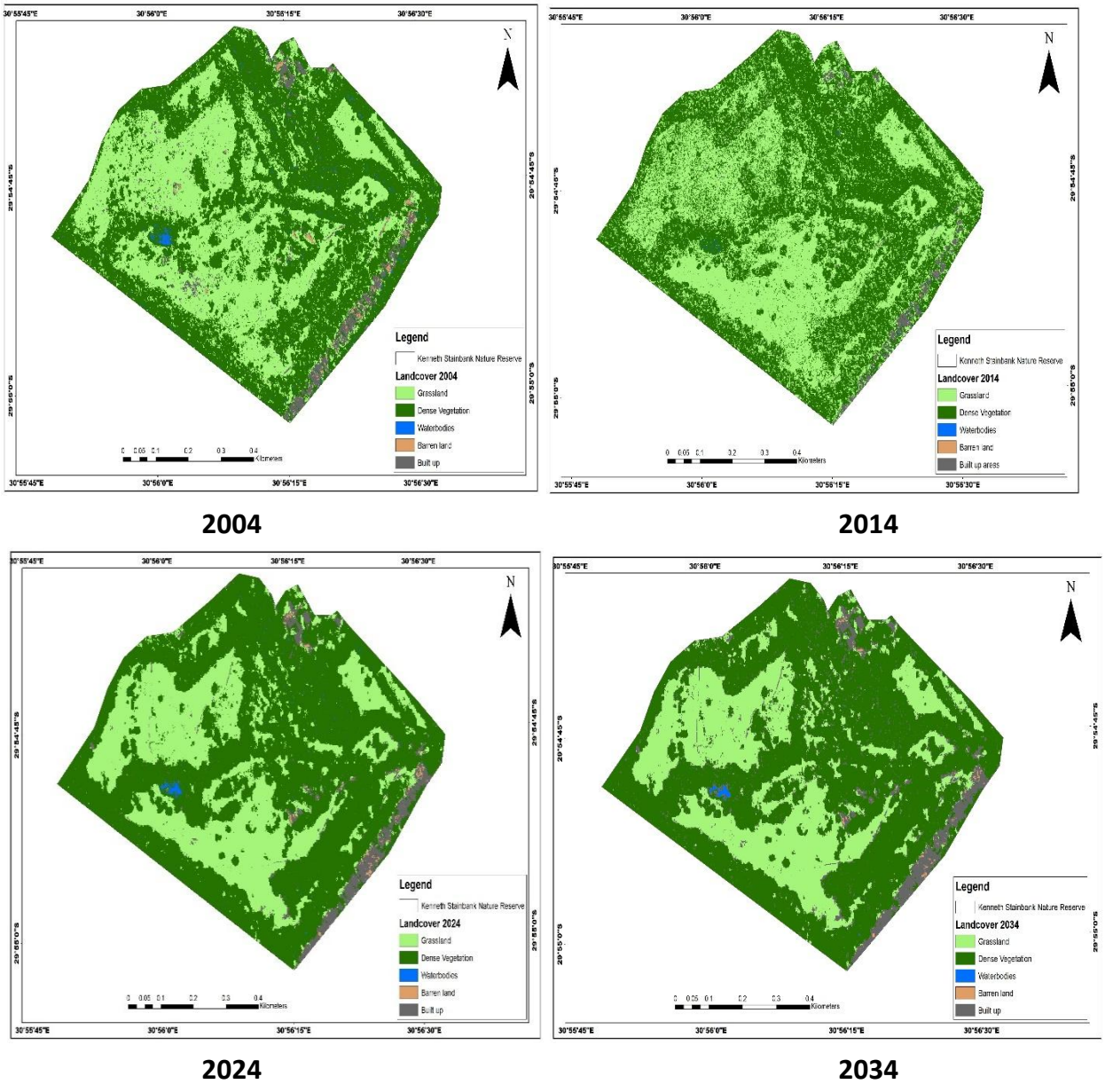
Authors, 2024

Table 4 provides valuable insights into the dynamic changes shaping the reserve's landscape, highlighting the interplay between conservation efforts, natural processes, and infrastructural developments. From 135.70 Ha^2 in 2004, Dense Vegetation has grown to 148.34 Ha^2 in 2024, with a projected rise to 151.85 Ha^2 by 2034, underscoring successful conservation practices, natural regrowth, and effective management strategies aimed at preserving the reserve's biodiversity and maintaining its role as a haven for wildlife. In contrast, Grassland has experienced a decline. From 104.80 Ha^2 in 2004, it expanded slightly to 109.27 Ha^2 in 2014 before dropping significantly to 81.37 Ha^2 in 2024, with further reductions expected, reaching 79.62 Ha^2 by 2034. This decrease may indicate a gradual transition of open grasslands into dense vegetation or conversion for other uses within the reserve. Waterbodies exhibit fluctuating patterns, shrinking from 1.52 Ha^2 in 2004 to 0.55 Ha^2 in 2014, followed by an increase to 2.30 Ha^2 in 2024 and a subsequent projected decrease to 0.68 Ha^2 in 2034. These changes may result from hydrological variability, restoration efforts, or other environmental factors affecting water features within the reserve. Built-Up Areas, however, show a marked increase, growing from 10.11 Ha^2 in 2004 to 20.19 Ha^2 in 2024, with projections reaching 21.67 Ha^2 by 2034. This growth reflects ongoing infrastructure development to enhance visitor facilities, such as hiking amenities, interpretive centers, or maintenance areas, balancing the reserve's role as a recreational space and a conservation area. Thus, the results indicate that KSNR is undergoing gradual yet significant transformations, with efforts to expand and preserve dense vegetation

while accommodating infrastructural growth. Figure 6 depicts the LULC classification for KSNR from 2004-2034.

Figure 6.

LULC classification for KSNR from 2004-2034.



2004 **2014**

2024 **2034**

Mitchell Park Zoo (MPZ)

A cherished destination for families, the 3.8-hectare MPZ is home to a diverse array of creatures, including tortoises, meerkats, vibrant exotic birds, and charming small mammals like duikers and lemurs. Complementing its wildlife exhibits, the zoo boasts meticulously manicured gardens, a lively children's play area, and a delightful café, offering an all-in-one experience for visitors of all ages. Its unwavering commitment to animal care and environmental education enhances its reputation as both a recreational haven and an educational gem. Table 5 presents the LULC distribution for MPZ from 2004 to 2034.

Table 5.

The LULC distribution for MPZ from 2004-2034.

S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	2.5073	2.3029	2.1919	1.8961
2.	Grassland	0.3748	0.3953	0.3594	0.3904
3.	Waterbodies	0	0	0	0
4.	Barren Land	0.1743	0.5461	0.1075	0.1153
5.	Built-Up Area	0.7436	0.8670	1.1411	1.2969

Authors, 2024

Figure 7.

LULC classification for MPZ from 2004-2034.

2004 **2014**

2024 **2034**

Table 5 reveals significant shifts in the distribution of LULC within the zoo's compact 3.8-hectare space. Dense Vegetation, the predominant LULC type in the zoo, has steadily decreased over the years. From 2.51 Ha² in 2004, it dropped to 2.19 Ha² in 2024, with a further decline projected to 1.90 Ha² by 2034. This reduction may be attributed to the gradual expansion of

built-up areas, the reconfiguration of animal enclosures, or modifications to accommodate visitor amenities. While the decrease highlights the challenge of balancing development with ecological preservation, it underscores the need for proactive strategies to maintain the zoo's green cover. Grassland has shown relatively minor fluctuations, remaining stable between 0.35 Ha^2 and 0.39 Ha^2 throughout the study period. This consistency reflects the zoo's effort to maintain open grassy spaces for recreational purposes and animal habitats while minimizing disruption to its layout. Barren Land demonstrates variable patterns, rising to a peak of 0.55 Ha^2 in 2014 before decreasing to 0.11 Ha^2 in 2024 and stabilizing thereafter. This trend likely represents temporary land clearance or construction activities, followed by restoration efforts to reclaim and repurpose the cleared areas for other uses. Built-Up Areas have seen a steady increase over the years, growing from 0.74 Ha^2 in 2004 to 1.14 Ha^2 in 2024, with further growth projected to 1.30 Ha^2 by 2034. This expansion reflects infrastructural upgrades, such as improved animal enclosures, visitor facilities, and recreational amenities, aimed at enhancing the zoo's appeal as a family-friendly destination. However, this growth must be carefully managed to ensure it does not compromise the zoo's ecological integrity. Figure 7 depicts the LULC classification for MPZ from 2004-2034.

Natal Sharks Board (NSB)

NSB spans an impressive 320 km^2 and serves as both a hub for scientific research and an educational center. Situated near Umhlanga, this iconic institution offers visitors an immersive journey into the world of sharks and marine ecosystems. Through captivating interactive exhibits, live shark dissections, and enlightening presentations, the NSB provides a rare glimpse into the intricate behaviors of these oceanic predators. Beyond its role as a tourist attraction, it stands as a beacon of awareness, championing the preservation of marine life and inspiring a deeper appreciation for the wonders of the ocean. Table 6 showcases the LULC distribution for the NSB from 2004 to 2024.

Table 6.

The LULC distribution for NSB from 2004-2024.

S/N	LULC Types	2004 (in km^2)	2014 (in km^2)	2024 (in km^2)	2034 (in km^2)
1.	Dense Vegetation	168.4788	77.0962	61.3069	54.5769
2.	Grassland	89.3307	150.8079	132.9417	146.4017
3.	Waterbodies	0	0	0	0
4.	Barren Land	51.5754	70.8878	76.6991	69.9691
5.	Built-Up Area	13.3523	23.9390	51.7934	58.5234

Table 6 highlights significant transformations in the NSB. In 2004, dense vegetation dominated the area, covering 168.48 km^2, but it has undergone a sharp decline over the years, reducing to 61.31 km^2 in 2024 and projected to further decrease to 54.58 km^2 by 2034. This consistent loss likely stems from urban expansion, infrastructural projects, and shifts in land use priorities. Grassland, conversely, has seen a fluctuating yet significant increase, expanding from

89.33 km² in 2004 to 132.94 km² in 2024, with a projected growth to 146.40 km² by 2034. This increase might result from the conversion of dense vegetation to less ecologically complex landscapes, such as open spaces for recreational or agricultural purposes. Barren land has steadily expanded from 51.58 km² in 2004 to 76.70 km² in 2024, with a slight decline projected to 69.97 km² by 2034. The peak in barren land suggests temporary activities such as land clearing for construction or agriculture. However, the expected decrease might indicate efforts to restore or repurpose some of these cleared areas. Built-up areas have experienced exponential growth, expanding from 13.35 km² in 2004 to a significant 51.79 km² in 2024, and projected to further increase to 58.52 km² by 2034. This increase reflects urbanization and infrastructure development, likely to accommodate the growing demand for research facilities, educational spaces, and residential or commercial structures in proximity to the NSB.

Figure 8.

LULC classification for NSB from 2004-2034.

2004 **2014**

2024 **2034**

The results underscore a critical challenge of balancing development with environmental sustainability. The increase in grassland offers some ecological compensation, but the significant reduction in dense vegetation calls for targeted conservation programs. Moreover, the steady

expansion of barren land reflects the need for better land reclamation and sustainable development practices. The NSB, as a leader in marine conservation, could expand its scope to advocate for terrestrial biodiversity preservation, complementing its ocean-focused initiatives. This approach would safeguard the area's natural heritage while accommodating future development needs. Figure 8 depicts the LULC classification for NSB from 2004-2034.

Phezulu Safari Park (PSP)

PSP offers an unforgettable fusion of wildlife adventures and cultural immersion. Visitors can embark on thrilling game drives to witness majestic giraffes, zebras, and wildebeest in their natural habitat. The park's awe-inspiring panoramic views of rolling hills make it a premier destination for those craving a harmonious blend of adventure, cultural enrichment, and the serene beauty of nature. Spanning 633 Ha, PSP encapsulates the essence of South Africa's diverse heritage. Table 7 illustrates the LULC distribution of PSP from 2004 to 2034.

Table 7.

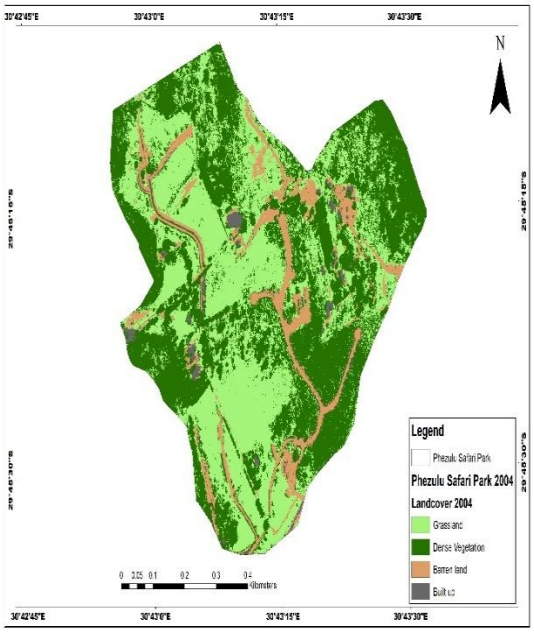
The LULC distribution for PSP from 2004-2024.

S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	495.4376	426.5195	406.6987	399.6268
2.	Grassland	46.158	40.6470	57.18	61.6821
3.	Waterbodies	0	0	0	0
4.	Barren Land	15.6153	61.9971	26.1702	17.5163
5.	Built-Up Area	75.0663	103.9338	142.9611	154.1748

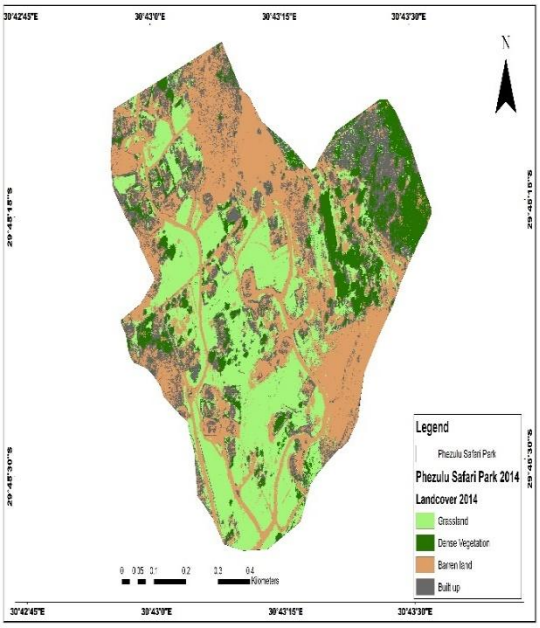
Table 7 illustrates significant shifts in LULC within PSP over the 30-year period (2004–2034). In 2004, dense vegetation covered the majority of PSP's land area (495.44 ha^2), underscoring its ecological richness. However, by 2014, this figure declined to 426.52 ha^2 and continued to shrink to 406.70 ha^2 by 2024, with a further reduction to 399.63 ha^2 projected for 2034. This consistent decrease points to ongoing deforestation, possibly due to infrastructural expansion, human encroachment, or natural ecosystem changes. Grassland exhibited a fluctuating pattern, decreasing from 46.16 ha^2 in 2004 to 40.65 ha^2 in 2014, followed by a significant increase to 57.18 ha^2 in 2024 and a projected rise to 61.68 ha^2 in 2034. This growth may indicate natural regeneration, habitat restoration efforts, or a shift in land management priorities, suggesting a positive trend in reclaiming open spaces for grazing and wildlife. Barren land increased dramatically from 15.62 ha^2 in 2004 to a peak of 61.99 ha^2 in 2014. However, by 2024, barren land reduced significantly to 26.17 ha^2, with a further decline projected to 17.52 ha^2 by 2034. This trend suggests initial land degradation followed by successful reclamation and re-vegetation efforts, signaling progress in restoring degraded landscapes. Built-up areas showed a steady and substantial rise, growing from 75.07 ha^2 in 2004 to 103.93 ha^2 in 2014, and further to 142.96 ha^2 in 2024, with a projected increase to 154.17 ha^2 by 2034. This growth reflects the expanding infrastructure for tourism, cultural exhibits, or local community settlements, emphasizing the balance between development and conservation. Figure 9 depicts the LULC classification for PSP from 2004-2034.

Figure 9.

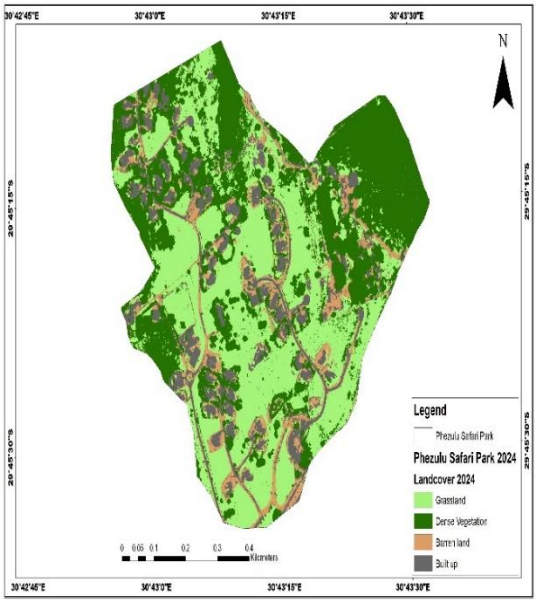
LULC classification for PSP from 2004-2034.



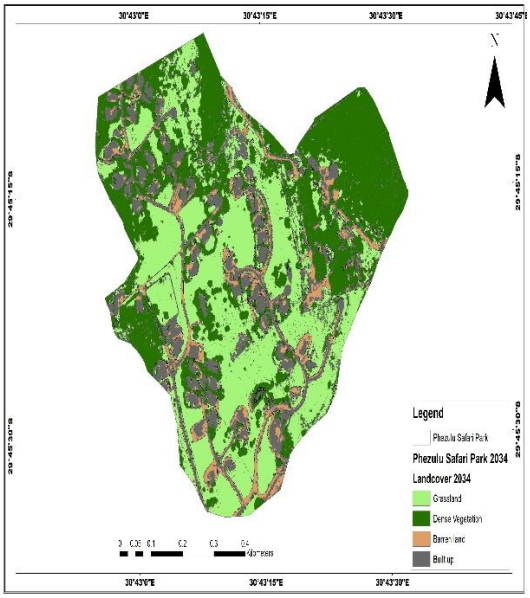
2004



2014



2024



2034

Queen Elizabeth Grassland (QEG)

The QEG spans 87 Ha^2, serving as a vital sanctuary for the city's dwindling grassland ecosystems. This cherished conservation area teems with life, providing refuge to diverse bird species, small mammals, and an array of indigenous plants. Its expansive, open landscapes invite visitors to immerse themselves in tranquil nature walks, enjoy captivating birdwatching experiences, and marvel at the untouched beauty of South Africa's natural grasslands. Table 8 illustrates the LULC dynamics for QEG from 2004 to 2034.

Table 8.

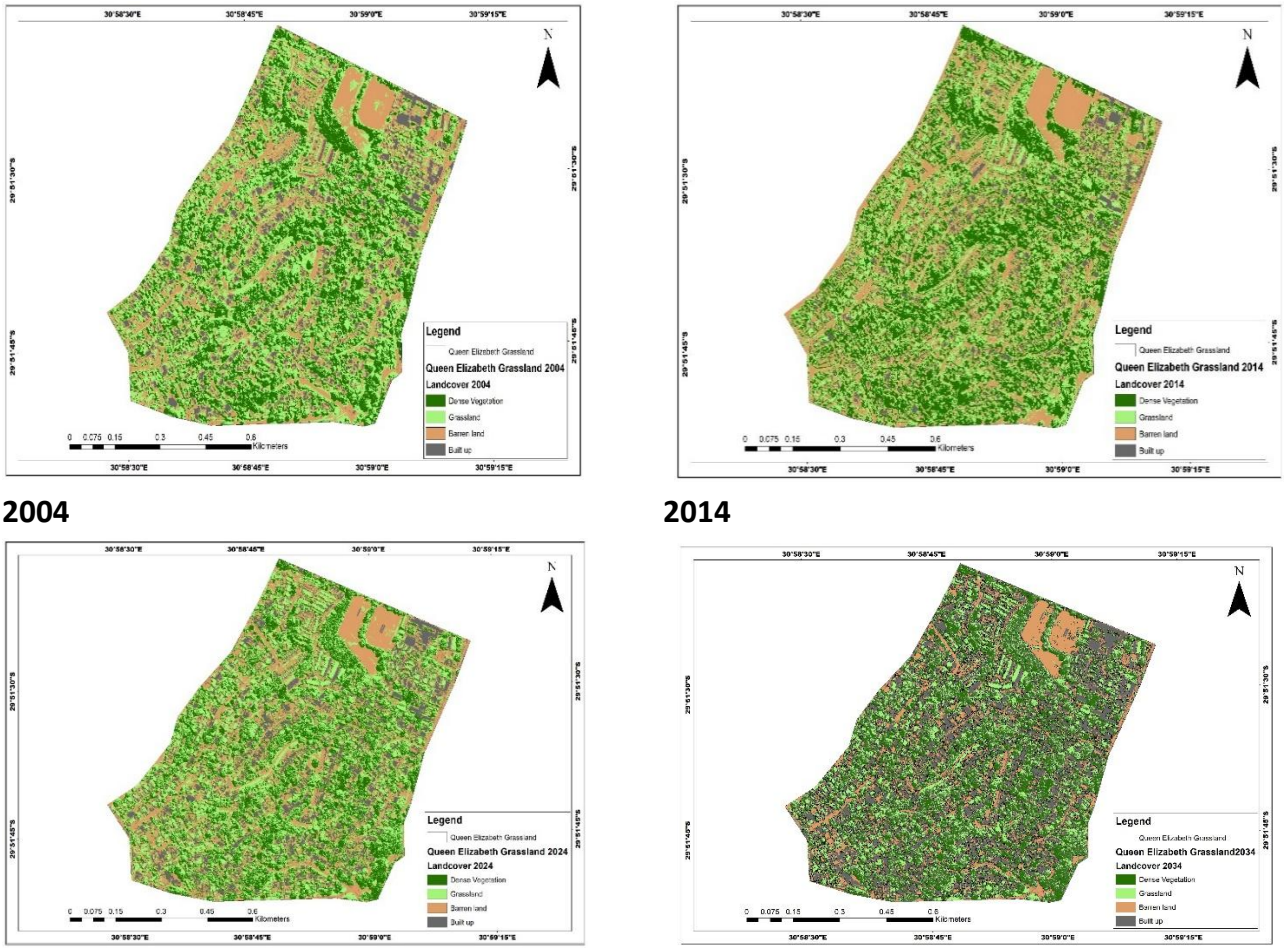
The LULC distribution for QEG from 2004-2034.

S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	31.3725	35.7113	31.3677	28.9243
2.	Grassland	17.3098	11.9858	14.4766	15.4766
3.	Waterbodies	0	0	0	0
4.	Barren Land	27.0406	30.1995	27.5465	28.5465
5.	Built-Up Area	13.6277	13.7857	13.69	17.690

Authors, 2024

Figure 10.

LULC classification for QEG from 2004-2034.



2004 **2014**

2024 **2034**

Table 8 reveals that dense vegetation, which represents the core of QEG's ecological richness, showed a slight increase from 31.37 Ha^2 in 2004 to 35.71 Ha^2 in 2014, which is likely attributed to restoration efforts or natural regrowth. However, by 2024, this figure declined to 31.37 Ha^2 and is projected to decrease further to 28.92 Ha^2 in 2034. This trend suggests increasing stress on vegetation, potentially from environmental factors such as climate variability or human-induced pressures like encroachment. Grassland coverage, the hallmark of QEG, experienced an initial decline from 17.31 Ha^2 in 2004 to 11.99 Ha^2 in 2014, possibly due to

encroachment or changes in vegetation density. However, it began recovering, reaching 14.48 Ha^2 in 2024, and is projected to expand further to 15.48 Ha^2 by 2034. This resurgence may reflect improved management practices, rewilding efforts, or the adaptability of grasslands to changing conditions. Barren land showed fluctuations, increasing from 27.04 Ha^2 in 2004 to 30.20 Ha^2 in 2014, indicating possible soil degradation or deforestation during that period. However, a reduction to 27.55 Ha^2 in 2024 and a modest rise to 28.55 Ha^2 by 2034 suggest localized land degradation alongside some recovery or stabilization initiatives. The most concerning trend is the steady growth of built-up areas, which increased from 13.63 Ha^2 in 2004 to 13.79 Ha^2 in 2014, further rising to 13.69 Ha^2 in 2024, and projected to reach 17.69 Ha^2 by 2034. This expansion reflects ongoing urbanization, potentially threatening the ecological balance of QEG and emphasizing the need for stricter conservation policies to limit infrastructural development, and the recovery of grassland suggests that with targeted interventions, degraded ecosystems can be rehabilitated. Proactive land management strategies, including afforestation and erosion control, are vital to reducing barren land and safeguarding QEG's ecological integrity. Thus, while QEG remains a vital ecological hub, its resilience depends on deliberate and sustained conservation efforts to counteract urbanization and ensure the long-term survival of its unique grassland ecosystem. Figure 10 depicts the LULC classification for QEG from 2004-2034.

Umgeni River Bird Park (URBP)

A haven for bird enthusiasts, the URBP boasts of an impressive collection of over 200 bird species of rare and endangered varieties that captivate visitors of all ages. This avian sanctuary features immersive walk-through aviaries, mesmerizing cascading waterfalls, and engaging bird shows that blend entertainment with education, emphasizing the importance of bird conservation. Nestled along the picturesque banks of the Umgeni River, the park provides a tranquil escape for families and nature lovers, offering an opportunity to experience the colorful and dynamic world of birds. Spanning 3.5 Ha^2, URBP is a hub of biodiversity and environmental awareness. Table 9 illustrates the LULC distribution of URBP from 2004 to 2034.

Table 9.

The LULC distribution for URBP from 2004-2024.

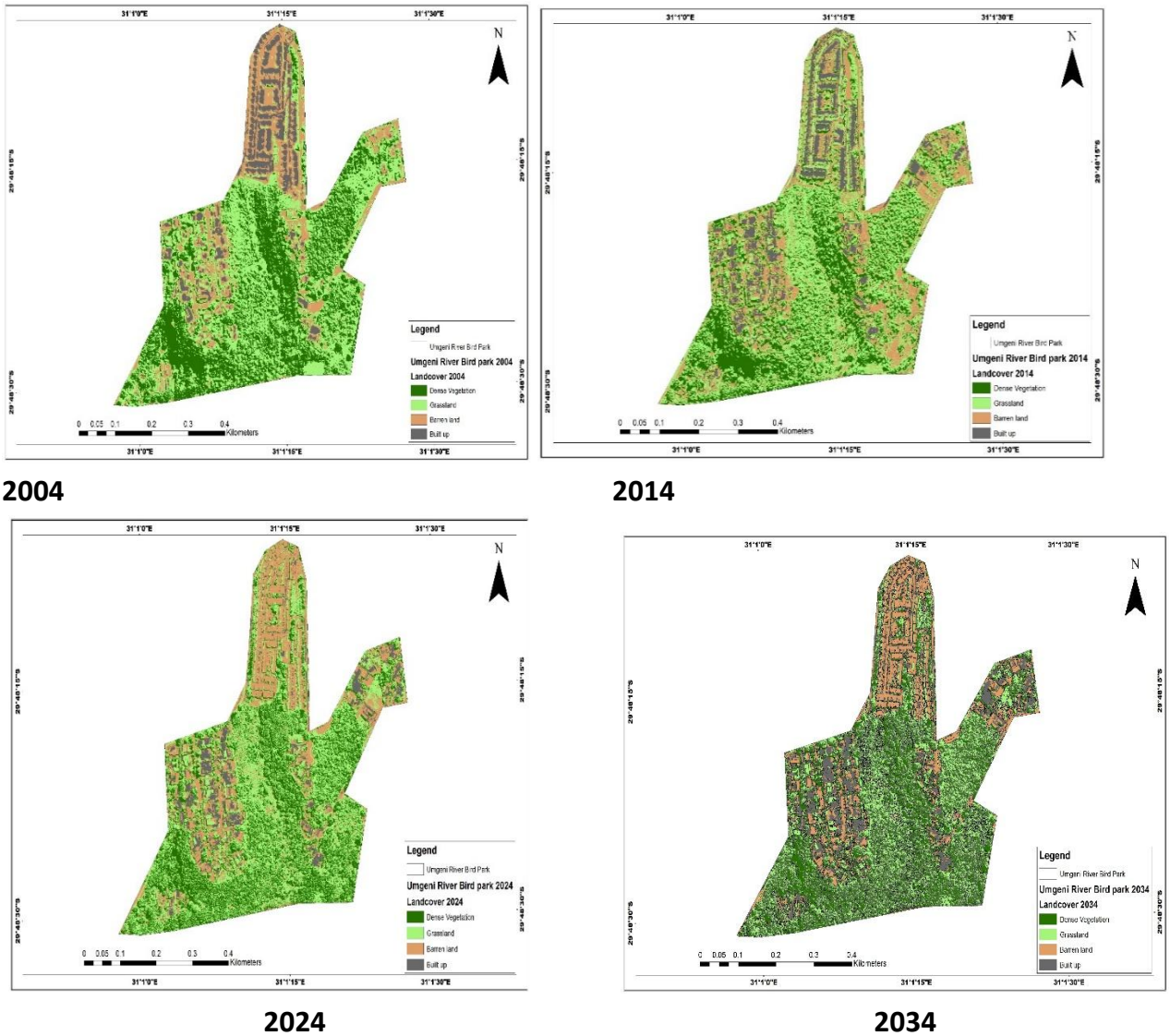
S/N	LULC Types	2004 (in Ha^2)	2014 (in Ha^2)	2024 (in Ha^2)	2034 (in Ha^2)
1.	Dense Vegetation	0.9461	0.8423	0.9216	0.6725
2.	Grassland	1.4559	1.2765	1.1504	1.2744
3.	Waterbodies	0	0	0	0
4.	Barren Land	0.427	0.8339	0.3907	0.4041
5.	Built-Up Area	0.122	0.5473	1.0398	1.1490

Table 9 highlights a fluctuating trend of dense vegetation, which decreased slightly from 0.9461 Ha^2 in 2004 to 0.8423 Ha^2 in 2014, rebounded to 0.9216 Ha^2 in 2024, but is projected to drop significantly to 0.6725 Ha^2 by 2034. This decline may be attributed to urban development

pressures or adjustments to park infrastructure, which could affect the natural habitats of birds and other wildlife. Grassland also decreased from 1.4559 Ha^2 in 2004 to 1.2765 Ha^2 in 2014 and further to 1.1504 Ha^2 in 2024. However, it is expected to recover slightly to 1.2744 Ha^2 by 2034, likely due to habitat restoration efforts aimed at balancing urban encroachment with the park's biodiversity goals. Barren land exhibited an increase from 0.427 Ha^2 in 2004 to 0.8339 Ha^2 in 2014, potentially due to construction or renovation activities. By 2024, barren land reduced to 0.3907 Ha^2, but projections for 2034 show a slight uptick to 0.4041 Ha^2, possibly signaling periodic maintenance or minor expansions within the park. The most significant change is observed in built-up areas, which expanded dramatically from 0.122 Ha^2 in 2004 to 0.5473 Ha^2 in 2014 and further to 1.0398 Ha^2 in 2024, with projections reaching 1.1490 Ha^2 by 2034.

Figure 11.

LULC classification for URBP from 2004-2034.



2004 **2014**

2024 **2034**

This growth reflects infrastructural development, such as visitor facilities, aviary expansions, and other amenities to enhance the park's appeal. The slight recovery in grassland by 2034 suggests ongoing efforts to mitigate habitat loss. Strategic land management practices

and continued restoration efforts will be essential to preserve the unique biodiversity of URBP while maintaining its role as a key educational and recreational site. Figure 11 depicts the LULC classification for URBP from 2004-2034.

VALIDATION OF LULC ANALYSIS RESULTS IN THE STUDY AREA

To ensure the precision and dependability of the LULC analysis, validation was conducted using two key indices: the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI).

Normalized Difference Vegetation Index (NDVI): NDVI is a vital remote sensing tool for assessing vegetation health, coverage, and density through satellite imagery. It operates by comparing reflectance values of near-infrared (NIR) and red (RED) light to highlight vegetated areas. Satellite images from Landsat 7 ETM, 8, and 9 were obtained via USGS Earth Explorer. For NDVI computation, Bands 5 and 4 were used for 2014 and 2024, while Bands 4 and 3 were utilized for 2004. The NDVI formula is:

NDVI= NIR+RED/NIR−RED

Where:

NIR represents near-infrared reflectance; RED represents red band reflectance; NDVI values typically range between -1 and +1:

Higher values (closer to +1) indicate dense, healthy vegetation; Near-zero values suggest sparse vegetation or bare land. Negative values correspond to non-vegetated surfaces like urban areas or water bodies. The NDVI results revealed the following trends:

2004: -0.1138 to 0.4578

2014: -0.1571 to 0.6546

2024: -0.1283 to 0.4972

The NDVI maps indicated that urbanized and barren lands had very low vegetation indices, whereas dense vegetation zones exhibited higher values, confirming expected land cover trends. Areas in green represented minimal vegetation, yellow depicted unhealthy vegetation, and dark green signified robust vegetation growth.

Normalized Difference Built-up Index (NDBI)

NDBI is an effective metric for identifying urbanized regions by distinguishing built-up areas from natural landscapes. It is computed based on the contrast between shortwave infrared (SWIR) and near-infrared (NIR) reflectance, providing insights into urban expansion. The formula used is:

NDBI= SWIR+NIR/SWIR−NIR

Where: SWIR represents shortwave infrared reflectance; NIR represents near-infrared reflectance. For the 2004 dataset, Band 5 (SWIR) and Band 4 (NIR) were employed, whereas for 2014 and 2024, Band 6 (SWIR) and Band 5 (NIR) were used. The computed NDBI values were:

2004: -0.3080 to 0.2481

2014: -0.4153 to 0.4090

2024: -0.3559 to 0.2845

NDBI results showed that green areas had little to no built structures, yellow zones contained a mix of vegetation and built-up areas, while red regions indicated extensive urban development. The findings confirmed a significant increase in urban sprawl and agricultural encroachment into previously vegetated areas. Hence, the integration of NDVI and NDBI indices provided robust evidence of LULC transformations in Durban Metropolis between 2004 and 2024. The analysis validated trends in urban expansion, vegetation decline, and land cover shifts, reinforcing the reliability of the study's findings.

Alignment of Research Results of the Study with Existing Literature on LULC Dynamics

The findings of this study align closely with the results reported in the literature, particularly those by Tewabe and Fentahun (2020), Chughtai et al. (2021), and Das and Angadi (2022), which highlight comparable trends in land use and land cover (LULC) dynamics. These studies collectively underscore the rapid expansion of urban landscapes, the decline in vegetative cover, and the encroachment of built-up areas into previously green and agricultural spaces—patterns that are vividly reflected in our analysis. For instance, Tewabe and Fentahun (2020) documented significant urban sprawl in Ethiopia, where fertile agricultural land was increasingly replaced by infrastructure and settlements, mirroring the urban expansion trends observed in Durban Metropolis. Similarly, Chughtai et al. (2021) demonstrated that growing population pressures in South Asian megacities have led to a surge in built-up areas at the expense of natural landscapes, a transformation that aligns with the rising Normalized Difference Built-up Index (NDBI) values in this study. Furthermore, Das and Angadi (2022) provided compelling evidence of deforestation and vegetation loss in response to land-use change, a phenomenon echoed by our Normalized Difference Vegetation Index (NDVI) analysis, which revealed declining vegetation indices over time. Together, these studies reinforce a universal pattern of rapid urbanization, environmental stress, and shifting land dynamics, corroborating the findings of this research. The striking similarities between these studies and our results not only validate the methodology employed but also emphasize the urgent need for sustainable urban planning and conservation strategies in rapidly developing regions.

DISCUSSION

This study has explored the LULC changes in Durban's recreational parks from 2004 to 2024, providing invaluable insights into the dynamics of urban development, environmental sustainability, and the role of green spaces in urban settings. The findings of this research are significant, as they reveal not only the transformation of the city's green spaces but also the broader implications for urban management and ecological conservation. Through a combination of spatial analysis, Place-Based Education (PBE), and community engagement, the study provides a multifaceted approach to understanding how urban expansion influences land-use patterns and the sustainability of urban ecosystems. One of the key takeaways from this research is the rapid urban expansion in Durban, particularly in areas previously dominated by

natural vegetation or agricultural land. The spatial analysis of LULC over the past two decades reveals a clear shift towards more built-up areas and barren lands, with a notable encroachment into areas that were once part of the city's ecological assets—its parks and green spaces. The study's use of NDVI and NDBI indices has been instrumental in illustrating these changes, confirming the urban sprawl, and highlighting the shrinking of ecologically rich zones in favor of urban development. While urban growth is inevitable, the challenge lies in finding a balance between development and the preservation of natural habitats that are crucial for biodiversity conservation, climate resilience, and community well-being. The importance of green spaces in cities, particularly parks, cannot be overstated. Not only do they serve as recreational hubs for residents, but they are also critical in enhancing the quality of life in urban environments by improving air quality, providing spaces for social interaction, and fostering mental and physical health. In the case of Durban, the study highlights how these spaces, often overlooked as mere recreational areas, are ecologically significant and need to be carefully managed to ensure their sustainability amidst rapid urbanization. The findings from this research underscore the need for integrated urban planning that incorporates both development goals and environmental priorities.

The Place-Based Education (PBE) framework has proven to be an invaluable tool in examining these issues, as it emphasizes the importance of engaging local communities with their environments. By situating learning within Durban's parks, this study underscores the potential of place-based learning to foster a deeper understanding of ecological dynamics, urban development, and sustainable practices. PBE allows for a hands-on exploration of the relationship between people and their environment, offering insights into how local knowledge can complement scientific research in managing urban green spaces. The parks are not just physical spaces; they are learning environments where local residents, students, and urban planners can better understand the ecological, social, and economic functions that these spaces provide. The application of PBE in this study also emphasizes the importance of community involvement in the decision-making process regarding urban land use. As urban areas continue to expand, it is critical that local populations are not only aware of the ecological and social roles of green spaces but are also actively engaged in shaping the future of these spaces. This approach can lead to more inclusive urban policies that reflect the needs of both the human and ecological communities. The study's findings suggest that there is a growing awareness in Durban of the importance of green spaces, but there remains a gap in terms of policy implementation and effective land-use planning. It is crucial that stakeholders, including urban planners, policymakers, and local communities, work together to ensure that Durban's parks and recreational areas continue to thrive as both educational resources and ecological sanctuaries. The study contributes to the growing body of research on urban sustainability and the role of green infrastructure in mitigating the effects of urbanization. With the increasing pressures of climate change, urban areas like Durban face numerous challenges, including the heat island effect, biodiversity loss, and water management issues. By maintaining and

enhancing its green spaces, Durban can not only improve its residents' quality of life but also contribute to environmental resilience. This study demonstrates that recreational parks are integral to these efforts and should be viewed as critical infrastructure that provides far-reaching benefits beyond their immediate recreational uses. This research also paves the way for future studies on the relationship between urbanization and ecological health in South African cities and beyond. By integrating spatial data analysis with community-based approaches, the study provides a robust model for understanding how urban landscapes evolve and how best to manage the delicate balance between development and conservation. It highlights the importance of incorporating sustainable urban design into urban growth strategies, ensuring that cities can expand without sacrificing their ecological integrity. In a nutshell, the findings from this study offer critical insights into the changes occurring within Durban's recreational parks and the broader implications for urban management and environmental sustainability. By applying Place-Based Education principles, the study highlights the importance of community engagement and local knowledge in shaping the future of urban green spaces. The research demonstrates that parks and recreational areas are far more than just leisure spaces—they are vital ecological assets that contribute to urban resilience, biodiversity conservation, and the overall well-being of urban populations. As urbanization continues to accelerate, this study reinforces the need for integrated, sustainable land-use planning that prioritizes the preservation of these invaluable spaces

In addition, this study analyzed the LULC changes in Durban's recreational parks between 2004 and 2024, providing key insights into urban growth patterns, environmental health, and sustainability. The findings clearly indicate that urban expansion has significantly encroached upon previously vegetated and natural areas, with an increase in built-up environments and a corresponding loss of green spaces. Over the study period, NDVI values, which reflect vegetation health, showed a noticeable decline. In 2004, the NDVI ranged from -0.113797 to 0.457789, which reflects a mix of healthy vegetation and barren land. By 2014, the range increased to -0.157078 to 0.654621, indicating further deterioration in vegetation quality as urban sprawl continued. In 2024, the NDVI ranged from -0.128284 to 0.497212, highlighting ongoing vegetation loss. This trend points to the increasing degradation of ecological resources and the depletion of ecosystem services provided by parks and green spaces. Furthermore, the NDBI values, which measure urbanization, also showed a clear shift towards more developed areas. For 2004, NDBI values ranged from -0.308048 to 0.248079, reflecting less urbanization. However, by 2014, the range shifted to -0.415255 to 0.408963, and by 2024, it spanned from -0.35594 to 0.284506, indicating a steady rise in built-up areas. These changes corroborate the findings of urban encroachment into previously vegetated and ecologically significant spaces.

Implications of Research Findings for LULC Sustainability and Economic Development: The findings of this research highlight significant implications for both LULC sustainability and economic development in urban contexts. The rapid urbanization observed in Durban threatens the biodiversity and environmental resilience of the city, with the loss of green spaces

jeopardizing essential ecological functions such as carbon sequestration, water filtration, and microclimate regulation. Recreational parks, once valuable for public health and ecological diversity, are at risk of disappearing in favor of urban development, which could lead to long-term environmental degradation. From an urban planning perspective, the study stresses the importance of integrated land-use management that ensures urban growth does not come at the expense of ecological health. Green spaces are critical not only for ecosystem services but also for providing social, recreational, and cultural benefits to urban populations. Preserving and expanding these spaces through sustainable urban planning practices is essential to maintaining a balance between development and environmental stewardship. On the economic front, while urbanization often correlates with economic growth, the loss of green spaces can have hidden economic costs. Parks and recreational areas contribute to economic development by boosting tourism, enhancing the attractiveness of cities for investment, and improving the health and well-being of the population, thereby reducing healthcare costs. As cities like Durban continue to grow, it is essential to recognize the economic value of green infrastructure and incorporate its preservation into long-term urban development plans. Thus, the study underscores the need for careful consideration of LULC changes in urban environments and calls for a sustainable balance between development and ecological preservation. As urban areas like Durban continue to expand, it is vital to preserve and enhance green spaces not only for environmental health but also for economic sustainability and the overall well-being of urban residents.

CONCLUSION AND RECOMMENDATIONS

This study highlights the critical issue of LULC changes in Durban Metropolis, South Africa, with a particular focus on the growing tension between urban sprawl and the ecological sustainability of recreational parks. The findings underscore the increasing pressure on green spaces due to rapid urban expansion, which threatens biodiversity, undermines ecosystem resilience, and exacerbates environmental degradation. Through a spatio-temporal analysis using GIS technology, the study reveals alarming trends of vegetation loss and urban encroachment, with projections indicating further challenges in the coming decade. This research not only contributes to understanding these dynamics but also emphasizes the role of Higher Educational Institutions (HEIs) in fostering environmental literacy and promoting sustainable development. By demonstrating how GIS can be integrated into both research and pedagogy, the study advocates for the alignment of environmental education with real-world conservation efforts, offering new opportunities for educators and students to engage in ecosystem preservation. Furthermore, the Place-Based Education (PBE) framework adopted for the study is more than just a theoretical tool, it is a guiding principle that empowers this study to explore Durban's urban landscape with a fresh perspective on sustainability, community engagement, and land-use change. By integrating PBE into the study of LULC and urban management, this research provides valuable insights into how recreational parks and green spaces can serve as critical components of sustainable urban development. The study demonstrates that by immersing

learners and urban planners in the real-life dynamics of urban ecosystems, we can foster a deeper understanding of the challenges and opportunities presented by urbanization. Ultimately, PBE provides the foundation for more informed, sustainable approaches to urban management, ensuring that future urban spaces remain both ecologically resilient and socially equitable.

The study recommends a multifaceted approach to address the growing threats to Durban's recreational parks and broader ecological systems. First, it is essential to integrate GIS-based tools into the curriculum of HEIs, especially in the context of urban sustainability and environmental management. This would encourage students to develop critical thinking and analytical skills that can be applied to real-world environmental challenges. Additionally, it is crucial to promote place-based learning, where students engage with local ecosystems, learn about their significance, and become active participants in conservation efforts. Moreover, policymakers and urban planners must adopt more robust conservation strategies that prioritize the protection of green spaces, including the establishment of stricter zoning regulations and the implementation of green infrastructure. Finally, continued research on LULC changes and ecological sustainability should be prioritized to ensure informed decision-making for the future of Durban Metropolis and its recreational parks. From the foregoing, the study envisions a future where urban development and ecological sustainability can coexist harmoniously, fostering a resilient environment for future generations.

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