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# Investigating Durban's Morphological Dynamics and Spatial Prediction Techniques for Urban Geography Pedagogy

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## ABSTRACT

This study highlighted the transformative potential of geospatial analysis and spatial prediction techniques in using the dynamic morphology of Durban Metropolis as a model for fostering innovative, data-driven learning experiences. The methodology integrated quantitative and geospatial data analysis of Land Use and Land Cover (LULC) changes from 2004 to 2024 using Geographic Information Systems (GIS)-based change detection tools to identify and predict LULC change patterns in 2034. The research findings revealed that built-up areas expanded significantly from 123.21 km² (5.38%) in 2004 to 442.92 km² (19.32%) in 2024, while agricultural lands, dense vegetation, and water bodies steadily declined, signalling ongoing environmental changes and urban pressures that are predicted to intensify to 520.3 km$^2$ (22.7%) by 2034. The study concluded that Durban Metropolis is rapidly expanding with a concomitant decline in vegetation LULC, thus highlighting the urgent need for sustainable urban planning and environmental conservation strategies. These findings have profound implications for urban geography pedagogy, providing data-driven insights that enhance curriculum development, equip students with spatial analysis skills, and promote informed decision-making on urban sustainability challenges. This study is original in integrating historical LULC analysis, GIS-based spatial modelling, and urban geography pedagogy, thereby offering a novel approach to linking urban studies with educational applications. This study recommends the integration of GIS-based predictive modelling into urban geography education, contributing to research knowledge by offering an innovative, data-driven approach that enhances spatial literacy, informs sustainable urban planning, and empowers students with real-world analytical skills for addressing future urban challenges.

***Keywords:*** *Education Curriculum, Geography Pedagogy, Geo-Spatial Analysis, Land Use Land Cover (LULC), Spatial Intelligence.*

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## INTRODUCTION

Urbanization is one of the most significant global trends of the 21st century,[1] driving economic growth, innovation, and improved living standards.[2] However, when left uncontrolled, it can lead to overcrowded cities, environmental degradation, and unsustainable resource consumption, highlighting the urgent need for effective strategies to manage urban growth.[3] This is where advanced analytical

[1] Hania Zlotnik, "World Urbanization: Trends and Prospects," in *New Forms of Urbanization* (Routledge, 2017), 43–64.
[2] Chaolin Gu, "Urbanization: Processes and Driving Forces," *Science China Earth Sciences* 62, no. 9 (2019): 1351–60.
[3] Gu, "Urbanization: Processes and Driving Forces."

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tools such as geospatial analysis and spatial prediction techniques become invaluable, offering critical insights into the complex dynamics of urban development.[4] The purpose of this study is to explore how these tools can revolutionize urban geography pedagogy, providing students with a hands-on approach to understanding the rapidly evolving urban morphology of coastal cities like Durban, and as elucidated by Cobbinah and Addaney, these cities, including Durban, are experiencing fast-paced urbanization that is reshaping their physical and socio-economic landscapes.[5]

As urban areas expand, understanding the drivers and patterns of urban morphology is crucial for fostering sustainable development.[6] Yet, traditional urban geography education often falls short by not incorporating modern technologies that could enhance students' ability to analyze and predict urban changes. In this context, geo-spatial analysis and spatial prediction techniques serve as powerful tools for both understanding and teaching the processes of urban growth and transformation.[7] Durban, with its unique coastal environment, offers an insightful case study, illustrating the challenges and opportunities that arise from managing urban growth in coastal regions.[8] Unfortunately, the inadequacy of pedagogical frameworks that integrate real-time spatial data has created a gap in urban geography education, limiting students' ability to engage with future urban trends.[9]

This study addresses that gap by exploring how geospatial technologies, such as Geographic Information Systems (GIS), can be utilized in geography education. By allowing students to interact with and analyze Durban’s evolving urban landscape, they will be able to visualize both past and present dynamics, as well as predict growth patterns.

According to Olatoye and Fru, this hands-on approach not only provides students with a deeper understanding of urban challenges but also equips them with the skills necessary to address the complexities of urban sustainability.[10] Also, Fox and Goodfellow opined that the rapid and often uncontrolled urbanization of coastal cities presents a pressing challenge to sustainable development, particularly in regions like Durban, where growth outpaces planning and resource management.[11] As these cities expand, they face complex socio-economic, environmental, and spatial issues that require innovative solutions.[12] Unfortunately, traditional urban geography education has largely failed to integrate modern technological tools, such as geospatial analysis and spatial prediction techniques, which are essential for understanding and managing the intricate dynamics of urban morphology.[13] Without these advanced tools, students are left with limited opportunities to grasp the complexities of urban growth and transformation in real-time.[14]

Furthermore, despite the availability of vast spatial data and predictive modelling capabilities, educators often lack the frameworks to incorporate these technologies into the curriculum effectively.[15] This gap in pedagogy leaves students ill-prepared to engage with urban issues, hindering their ability to contribute to solutions for sustainable urban development. The need for a more robust, data-driven approach to urban geography education is critical, as it would equip learners with the skills necessary

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[4] Tolulope Ayodeji Olatoye, Sonwabo Perez Mazinyo, and Ahmed Mukalazi Kalumba, “The Utilization of Geospatial Technologies in Urban Vegetation Ecosystems Conservation: A Review,” *Journal of Studies in Social Sciences and Humanities (JSSSH),* no. 4 (2022): 387–401.

[5] Patrick B Cobbinah and Moses Addaney, *Sustainable Urban Futures in Africa* (New York: Routledge, 2022).

[6] Deden Rukmana, *The Routledge Handbook of Planning Megacities in the Global South* ( New York: Taylor & Francis , 2020).

[7] Pengyuan Liu and Filip Biljecki, “A Review of Spatially-Explicit GeoAI Applications in Urban Geography,” *International Journal of Applied Earth Observation and Geoinformation* 112 (2022): 102936.

[8] Catherine Sutherland et al., “Conceptualizing ‘the Urban’through the Lens of Durban, South Africa,” in *Urban Forum*, vol. 29 (Springer, 2018), 333–50.

[9] Jongwon Lee, “Beyond Geospatial Inquiry—How Can We Integrate the Latest Technological Advances into Geography Education?,” *Education Sciences* 13, no. 11 (November 13, 2023): 1128, https://doi.org/10.3390/educsci13111128.

[10] Tolulope Ayodeji Olatoye and Raymond Nkwenti Fru, “A Review towards Enhancing Geospatial Technologies in South African Rural Education,” *Journal of Culture and Values in Education* 7, no. 4 (December 25, 2024): 190–210, https://doi.org/10.46303/jcve.2024.48.

[11] Sean Fox and Tom Goodfellow, *Cities and Development* (Routledge, 2016).

[12] Till Sterzel et al., “Typology of Coastal Urban Vulnerability under Rapid Urbanization,” *PloS One* 15, no. 1 (2020): e0220936.

[13] Danai Gladman Machakaire, “Transformation of Urban Planning Practices Using Geo-Spatial Technology in Managing Rapid Urbanisation in Harare: Zimbabwe” (Cape Peninsula University of Technology, 2015).

[14] Mónica Sanchez-Sepulveda et al., “Virtual Interactive Innovations Applied for Digital Urban Transformations. Mixed Approach,” *Future Generation Computer Systems* 91 (2019): 371–81.

[15] Joseph J. Kerski, “Online, Engaged Instruction in Geography and GIS Using IoT Feeds, Web Mapping Services, and Field Tools within a Spatial Thinking Framework,” *The Geography Teacher* 19, no. 3 (2022): 93–101.

to navigate and address the evolving challenges of coastal urbanization. This study aims to address this gap by exploring how geospatial analysis and spatial prediction techniques can be integrated into geography education, specifically through the lens of Durban's urban growth.

## LITERATURE REVIEW

### Integrating Urban Morphology and Land Use Change into Geography Curriculum

Urbanization, as one of the defining trends of the 21st century, has reshaped cities globally, creating complex spatial, social, and environmental challenges. Neumann argues that coastal cities are particularly vulnerable due to their rapid population growth and exposure to environmental hazards.[16] Durban, a rapidly expanding coastal city in South Africa, exemplifies these challenges, making it a compelling case for investigating urban morphological dynamics.[17]

Understanding the patterns and drivers of urban transformation is crucial for fostering sustainable development, particularly in coastal cities where urban pressures often compromise ecological integrity and socio-economic stability. Geospatial analysis and spatial prediction techniques have emerged as essential tools for urban studies, offering valuable insights into how cities evolve over time. Olatoye and Naidu demonstrated the effectiveness of GIS and spatial modelling in tracking land use changes, forecasting growth, and guiding urban planning decisions.[18]

These tools enable researchers to visualize and analyze complex spatial data, bridging the gap between theoretical urban geography and practical application. However, despite their transformative potential, many urban geography curricula remain rooted in traditional approaches that lack the integration of these advanced technologies. From an educational perspective, Huang et al. emphasized the importance of hands-on, experiential learning in fostering critical thinking and problem-solving skills among students.[19] Constructivist learning theorists advocate for pedagogical strategies that actively involve learners in analyzing real-world issues, promoting deeper engagement and meaningful learning experiences. In line with this, incorporating geospatial tools into geography education empowers students to explore dynamic urban environments, analyze spatial patterns, and predict changes.[20] Despite the extensive body of research on urbanization and geospatial technologies, there remains a gap in studies focusing on their integration into pedagogy for urban geography, particularly in coastal cities like Durban. Most research has primarily concentrated on using GIS for urban planning and environmental management, with limited emphasis on its pedagogical potential. This study addresses that gap by exploring how geospatial analysis and spatial prediction techniques can revolutionize urban geography education.

### Teaching Predictive Spatial Modeling for Urban Growth

Predictive spatial modelling plays a crucial role in understanding and forecasting urban growth patterns, providing valuable insights for urban planners, policymakers, and educators. In geography education, introducing students to spatial modelling techniques such as Cellular Automata (CA), and Markov Chain Analysis (MCA), among other learning models equips them with analytical skills to assess past trends and predict future LULC changes.[21] These methodologies enable students to understand how urban landscapes evolve due to socio-economic, environmental, and policy-driven factors.[22] By integrating predictive modelling into the geography curriculum, educators can enhance students' ability

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[16] Barbara Neumann et al., "Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding-a Global Assessment," *PloS One* 10, no. 3 (2015): e0118571.

[17] William J. Sutherland et al., "A 2018 Horizon Scan of Emerging Issues for Global Conservation and Biological Diversity," *Trends in Ecology & Evolution* 33, no. 1 (2018): 47–58.

[18] Tolulope Ayodeji Olatoye and Maheshvari Naidu, "Integrating Geo-Spatial Analysis with Cultural and Social Dynamics of Green Space Access in Durban Central Business District, South Africa," n.d.

[19] Yueh-Min Huang et al., "Empowering Virtual Reality with Feedback and Reflection in Hands-on Learning: Effect of Learning Engagement and Higher-order Thinking," *Journal of Computer Assisted Learning* 40, no. 4 (2024): 1413–27.

[20] Olatoye and Fru, "A Review towards Enhancing Geospatial Technologies in South African Rural Education."

[21] Aqil Tariq and Faisal Mumtaz, "A Series of Spatio-Temporal Analyses and Predicting Modeling of Land Use and Land Cover Changes Using an Integrated Markov Chain and Cellular Automata Models," *Environmental Science and Pollution Research* 30, no. 16 (2023): 47470–84.

[22] Khadim Hussain et al., "Assessing Forest Fragmentation Due to Land Use Changes from 1992 to 2023: A Spatio-Temporal Analysis Using Remote Sensing Data," *Heliyon* 10, no. 14 (2024).

to analyze spatial patterns, interpret geospatial data, and apply their knowledge to real-world urban planning challenges. According to Ghosh et al, CA is a spatial simulation technique that models urban growth based on defined rules, local interactions, and transition probabilities.[23] It allows students to observe how cities expand over time by simulating complex spatial patterns through a grid-based approach. MCA on the other hand, is a statistical method that predicts land-use transitions based on past trends and probabilistic calculations.[24]

Hence, students can estimate the likelihood of different LULC categories changing in the future by applying MCA, and this helps them to understand urban expansion scenarios.[25] In addition, machine learning models, such as neural networks and decision trees, offer advanced predictive capabilities by analyzing large datasets and identifying non-linear relationships in urban growth processes.[26] Hence, the Integration of predictive spatial modelling into geography education requires a curriculum that balances theoretical concepts with hands-on GIS applications.

## METHODOLOGY

### The Study Area

According to Olatoye and Naidu, Durban's unique geographical and climatic characteristics further underscore its importance as a study site. The city enjoys a subtropical climate, shaped by the Agulhas Current flowing poleward along its 100-kilometer coastline.[27] mahmThese warm currents moderate temperatures result in mild, dry winters with daytime temperatures averaging 11°C and hot, humid summers reaching an average of 28°C.[28] The rainy season typically spans from September to March, contributing to an annual precipitation exceeding 1,000 millimetres.[29] Figure 1 presents the digitized map of the study area.

[23] Pramit Ghosh et al., "Application of Cellular Automata and Markov-Chain Model in Geospatial Environmental Modeling-A Review," *Remote Sensing Applications: Society and Environment* 5 (2017): 64–77.
[24] Quanli Xu, A-Xing Zhu, and Jing Liu, "Land-Use Change Modeling with Cellular Automata Using Land Natural Evolution Unit," *Catena* 224 (2023): 106998.
[25] Olatoye and Fru, "A Review towards Enhancing Geospatial Technologies in South African Rural Education."
[26] Ghosh et al., "Application of Cellular Automata and Markov-Chain Model in Geospatial Environmental Modeling-A Review."
[27] Olatoye and Naidu, "Integrating Geo-Spatial Analysis with Cultural and Social Dynamics of Green Space Access in Durban Central Business District, South Africa."
[28] Debra Roberts et al., "Durban, South Africa," in *Cities on a Finite Planet* (Routledge, 2016), 96–115.
[29] Roberts et al., "Durban, South Africa."

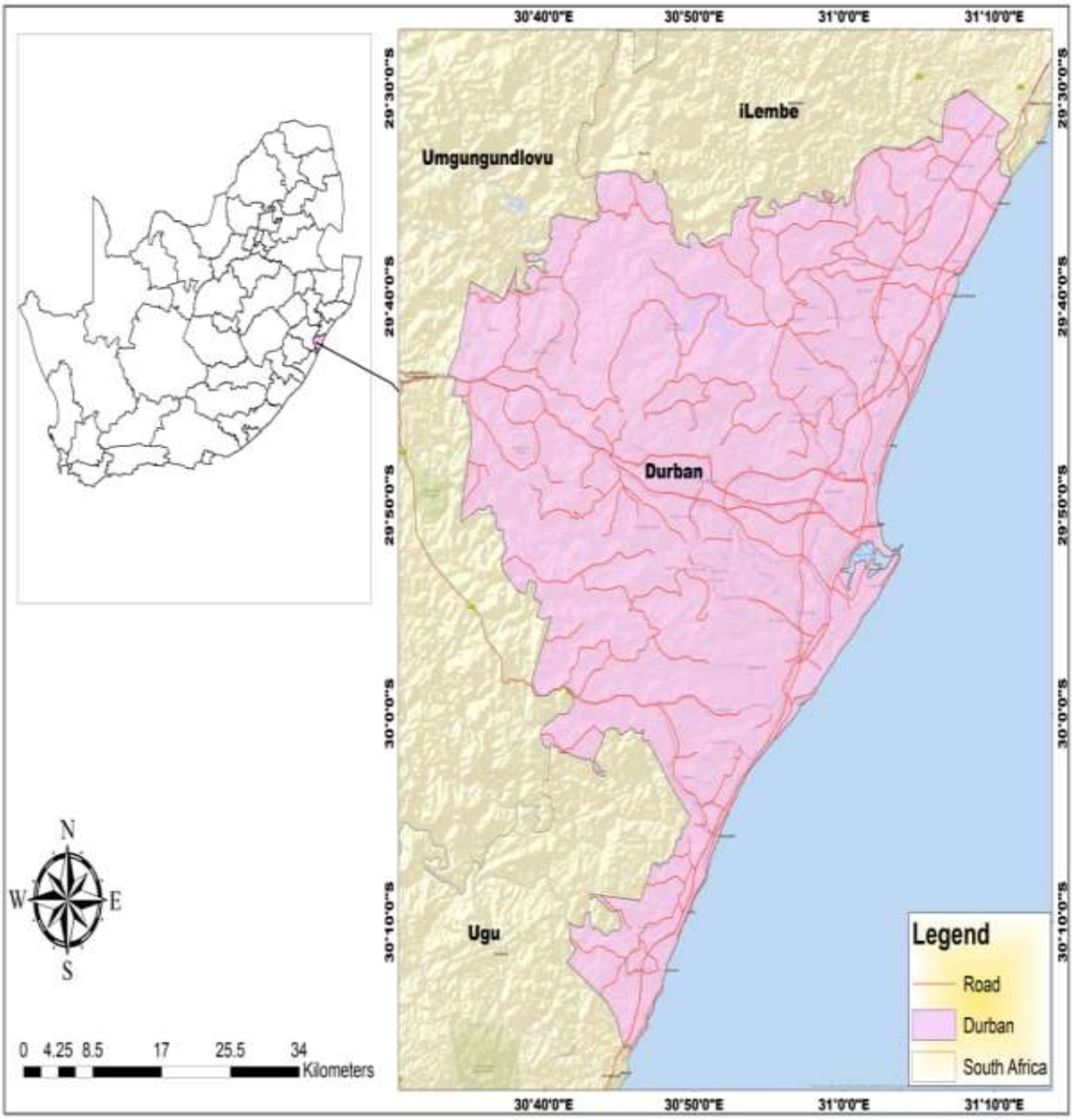


*Figure 1: Digitized Political Map of the Study Area*

This study employed an innovative methodology that combined advanced geo-spatial analysis with spatial prediction techniques to thoroughly explore Durban's urban morphology. Initially, spatial data were collected from the United States Geological Survey (USGS) website, providing a robust foundation for analysis. A time-series analysis of land use and land cover (LULC) changes from 2004 to 2024 was conducted to identify significant patterns in urban growth, environmental changes, and land transformation. Building on this historical data, spatial modelling techniques were applied using ArcGIS 10.8 Software to predict urban growth trajectories extending to 2034. These models utilized sophisticated algorithms to simulate potential future scenarios based on established trends, offering a forward-looking perspective on urban development.

**Image Processing and LULC Classification**

To ensure an accurate analysis of LULC changes, a rigorous image processing and classification approach was employed. Landsat 5 TM (2004), Landsat 8 and 9 OLI/TIRS (2014 and 2024) satellite images, covering path 168 and rows 81 and 82, were spatially georeferenced with a 30m spatial resolution to align them with the study area. Radiometric correction was performed to enhance image quality, followed by raster clipping to confine the analysis to the defined geographic extent. To further prepare the data for classification, a multispectral composite was created, ensuring optimal spectral differentiation between land cover types. The supervised image classification method was then applied, where spectral signatures were trained using sample datasets to classify the images into six distinct land cover categories: built-up areas, grassland, dense vegetation, water, and barren land. Utilizing the maximum likelihood classification (MLC) algorithm, pixels were assigned to the class with the highest probability based on their spectral reflectance, ensuring precision in distinguishing various LULC types. This process provided a robust foundation for assessing Durban's urban expansion and ecological transformations over time.

## PRESENTATION OF RESULTS

This study's findings reveal significant transformations in Durban's urban morphology, highlighting the rapid expansion of built-up areas and the corresponding decline of vegetation LULC over the past two decades. The research uncovers the extent of urban sprawl, the shifting patterns of LULC, and the potential future trajectories of urban growth. These insights not only provide empirical evidence of Durban's evolving cityscape but also serve as a valuable resource for geography education, equipping students with real-world case studies to enhance their spatial analysis skills. Table 1 reveals the coverage area for each of the 6 LULC classes in 2004.

**Table 1: Coverage area for each of the 6 classes of LULC (in km$^2$) of Durban in 2004**

| S/NO | LULC Types | Area | Percentage (%) |
|---|---|---|---|
| 1. | Built up Areas | 123.2118 | 5.375352347 |
| 2. | Grassland | 504.7884 | 22.02236726 |
| 3. | Dense Vegetation | 567.2106 | 24.7456561 |
| 4. | Agricultural Land Use | 143.6346 | 6.266336376 |
| 5. | Water Bodies | 47.8485 | 2.087483072 |
| 6. | Barren land | 905.4684 | 39.50280484 |

Table 1 reveals that in 2004, Durban's LULC showcased a landscape dominated by natural features. Barren land occupied the largest portion at 39.50% (905.47 km$^2$), followed by dense vegetation at 24.75% (567.21 km$^2$) and grasslands at 22.02% (504.79 km$^2$). Agricultural land covered 6.27% (143.63 km$^2$), while water bodies accounted for just 2.09% (47.85 km$^2$). Built-up areas, representing only 5.38% (123.21 km$^2$), indicated moderate urban development at the time. Figure 2 depicts the digitized map of the study area in 2004.

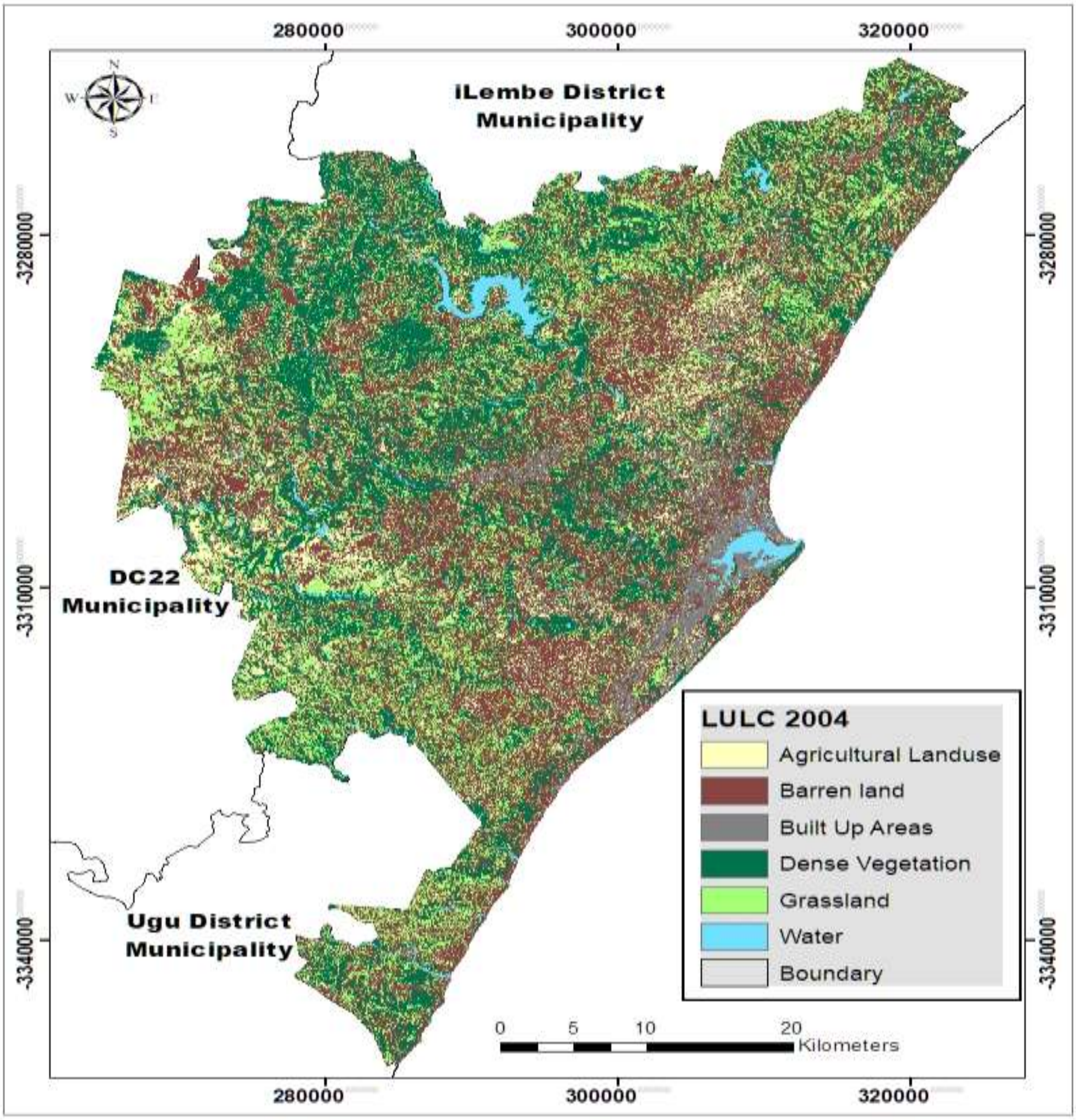


*Figure 2: Digitized Map of Durban in 2004*

**Table 2: Coverage area for each of the 6 classes of LULC (in km$^2$) of Durban in 2014**

| S/NO | LULC Types | Area | Percentage (%) |
|---|---|---|---|
| 1. | Built Up Areas | 282.2145894 | 12.31340277 |
| 2. | Grassland | 552.4069233 | 24.10225833 |
| 3. | Dense Vegetation | 843.7226778 | 36.81275719 |
| 4. | Agriculture Land Use | 78.71195039 | 3.434308445 |
| 5. | Water Bodies | 35.34508387 | 1.54215363 |
| 6. | Barren Land | 499.5289164 | 21.79511964 |

The LULC results in Table 2 depict that in 2014, the built-up areas increased to about 282.21 km$^2$ with 12. 31% of the total land area. Grassland occupied 52.407 km$^2$ with an increase to 24.10% of the total area. Dense vegetation occupied 843.72 km$^2$ with 36.81% making it the largest. Agriculture covered 78.71 km$^2$ with 3.43% of the total land area thus seen to have decreased from the previous year. Water bodies covered 35.35 km$^2$ with 1.84%, while barren land decreased to 499.53 km$^2$ with 21.80.% of the total land surface area. The result showed that the built-up area is increasing and is the driver of change in Durban. Figure 3 depicts the digitized map of the study area in 2014.

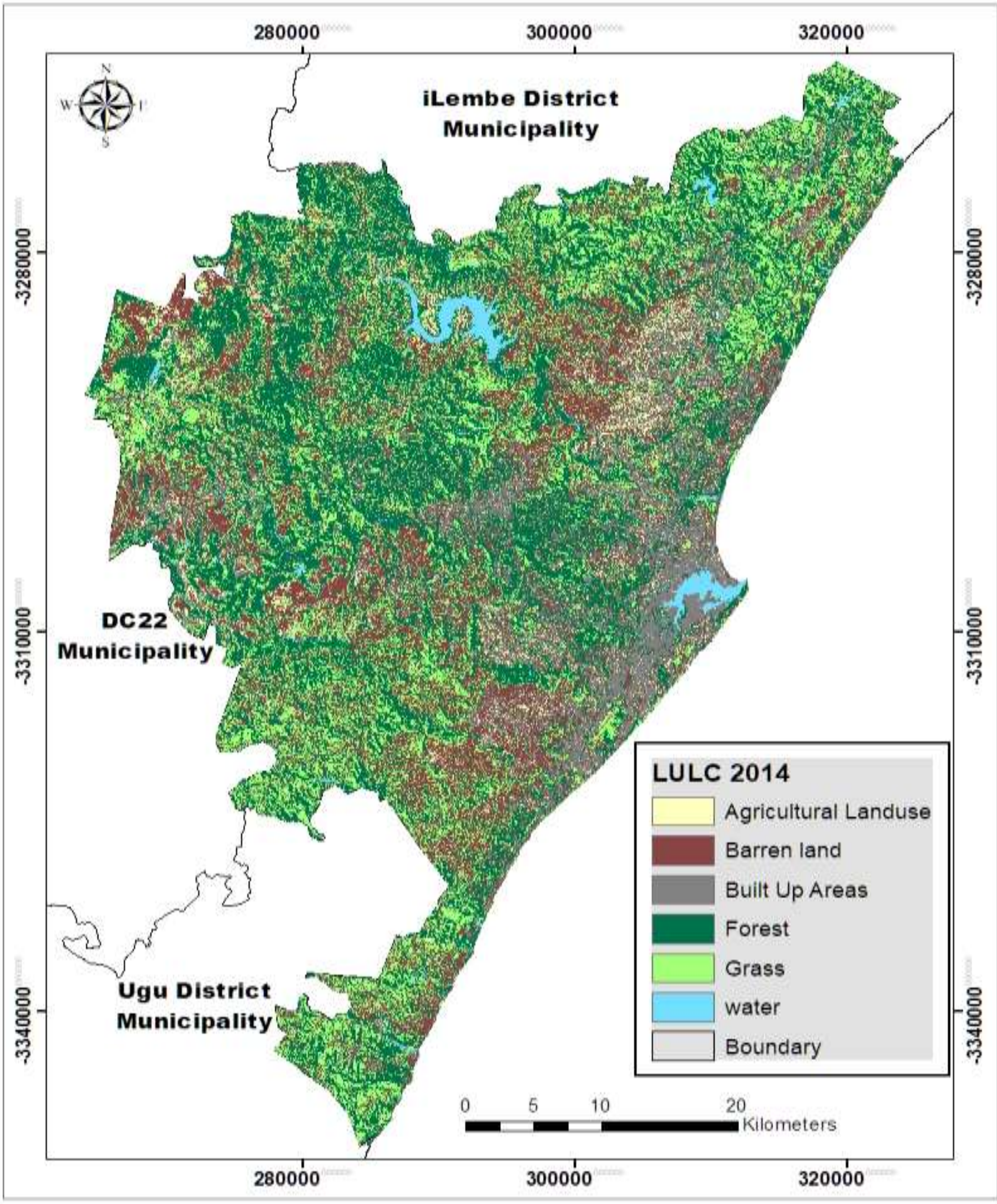


*Figure 4: Digitized Map of Durban in 2014*

**Table 3: Coverage area for each of the 6 classes of LULC (in km$^2$) of Durban in 2024**

| S/NO | LULC Types | Area | Percentage (%) |
|---|---|---|---|
| 1. | Built up | 442.9215 | 19.32330446 |
| 2. | Grassland | 786.1968 | 34.29935132 |
| 3. | Dense Vegetation | 553.4568 | 24.14562005 |
| 4. | Agricultural Land use | 51.7068 | 2.255808849 |
| 5. | Water Bodies | 29.1186 | 1.27035507 |
| 6. | Barren land | 428.7618 | 18.70556025 |

The 2024 LULC as indicated in Table 3 depicts that Built up areas have increased with a new coverage of 442.92 km$^2$ different from the previous years. The area now covers about 19.32 % of the total land area pointing as the key driver of land use change in Durban. Grassland occupied 786.19 km$^2$ constituting 34.30%. Dense vegetation covers 553.46 km$^2$ with 24.15%. Agriculture has reduced to

51.71 $km^2$ with approximately 2.26% of the land use. Water bodies occupied 29.12 $km^2$ with 1.27% of the total land area and barren land seems to have decreased to 428.76 $km^2$ with 18.71% which might be an indication that land has been cleared for future built up area. Figure 5 depicts the digitized map of the study area in 2024.

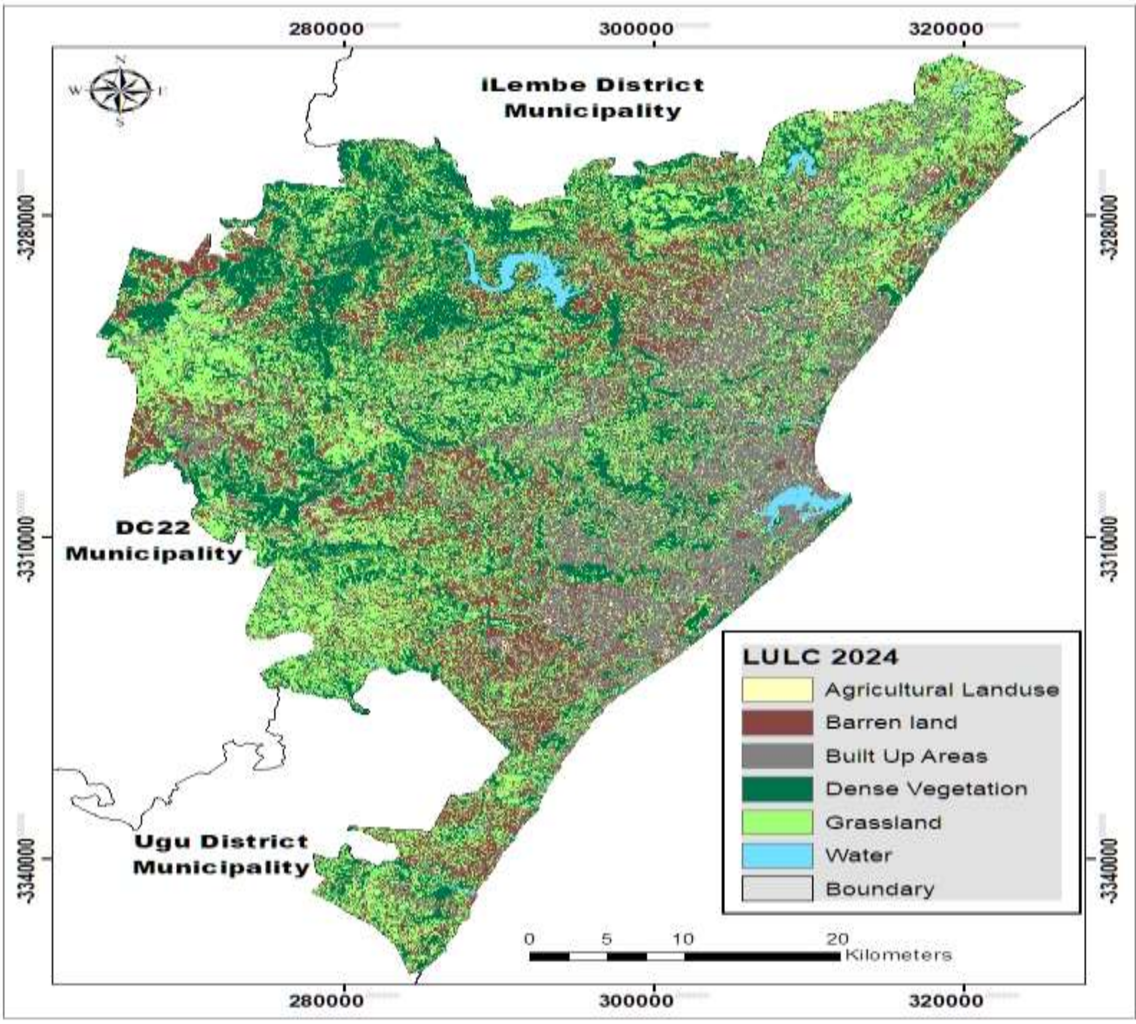


*Figure 5: Digitized Map of Durban in 2024*

**Table 4: Coverage area for each of the 6 classes of LULC (in $km^2$) of Durban in 2034**

| LULC Types | Area | Percentage (%) |
|---|---|---|
| Built Up Areas | 523.3206 | 22.69998944 |
| Grassland | 828.882 | 36.16157547 |
| Dense Vegetation | 434.4291 | 18.95280714 |
| Agricultural Land Use | 48.435 | 2.24395105 |
| Water | 23.8284 | 1.039559895 |
| Barren land | 433.2672 | 18.90211701 |

Table 4 depicts the LULC prediction for 2034, which was done with TerrSet software using the Markov chain formula. TerrSet is an integrated geospatial software system for monitoring and modeling the earth system for sustainable development.[30] Markov chain was used to predict and evaluate different scenarios for LULC change, formulate parameters and variables, and perceive patterns and their correlations. The Markov takes the maximum likelihood result of 2014 and 2024 as

[30] Hamad, Rahel, Heiko Balzter, and Kamal Kolo. "Predicting land use/land cover changes using a CA-Markov model under two different scenarios." *Sustainability* 10, no. 10 (2018): 3421.

the basis for prediction. It then takes the transition area change and the change probabilities of the dataset to predict the LULC for 2034. Based on the predicted result, the 2034 LULC indicates that Built up areas will continue to be the key driver of LULC change with its expected coverage to be 520.3206 $km^2$ with a total land coverage of 22.7%. Agriculture will decrease to 51.435 $km^2$ with 2.24% of the land use. Figure 6 depicts the digitized map of the study area in 2034.

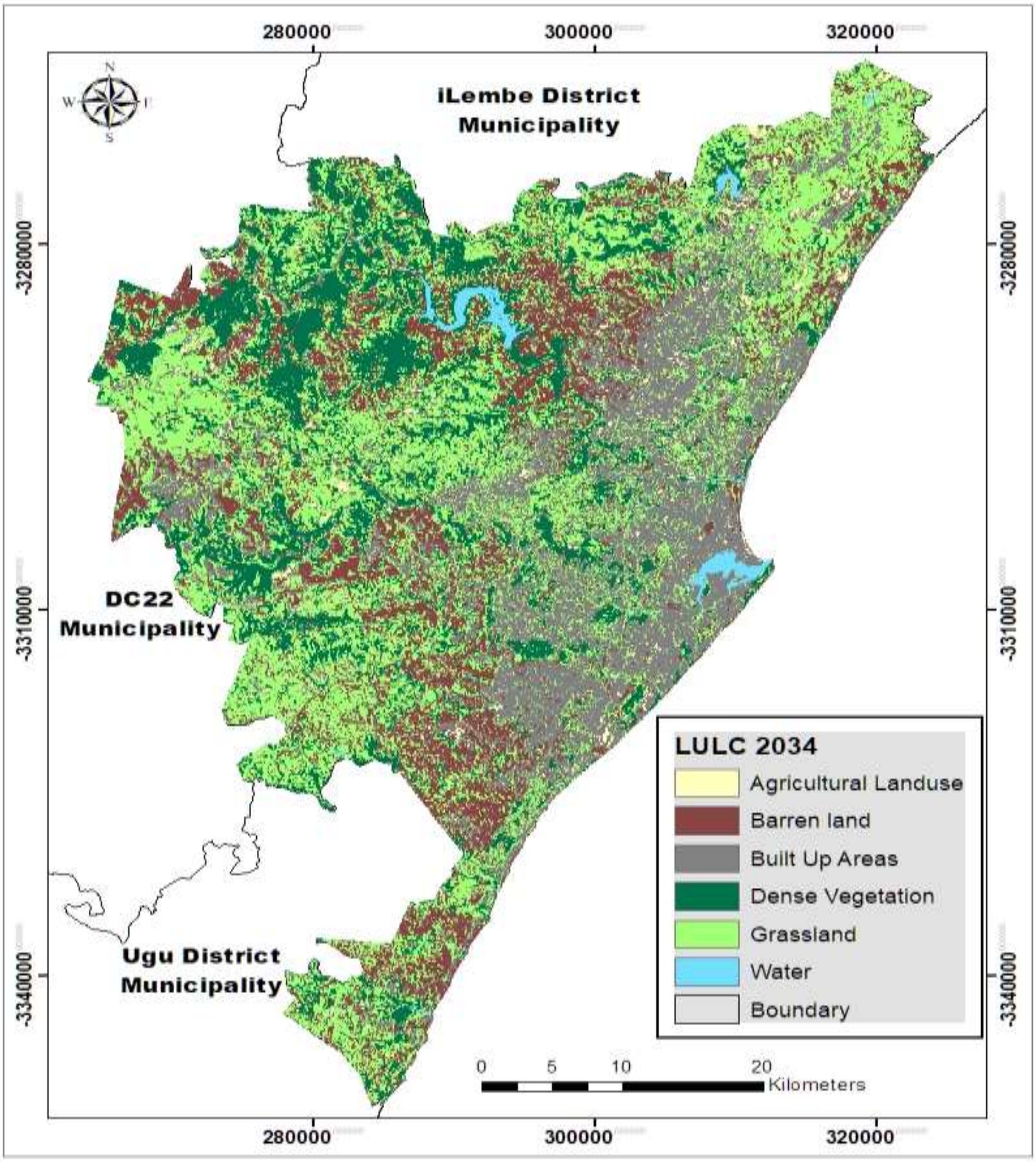


*Figure 6: A Projection Map of Durban in 2034*

**Digitized Overlay Maps of the Study Area from 2004 to 2024**

The digitized overlay maps of Durban from 2004 to 2024 offer a powerful visual representation of the city’s LULC changes over two decades. By layering spatial data from different years, the maps provide a comparative analysis of how the built-up areas, vegetation cover, water bodies, agricultural zones, grasslands, and barren lands have evolved over time. From 2004 to 2024, a significant expansion in built-up areas is evident, indicating increased urban development to accommodate population growth and economic activities. Conversely, dense vegetation and agricultural lands show noticeable shrinkage, underscoring the environmental trade-offs associated with urban expansion. In essence, the digitized overlay maps from 2004 to 2024 not only document Durban's morphological evolution but also serve as a vital tool for promoting sustainable urban planning and geography pedagogy. Figure 7 depicts the digitized overlay maps of the study area from 2004-2024.

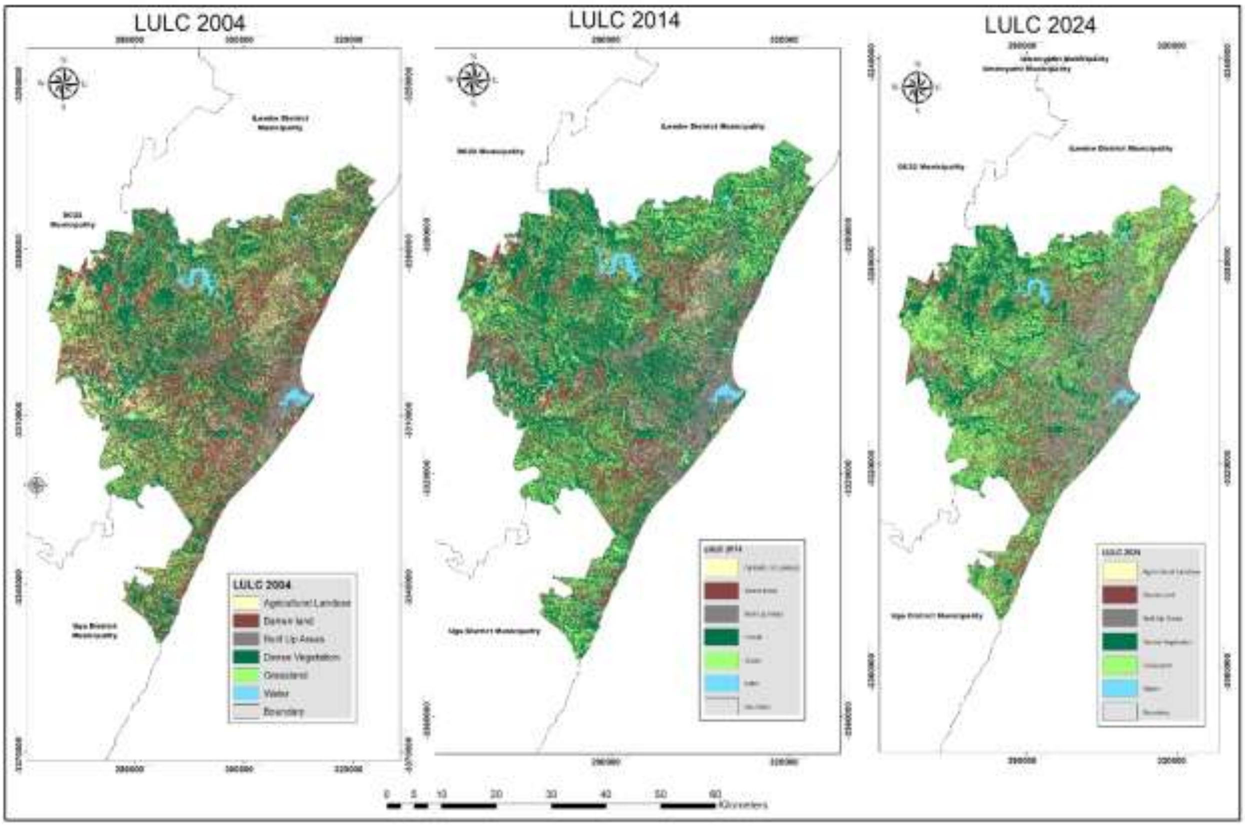


*Figure 7. Digitized Overlay Maps of the Study Area from 2004-2024 (Source: Authors)*

**Validation of LULC Results of the Study Area**

The LULC results were validated using the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built up Index (NDBI)

**a. Normalized Difference Vegetation Index (NDVI)**

NDVI (Normalized Difference Vegetation Index) is an indicator of plant health.[31] It is calculated based on visible and near-infrared light reflected by vegetation.[32] Healthy and unhealthy vegetation reflect and absorb these light spectra differently. Landsat 7 ETM, 8 and 9 satellite images were downloaded from USGS (USGS Earth Explore). The Landsat images band 5 and 4, representing the Near-infrared and Red, were used to analyze the NDVI of the study area for 2014 and 2024 while Landsat image bands 4 and 3 were used for 2004. The ArcGIS 10.8 Raster Calculator toolbox was used to process the satellite imagery.

$$NDVI = Near\ Infrared\ band - Red\ \ band \div Near\ Infrared\ band + Red\ band$$

In 2004, a vegetation range of -0.113797 to 0.457789, 2014 from -0.157078 to 0.654621 and 2024 from -0.128284 to 0.497212 which shows how healthy the vegetation is in the study area. The areas in green depict no or lack of vegetation while the yellow ones show unhealthy vegetation, and areas with deep green have healthier vegetation. Based on the result, the Built up areas and the barren land have a very low vegetation index while the dense vegetative area has the highest Vegetation index.

[31] Sha Huang et al., "A Commentary Review on the Use of Normalized Difference Vegetation Index (NDVI) in the Era of Popular Remote Sensing," *Journal of Forestry Research* 32, no. 1 (2021): 1–6.
[32] Genesis T. Yengoh et al., *Use of the Normalized Difference Vegetation Index (NDVI) to Assess Land Degradation at Multiple Scales: Current Status, Future Trends, and Practical Considerations* (Springer, 2015).

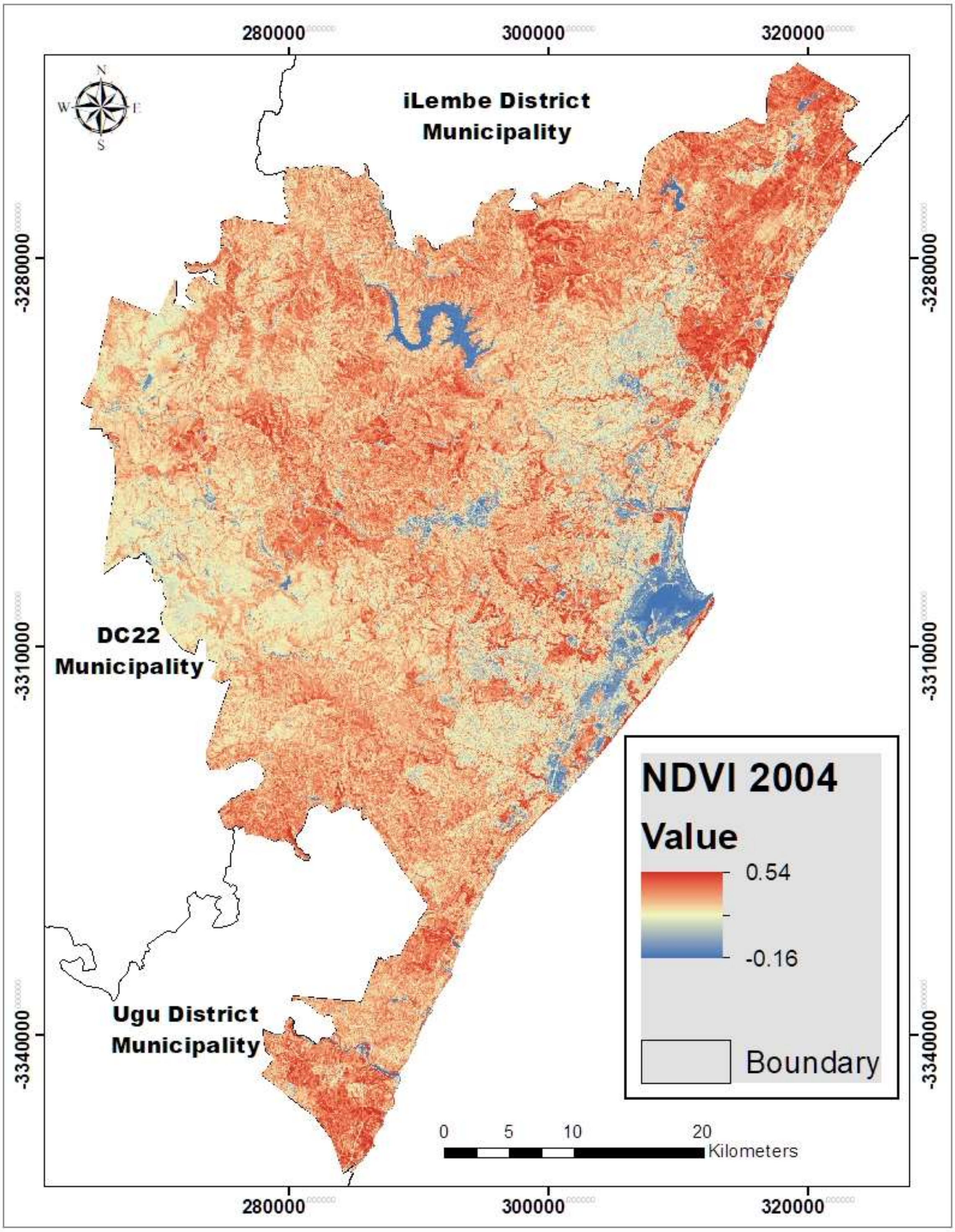


*Figure 8. Normalized Difference Vegetation Index (NDVI) for 2004*

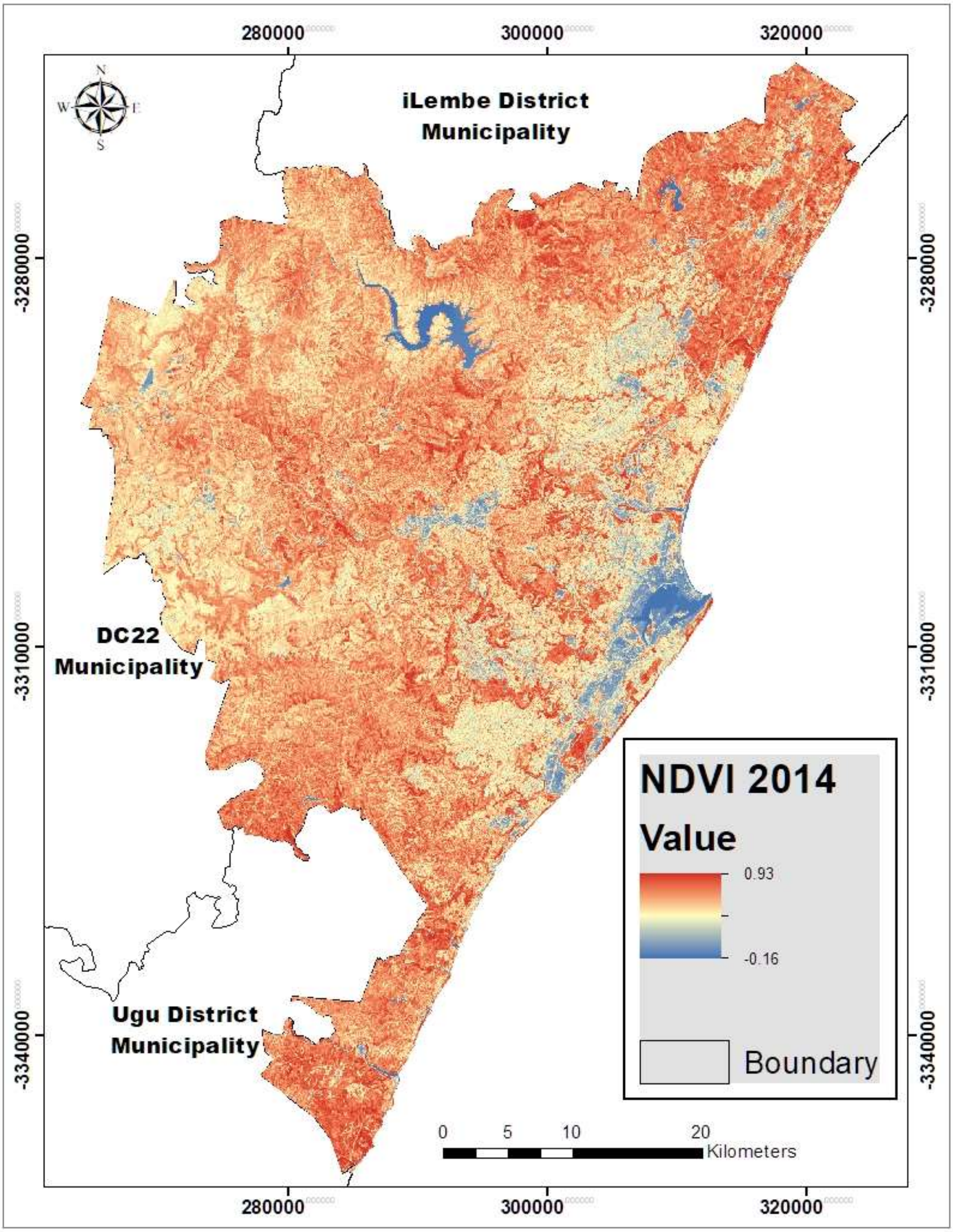


*Figure 9. Normalized Difference Vegetation Index (NDVI) for 2014*

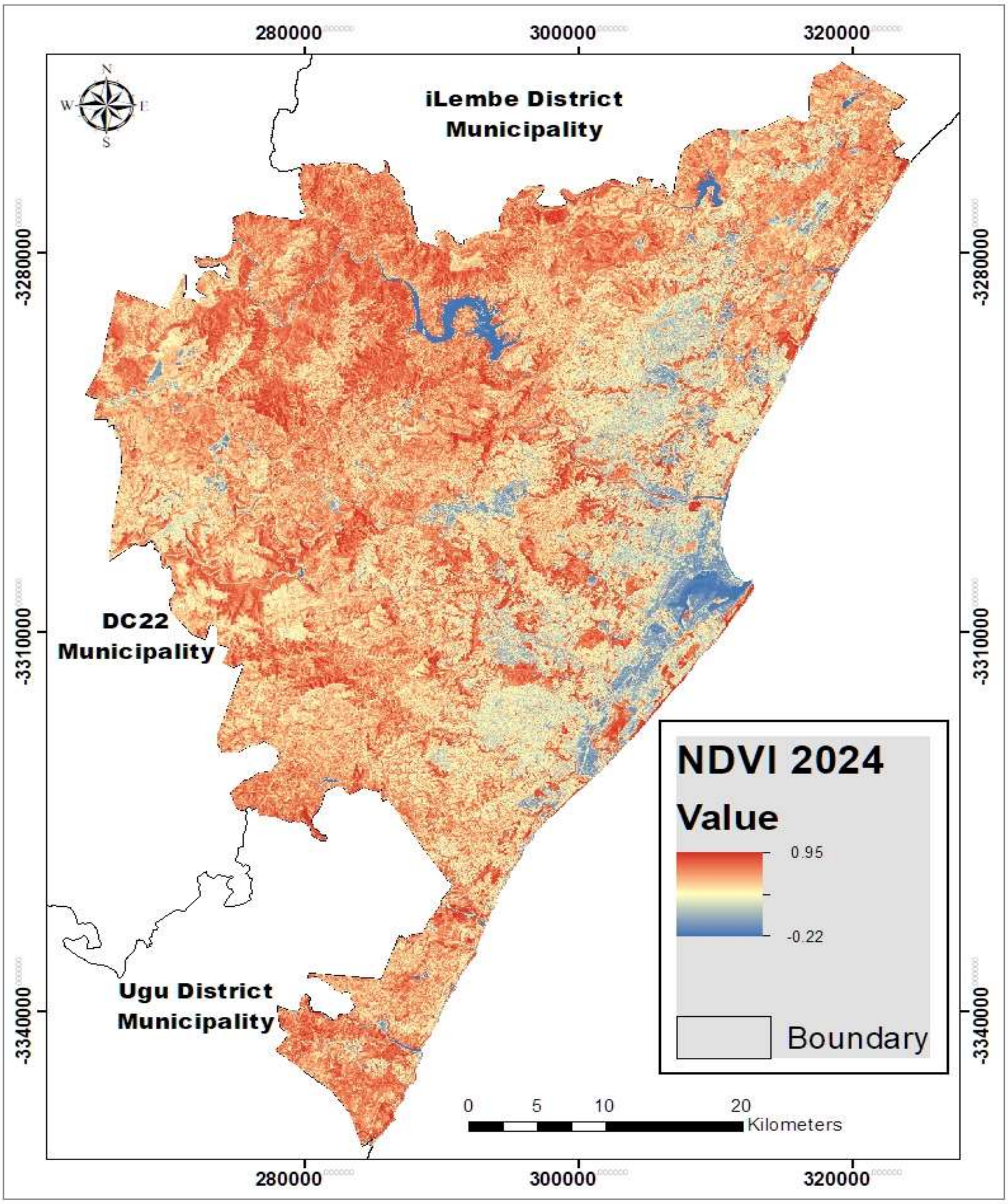


*Figure 10. Normalized Difference Vegetation Index (NDVI) for 2014*

a. **Normalized Difference Built up Index (NDBI)**

NDBI is an indicator used to separate built-up regions from undeveloped land by utilizing the differences in spectral reflectance of urban areas. It provides a quantitative measure of the degree of urbanization in a given area.[33] It is measured as

NDBI = (SWIR – NIR) / (SWIR + NIR)

For 2004 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4) while for 2014 and 2024 data, NDBI = (Band 6 – Band 5) / (Band 6 + Band 5).

[33] Hari Krishna Karanam and V B Neela, "Study of Normalized Difference Built-up (NDBI) Index in Automatically Mapping Urban Areas from Landsat TN Imagery," *Int J Eng Sci Math* 8 (2017): 239–48.

In 2004, the NDBI ratio ranged from -0.308048 to 0.248079, in 2014 from -0.415255 to 0.408963 and in 2024 from -0.35594 to 0.284506. The areas in green depict no built structure while the yellow ones show a mixture of built-up vegetation, and areas in red have high built-up structure. Based on the result, the Built-up areas and the barren land have a very high NDBI value while the vegetative areas have a low index.

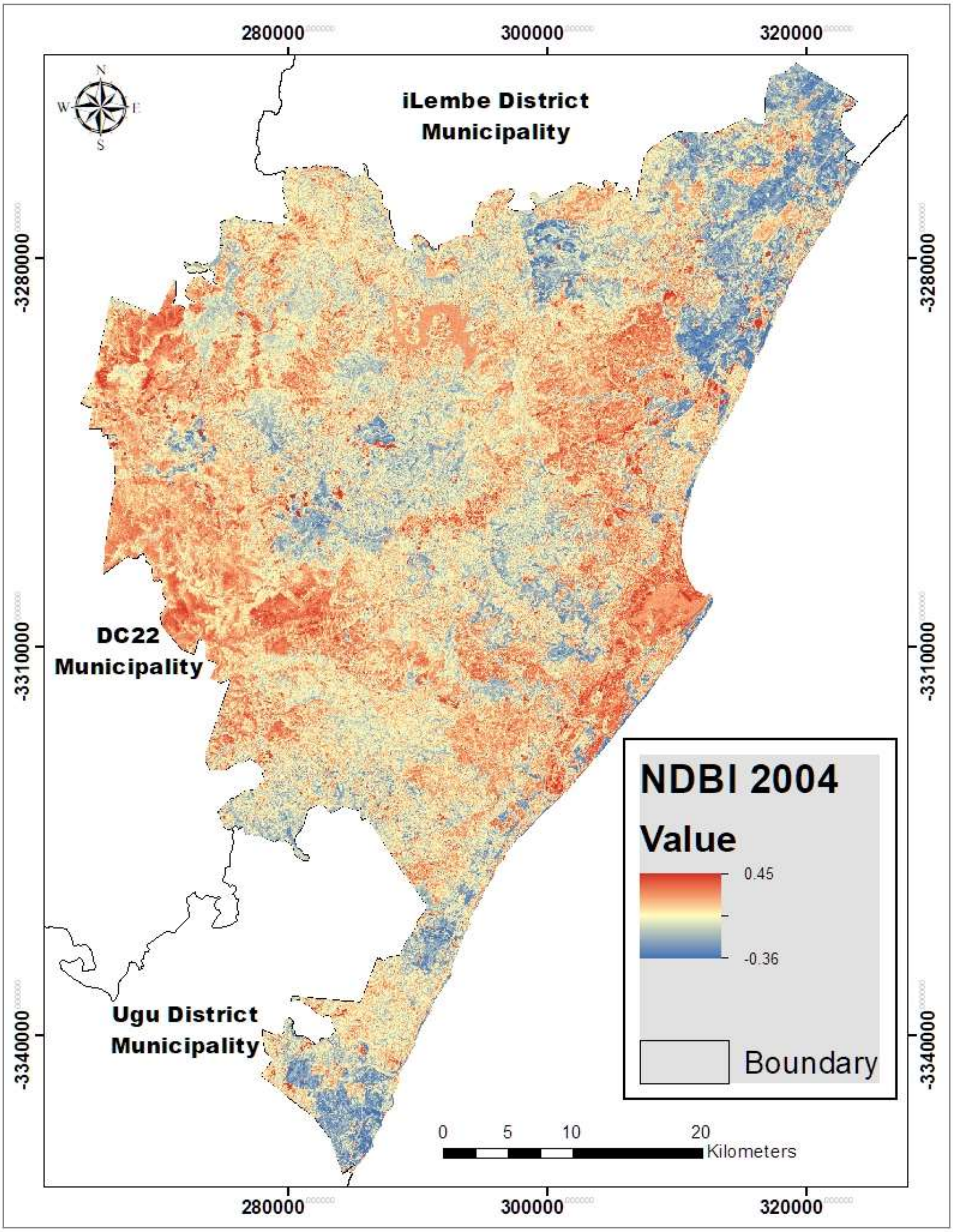


*Figure 11. Normalized Difference Built Up Index (NDBI) for 2004*

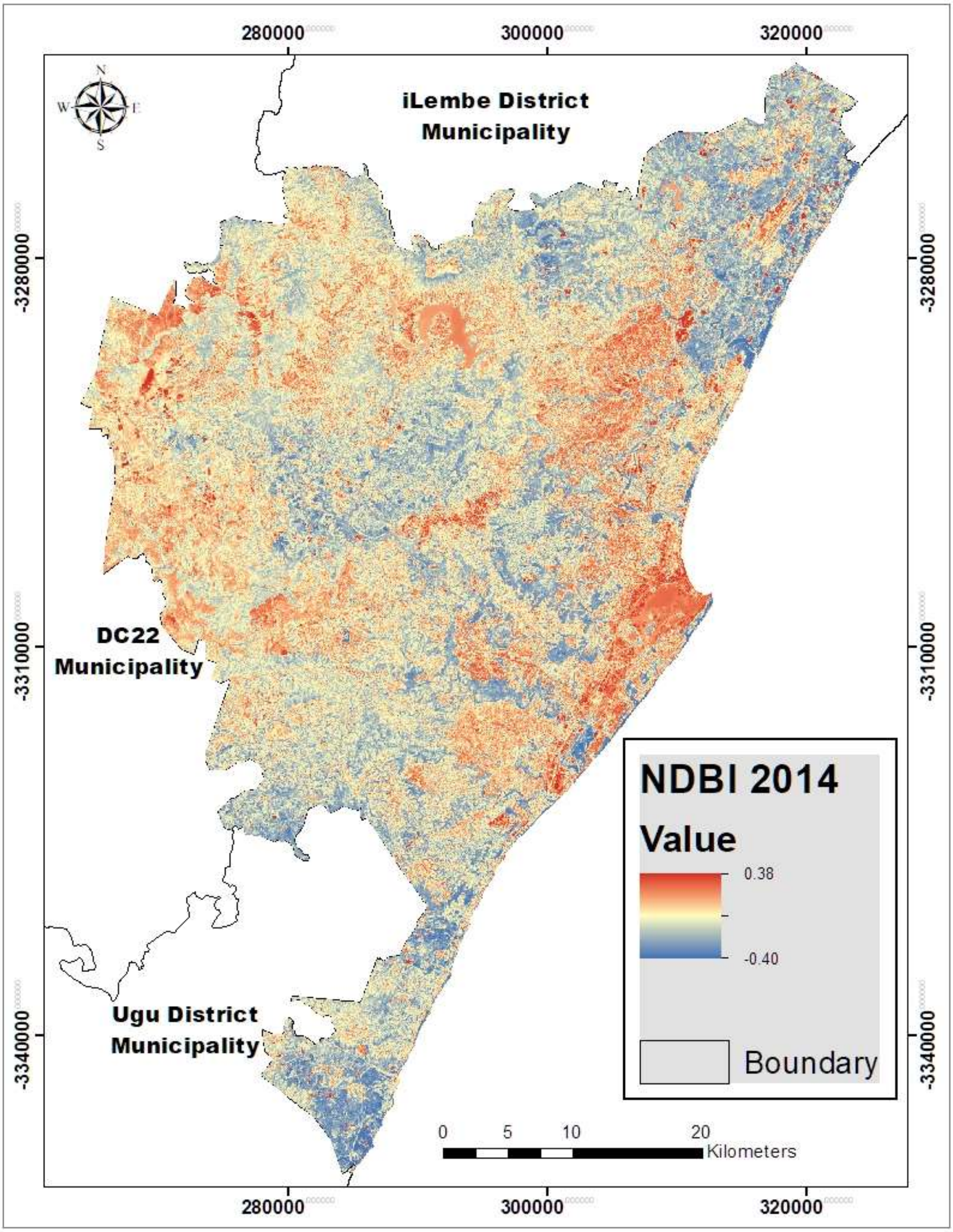


*Figure 12. Normalized Difference Built Up Index (NDBI) for 2014*

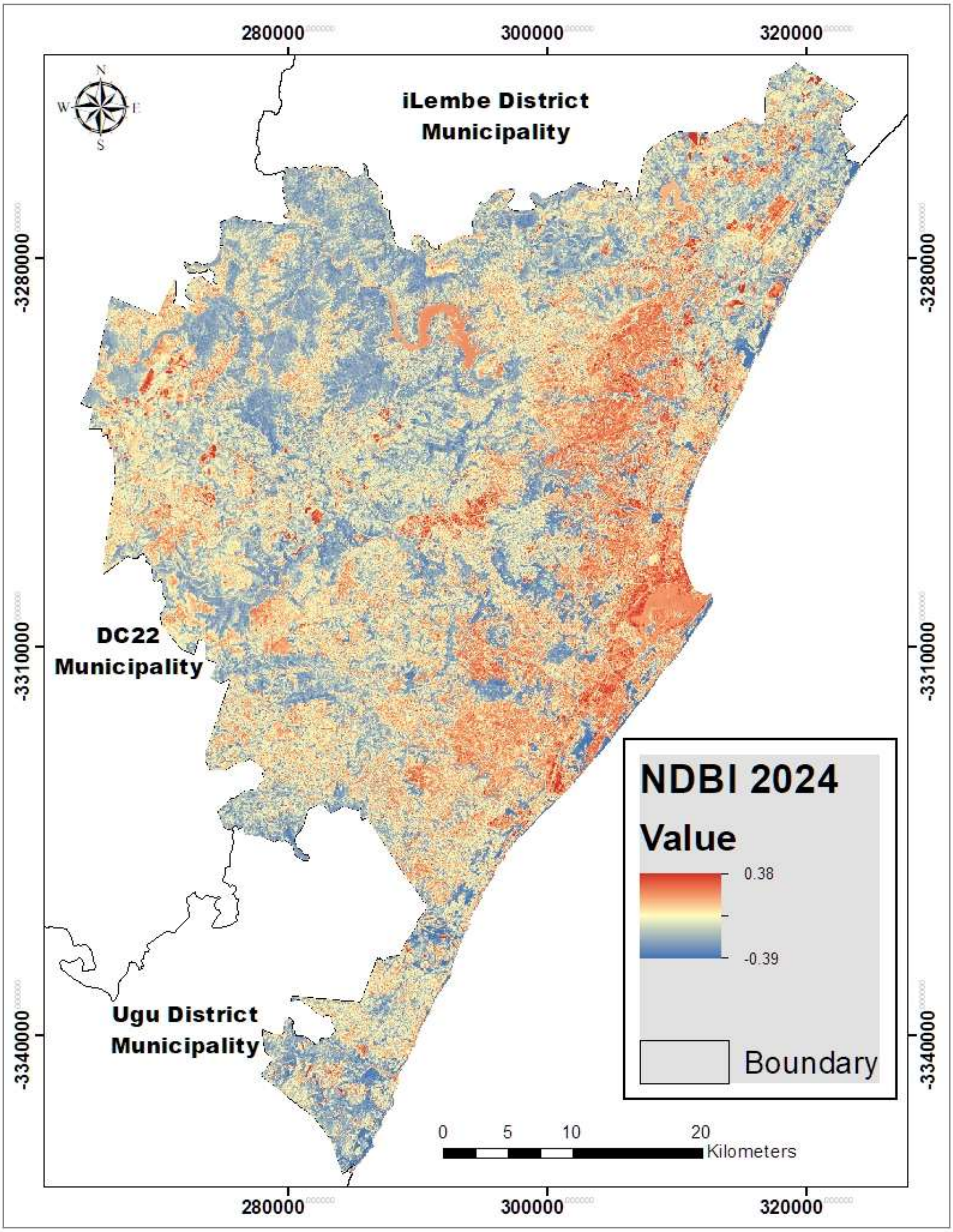


*Figure 13. Normalized Difference Built Up Index (NDBI) for 2024*

## DISCUSSION OF FINDINGS

The analysis of Durban's morphological dynamics from 2004 to 2024, alongside the 2034 LULC projections, reveals a scientifically significant trajectory of urban expansion with wide-ranging environmental and socio-economic implications. Employing a combination of remote sensing, GIS-based techniques, and predictive spatial modelling using the TerrSet software suite and the Markov chain algorithm, this study demonstrates the critical transformations in land use that reflect the broader processes of urbanization, ecological displacement, and land conversion in a rapidly developing South African metropolis. These findings contribute to the body of knowledge on urban geography by elucidating the quantitative and qualitative changes in Durban's landscape, and by offering a robust framework for geospatial pedagogy and applied urban sustainability planning.

**Scientific Interpretation of Morphological Dynamics:** Between 2004 and 2024, Durban underwent a pronounced shift from a landscape predominantly characterized by natural land covers to one increasingly dominated by anthropogenic structures. The initial dominance of barren land (39.50% in 2004) and dense vegetation (24.75%) suggests a peri-urban or semi-natural state in the early 2000s. However, this land pool progressively diminished over the years, giving way to built-up areas which grew from 5.38% in 2004 to 19.32% in 2024, a 259.4% increase in absolute area over two decades. This spatial conversion is scientifically significant as it highlights the critical thresholds at which ecological and urban systems intersect and often conflict. The projection for 2034 anticipates a further expansion of built-up land to 22.7% of total area. This trend confirms the validity of spatial prediction techniques employed, particularly the Markov chain, which leverages historical transition probabilities to model future states of land use. In this context, built-up areas function as the primary transition attractors, steadily encroaching upon agricultural land (which is projected to drop to just 2.24% by 2034) and natural vegetation, thereby underscoring a pattern of irreversible urban sprawl. The methodological integration of multi-temporal Landsat imagery, NDVI, and NDBI ensures scientific rigor in detecting and validating these land cover changes. The NDVI results consistently showed that healthy vegetation (with NDVI values closer to +1) is in decline, particularly in areas being replaced by infrastructure. Conversely, the rising NDBI values reflect intensification of urban impervious surfaces.

**Environmental Implications:** The environmental ramifications of these morphological transitions are profound. The continual conversion of vegetated and barren lands into built-up zones directly threatens biodiversity, fragments habitats, and disrupts ecosystem services such as carbon sequestration, air purification, and stormwater regulation. The decline in agricultural land also signals a reduction in urban and peri-urban food production capacity, raising concerns over local food security and sustainable land stewardship. Furthermore, the reduction in dense vegetation (from 843.72 km² in 2014 to 553.46 km² in 2024) could lead to an increase in the urban heat island (UHI) effect due to the prevalence of impervious surfaces and reduced evapotranspiration. These land transitions also heighten the city's vulnerability to climate change-related phenomena such as flash flooding and prolonged droughts, particularly in a coastal city like Durban. Hydrologically, the steady decline in water bodies (from 2.09% in 2004 to 1.27% in 2024) exacerbates the risk of water scarcity and degradation of aquatic ecosystems. This shrinkage can be attributed to land reclamation, catchment disruption, and altered drainage patterns due to urban infrastructure development. The presence of expansive barren lands transitioning to built-up zones may also lead to soil sealing and loss of groundwater recharge zones, disrupting local hydrological cycles.

**Socio-Economic Implications:** The socio-economic implications of the spatial dynamics observed in Durban are equally significant. The sharp increase in built-up areas reflects population pressure, rural-to-urban migration, and housing demand, suggesting a city that is rapidly densifying without commensurate infrastructure planning. This can lead to uneven development, informal settlements, and spatial inequality, particularly if urban growth outpaces service delivery and inclusive land use policies. The loss of agricultural land not only impacts food production but also disrupts rural livelihoods and traditional land tenure systems, potentially exacerbating socio-economic disparities. Marginalized communities, especially those in peri-urban areas, may face displacement or exclusion from new urban developments, a concern that reflects broader patterns of spatial injustice in post-apartheid urban planning. Conversely, the observed urban expansion may present economic opportunities in the form of increased employment in construction, retail, and services. However, such economic gains must be critically assessed against environmental costs and issues of long-term sustainability. Without sustainable planning frameworks, urban expansion risks perpetuating cycles of poverty, environmental degradation, and infrastructural inadequacy.

**Implications for Urban Geography Pedagogy:** From a pedagogical standpoint, the findings of this study offer critical teaching and learning opportunities in urban geography, geospatial science, and environmental studies. The dynamic LULC transitions and predictive modelling approach provide a robust empirical basis for engaging students in scenario analysis, systems thinking, and critical spatial inquiry. The integration of NDVI and NDBI as validation tools not only enhances technical competencies in remote sensing but also equips learners with analytical frameworks to assess urban ecological health and development intensity. Furthermore, these tools and data sets can be used in classrooms to simulate real-world urban planning scenarios, allowing students to interrogate trade-offs between development and conservation, design spatial justice interventions, and apply geographic theories to practice. By embedding such geospatial methodologies into curriculum design, educators can foster spatial literacy, environmental stewardship, and policy-oriented thinking among students. At this juncture, it is imperative to elucidate that this study provides a comprehensive scientific appraisal of Durban's land use transformation, using a multi-method geospatial approach. The findings underscore the need for a paradigm shift in urban governance that balances development needs with environmental protection and social equity. As cities like Durban continue to grow, the application of predictive spatial analysis in urban geography education becomes vital for preparing a generation of planners, researchers, and decision-makers who are capable of managing urban transitions in a scientifically informed and ethically grounded manner. The intersection of morphology, environment, and socio-economic dynamics must therefore be central to any discourse on sustainable urban futures.

## RECOMMENDATIONS

The study recommends the integration of GIS-based spatial analysis and predictive modelling into urban planning strategies to promote sustainable land use management. Policymakers should implement green infrastructure initiatives to mitigate the rapid decline of vegetation and address the environmental impacts of urban expansion. Additionally, urban planners must adopt data-driven decision-making approaches using NDVI and NDBI analyses to monitor land cover changes and improve resource allocation. In education, incorporating spatial modelling techniques into the geography curriculum will enhance students' analytical skills and prepare them for careers in urban and environmental management. Finally, further research should explore the socioeconomic and ecological implications of urban growth to develop comprehensive strategies for balancing development with environmental sustainability.

## CONCLUSION

This study has highlighted the rapid transformation of Durban's urban landscape, revealing a significant expansion of built-up areas at the expense of natural vegetation. The strong negative correlation between NDVI and NDBI underscores the pressing environmental challenges posed by unchecked urbanization, necessitating urgent interventions for sustainable land management. By integrating GIS-based spatial modelling into urban planning and geography education, this research provides a vital framework for informed decision-making and capacity-building in spatial analysis. Moving forward, a balanced approach to development, one that prioritizes both urban growth and ecological sustainability, is crucial to ensuring a resilient and livable city for future generations.

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