



# Advancing urban geography pedagogy in a South African metropolis through geospatial intelligence and applied spatial modelling

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## ABSTRACT

This study highlights the transformative potential of geo-spatial analysis and spatial prediction techniques in using the dynamic morphology of the Durban Metropolis as a model for fostering innovative, data-driven learning experiences. The methodology integrates quantitative and geospatial data analysis of Land Use and Land Cover (LULC) changes from 2004 to 2024 using GIS-based change detection tools to identify and predict LULC change patterns in 2034. The study was underpinned by a geospatial-analytical framework in which secondary remote sensing datasets, GIS-based LULC classification outputs, NDVI/NDBI indices, and Markov Chain spatial modelling served as the primary data collection instruments for interpreting urban change through a spatial–theoretical lens. The research findings revealed that built-up areas expanded significantly from 123.21 km<sup>2</sup> (5.38%) in 2004 to 442.92 km<sup>2</sup> (19.32%) in 2024, while agricultural lands, dense vegetation, and water bodies steadily declined, signaling ongoing environmental changes and urban pressures that are predicted to intensify to 520.3 km<sup>2</sup> (22.7%) by 2034. The study concludes 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 primarily contributes to the Scholarship of Teaching and Learning in its development and empirical validation of an integrative pedagogical model, and by articulating/testing a new signature pedagogy for urban geography.

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

## INTRODUCTION

Urbanization is one of the most significant global trends of the 21st century,<sup>1</sup> driving economic growth, innovation, and improved living standards.<sup>2</sup> However, when left uncontrolled, it can lead to

<sup>1</sup> Hania Zlotnik, “World Urbanization: Trends and Prospects,” in *New Forms of Urbanization* (Routledge, 2017), 43–64.

<sup>2</sup> Chaolin Gu, “Urbanization: Processes and Driving Forces,” *Science China Earth Sciences* 62, no. 9 (2019): 1351–60.

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overcrowded cities, environmental degradation, and unsustainable resource consumption, highlighting the urgent need for effective strategies to manage urban growth.<sup>3</sup> This is where advanced analytical tools like geo-spatial analysis and spatial prediction techniques become invaluable, offering critical insights into the complex dynamics of urban development.<sup>4</sup> 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.<sup>5</sup> As urban areas expand, understanding the drivers and patterns of urban morphology is crucial for fostering sustainable development.<sup>6</sup> 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.<sup>7</sup> 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.<sup>8</sup> 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.<sup>9</sup> This study addresses that gap by exploring how geo-spatial technologies, such as Geographic Information Systems (GIS), can be utilized in urban geography. 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 equips students with the skills necessary to address the complexities of urban sustainability.<sup>10</sup>

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.<sup>11</sup> As these cities expand, they face complex socio-economic, environmental, and spatial issues that require innovative solutions.<sup>12</sup> Unfortunately, traditional urban geography education has largely failed to integrate modern technological tools, such as geo-spatial analysis and spatial prediction techniques, which are essential for understanding and managing the intricate dynamics of urban morphology.<sup>13</sup> Without these advanced tools, students are left with limited opportunities to grasp the complexities of urban growth and transformation in real-time.<sup>14</sup> Furthermore, despite the availability of vast spatial data and predictive modeling capabilities, educators often lack the frameworks to incorporate these technologies into the curriculum effectively.<sup>15</sup>

This gap in pedagogy leaves students ill-prepared to engage with urban issues, hindering their ability to contribute to solutions for sustainable urban development. Hence, the study responds to the research question: *“To what extent does a pedagogical intervention integrating geospatial intelligence*

<sup>3</sup> Gu, “Urbanization: Processes and Driving Forces.”

<sup>4</sup> 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.

<sup>5</sup> Patrick B., Cobbinah and Moses Addaney, *Sustainable Urban Futures in Africa* (New York: Routledge, 2022).

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

<sup>7</sup> 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.

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

<sup>9</sup> Jongwon Lee, “Beyond Geospatial Inquiry—How Can We Integrate the Latest Technological Advances into Geography Education?,” *Education Sciences* 13, no. 11 (2023): 1128.

<sup>10</sup> 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 (2024): 190–210.

<sup>11</sup> Sean Fox and Tom Goodfellow, *Cities and Development* (London: Routledge, 2016).

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

<sup>13</sup> 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).

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

<sup>15</sup> 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.

and applied spatial modelling foster critical spatial literacy and transform students' understanding of post-apartheid urban socio-spatial inequalities in a South African metropolis?" The need for a more robust, data-driven approach to urban geography education is critical, as it would equip learners with the skills necessary to navigate and address the evolving challenges of coastal urbanization. This study aims to address this gap by exploring how geo-spatial analysis and spatial prediction techniques can be integrated into urban geography, 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.<sup>16</sup> Durban, a rapidly expanding coastal city in South Africa, exemplifies these challenges, making it a compelling case for investigating urban morphological dynamics.<sup>17</sup> 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. Geo-spatial 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 modeling in tracking land use changes, forecasting growth, and guiding urban planning decisions.<sup>18</sup> 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.<sup>19</sup> Constructivist learning theorists advocate for pedagogical strategies that actively involve learners in analyzing real-world issues, promoting deeper engagement, and meaningful learning experiences.<sup>20</sup> In line with this, incorporating geo-spatial tools into geography education empowers students to explore dynamic urban environments, analyze spatial patterns, and predict changes.<sup>21</sup> Despite the extensive body of research on urbanization and geo-spatial 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 geo-spatial analysis and spatial prediction techniques can revolutionize urban geography education.

### Teaching Predictive Spatial Modeling for Urban Growth

Predictive spatial modeling plays a crucial role in understanding and forecasting urban growth patterns, providing valuable insights for urban planners, policymakers, and educators.<sup>22</sup> In geography education, introducing students to spatial modeling techniques such as Cellular Automata (CA), and Markov Chain Analysis (MCA), among other learning models equips the students with analytical skills to assess past

<sup>16</sup> 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.

<sup>17</sup> 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.

<sup>18</sup> 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.

<sup>19</sup> 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.

<sup>20</sup> Olatoye and Fru, "A Review towards Enhancing Geospatial Technologies in South African Rural Education."

<sup>21</sup> Olatoye and Fru, "A Review towards Enhancing Geospatial Technologies in South African Rural Education."

<sup>22</sup> 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.

trends and predict future LULC changes.<sup>23</sup> These methodologies enable students to understand how urban landscapes evolve due to socio-economic, environmental, and policy-driven factors.<sup>24</sup> By integrating predictive modeling into the geography curriculum, educators can enhance learners' ability 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.<sup>25</sup> 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.<sup>26</sup> Hence, students can estimate the likelihood of different LULC categories changing in the future by applying MCA, and this helps the students to understand urban expansion scenarios.<sup>27</sup> 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.<sup>28</sup> Hence, the integration of predictive spatial modeling into geography education requires a curriculum that balances theoretical concepts with hands-on GIS applications.

## METHODOLOGY

### Research Design

This study adopted a mixed-methods geospatial research design, integrating quantitative spatial analysis with pedagogical interpretation to examine how geospatial intelligence and applied spatial modelling can enhance urban geography education in South Africa. The design strategically combined remote sensing, GIS-based land use modelling, and educational analysis, enabling the researchers to both quantify urban morphological change in Durban Metropolis and evaluate its instructional value for urban geography pedagogy.

### Quantitative Geospatial Component

The primary component of the research design was quantitative, focusing on temporal and spatial measurement of LULC change. Multi-temporal satellite imagery (2004, 2014, 2024) was sourced and processed using supervised classification techniques. Standard preprocessing procedures, including atmospheric correction, band stacking, masking, and geometric alignment, were applied to ensure spatial accuracy. Change detection algorithms, including post-classification comparison and transition matrices, were employed to quantify conversions among built-up areas, vegetation, agriculture, and water bodies. To project future urban expansion, the study utilised cellular automata–Markov chain modelling, enabling the prediction of LULC configurations for 2034. This predictive modelling formed the basis for identifying emerging environmental pressures and patterns of urban sprawl.

### Pedagogical and Curriculum Analysis Component

Complementing the spatial data analysis, the study incorporated a qualitative educational analysis, examining how geospatial outputs can be embedded in teaching and learning. Documents such as curriculum guidelines, university geography modules, and pedagogical frameworks were analysed to determine the alignment between current urban geography teaching practices and cutting-edge geospatial technologies. This component enabled the interpretation of spatial results through an educational lens, identifying opportunities where predictive spatial models can strengthen students' spatial reasoning, environmental literacy, and applied analytical skills. Both datasets were merged

<sup>23</sup> Tariq and 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."

<sup>24</sup> 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).

<sup>25</sup> 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.

<sup>26</sup> Quanli Xu, A-Xing Zhu, and Jing Liu, "Land-Use Change Modeling with Cellular Automata Using Land Natural Evolution Unit," *Catena* 224 (2023): 106998.

<sup>27</sup> Olatoye and Fru, "A Review towards Enhancing Geospatial Technologies in South African Rural Education."

<sup>28</sup> Ghosh et al., "Application of Cellular Automata and Markov-Chain Model in Geospatial Environmental Modeling-A Review."

under an integrated geospatial-pedagogical framework, allowing the study to move beyond descriptive mapping towards understanding *how* dynamic urban morphologies can be used as instructional tools. This integration made it possible to interpret spatial trends not only as environmental phenomena but also as pedagogical resources for developing student competence in GIS-based urban analysis.

### 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.<sup>29</sup> These warm current moderates result in mild, dry winters with daytime temperatures averaging 11°C and hot, humid summers reaching an average of 28°C.<sup>30</sup> The rainy season typically spans from September to March, contributing to an annual precipitation exceeding 1,000 millimeters.<sup>31</sup> Figure 1 presents the digitized map of the study area.

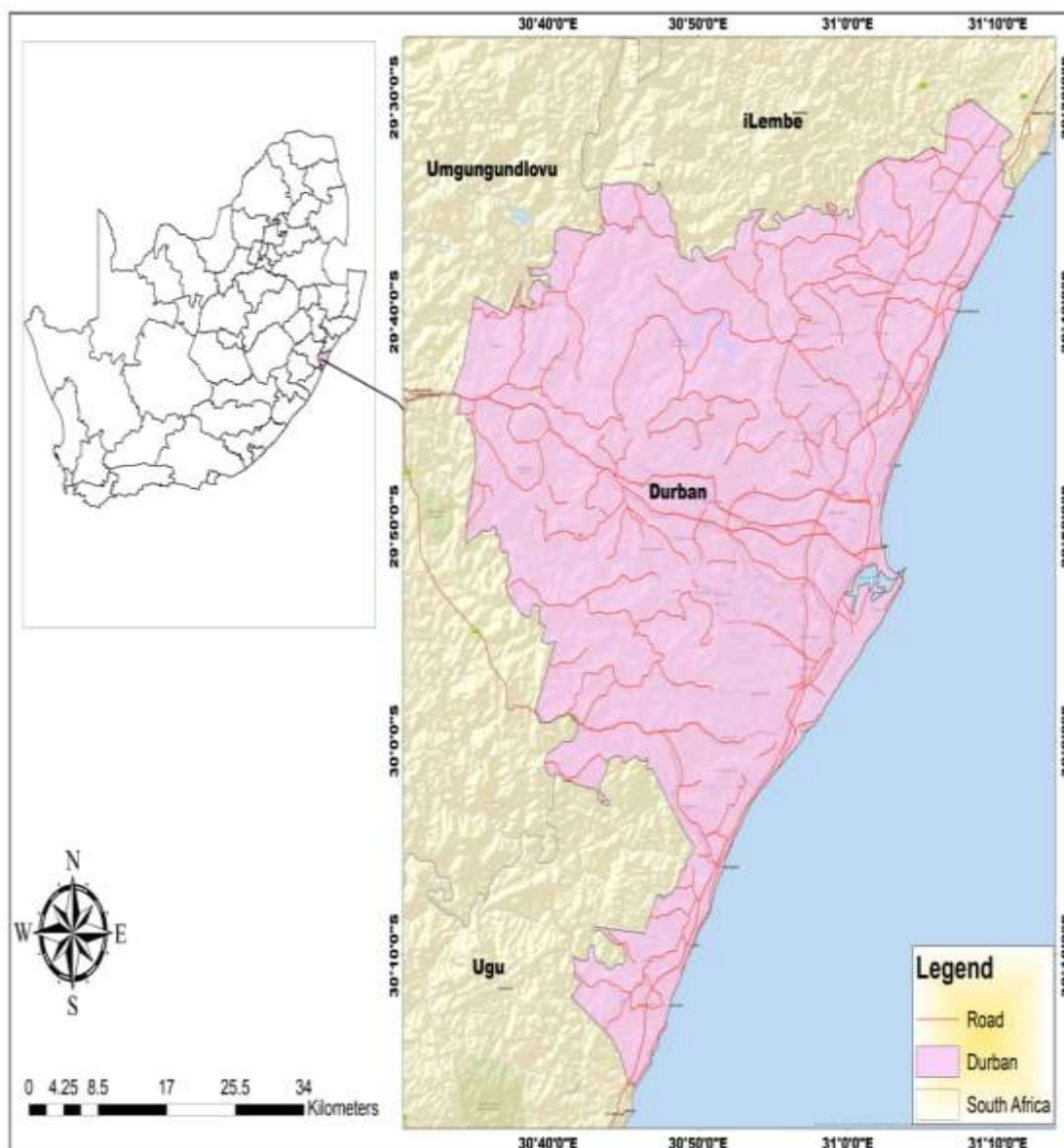


Figure 1: Digitized Political Map of the Study Area

<sup>29</sup> Olatoye and Naidu, "Integrating Geo-Spatial Analysis with Cultural and Social Dynamics of Green Space Access in Durban Central Business District, South Africa."

<sup>30</sup> Debra Roberts et al., "Durban, South Africa," in *Cities on a Finite Planet* (Routledge, 2016), 96–115.

<sup>31</sup> Meryl Jagarnath, Tirusha Thambiran, and Michael Gebreslasie, "Modelling Urban Land Change Processes and Patterns for Climate Change Planning in the Durban Metropolitan Area, South Africa," *Journal of Land Use Science* 14, no. 1 (2019): 81–109.

## **Sampling**

This study did not involve human participants; instead, it relied on purposively selected spatial datasets required for analyzing LULC change within the Durban Metropolis. A purposive sampling strategy was employed to obtain geospatial datasets that were spatially relevant, temporally consistent, and methodologically appropriate for multi-year comparative analysis. Satellite imagery for the years 2004, 2014, 2024, and predictive modelling inputs for 2034 were selected based on criteria such as spatial resolution, cloud cover percentage, spectral bands suitability, and compatibility with GIS-based change detection algorithms. Data sources included Landsat (TM, ETM+, OLI) imagery and municipal spatial layers obtained from publicly accessible geospatial repositories. The sampling period of 20 years was intentionally chosen to capture long-term urban growth trajectories and environmental transitions. This sampling approach ensured that only high-quality, comparable, and methodologically robust geospatial data were included to support accurate LULC classification, temporal analysis, and spatial prediction modelling.

## **Data Collection and Analysis Procedures**

Initially, spatial data were collected from the United States Geological Survey (USGS) website, providing a robust foundation for analysis. A time-series analysis of 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 modeling 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 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, agricultural land use, 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.

## **Ethical Considerations**

This study adhered to established ethical standards for research involving secondary geospatial datasets and educational applications. Since the analysis relied exclusively on publicly available satellite imagery, land-use datasets, and aggregated environmental information from reputable open-source portals of the USGS, no human participants were involved, and therefore, direct personal or sensitive data were not collected. Nonetheless, ethical clearance was sought and obtained from the Sol Plaatje University Ethics Committee to ensure compliance with the university's guidelines for responsible research conduct. All geospatial data were used solely for academic purposes and analyzed in accordance with fair-use and data-sharing policies of the respective providers. Proper citation and acknowledgment of data sources were maintained to uphold intellectual property and academic integrity. Care was taken to prevent any misrepresentation of spatial information, particularly during the creation of maps, models, and predictive surfaces. The study avoided generating outputs that could stigmatize specific communities or misinterpret urban growth dynamics. GIS analyses were conducted responsibly to ensure that spatial predictions did not imply determinism but were presented as

probabilistic, model-based projections. The study also ensured transparency by documenting all methodological steps, datasets used, and analytical tools employed. Finally, when integrating findings into pedagogical recommendations, the study considered ethical principles of inclusivity, equity, and responsible technological adoption in educational settings to avoid reinforcing spatial inequalities or digital divides.

### PRESENTATION OF FINDINGS

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<sup>2</sup>) 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<sup>2</sup>), followed by dense vegetation at 24.75% (567.21 km<sup>2</sup>) and grasslands at 22.02% (504.79 km<sup>2</sup>). Agricultural land covered 6.27% (143.63 km<sup>2</sup>), while water bodies accounted for just 2.09% (47.85 km<sup>2</sup>). Built-up areas, representing only 5.38% (123.21 km<sup>2</sup>), indicated moderate urban development at the time. Figure 2 depicts the digitized map of the study area in 2004.

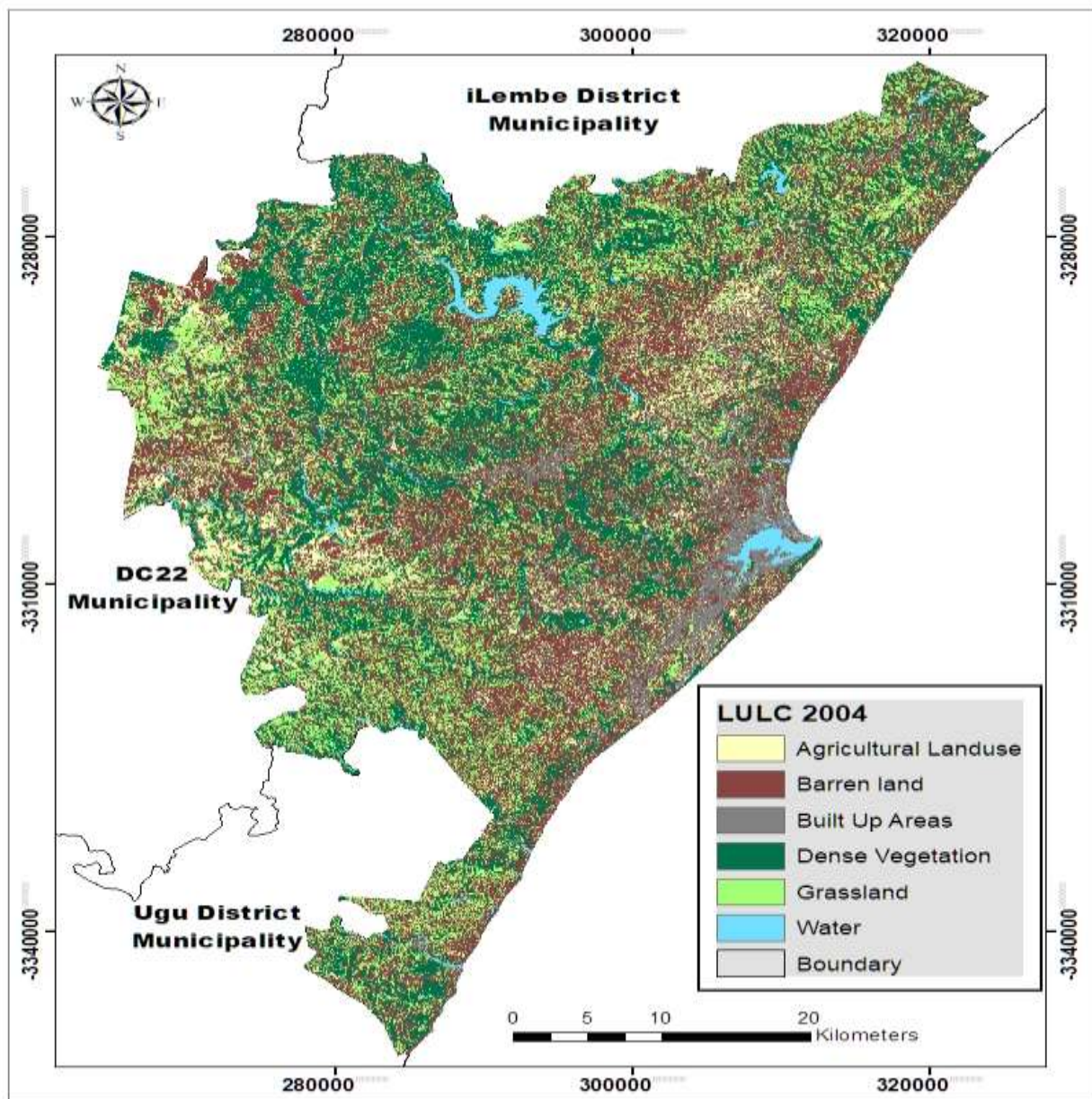


Figure 2: Digitized Map of Durban in 2004

Table 2: Coverage area for each of the 6 classes of LULC (in km<sup>2</sup>) 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<sup>2</sup> with 12.31% of the total land area. Grassland occupied 52.407 km<sup>2</sup> with an increase to 24.10% of the total area. Dense vegetation occupied 843.72 km<sup>2</sup>, accounting for 36.81%, making it the largest. Agriculture covered 78.71 km<sup>2</sup> with 3.43% of the total land area, thus seen to have decreased from the previous year. Water bodies covered 35.35 km<sup>2</sup> with 1.84%, while barren land decreased to 499.53 km<sup>2</sup> with 21.80% of the total land surface area. The result showed that 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.

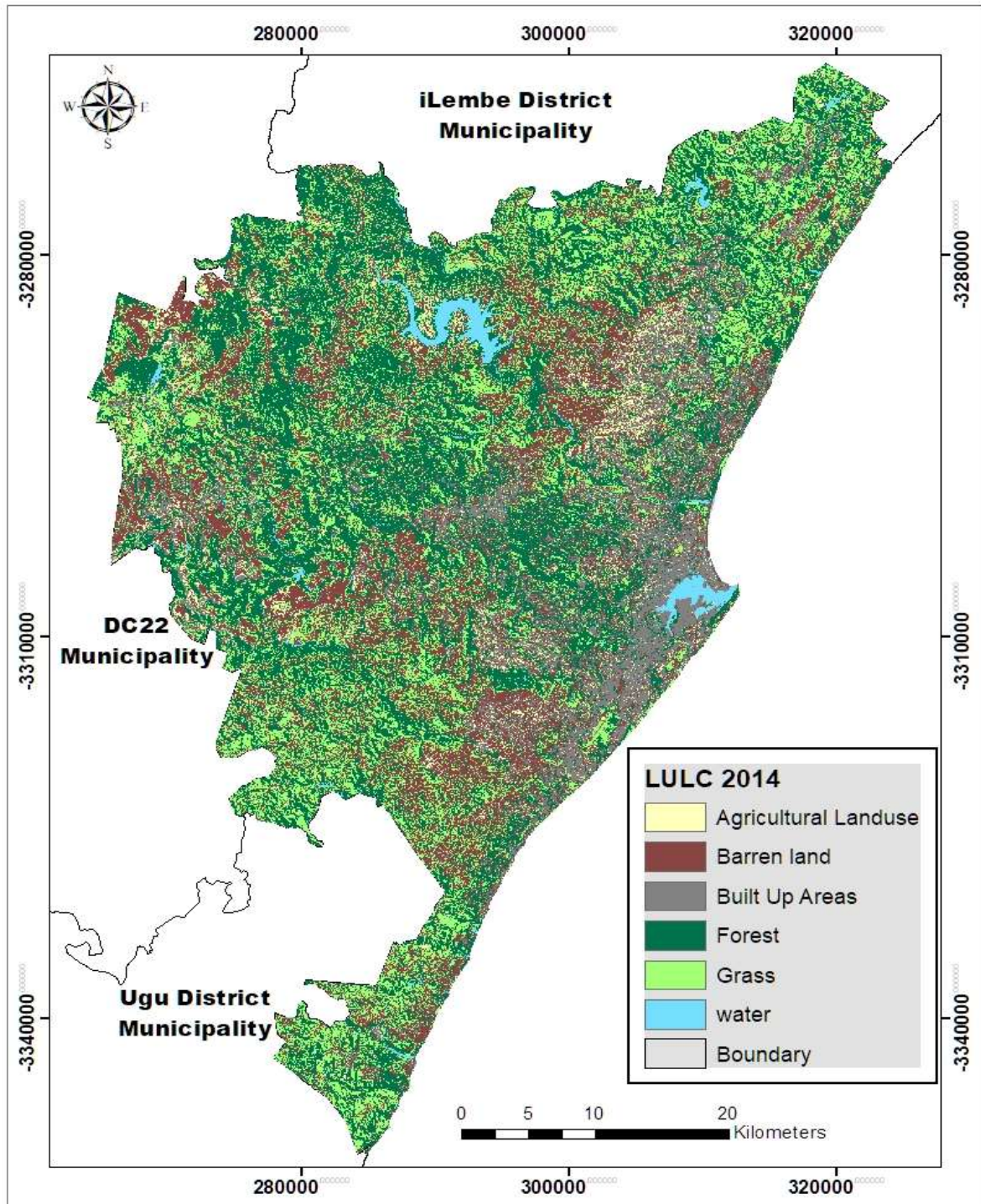


Figure 4: Digitized Map of Durban in 2014

Table 3: Coverage area for each of the 6 classes of LULC (in km<sup>2</sup>) 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<sup>2</sup>, different from the previous years. The area now covers about 19.32 % of the total land area, pointing to the key driver of land use change in Durban. Grassland occupied 786.19 km<sup>2</sup> constituting 34.30%. Dense vegetation covers 553.46 km<sup>2</sup> with 24.15%. Agriculture has reduced to 51.71 km<sup>2</sup> with approximately 2.26% of the land use. Water bodies occupied 29.12 km<sup>2</sup> with 1.27% of the total land area, and barren land seems to have decreased to 428.76 km<sup>2</sup> 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.

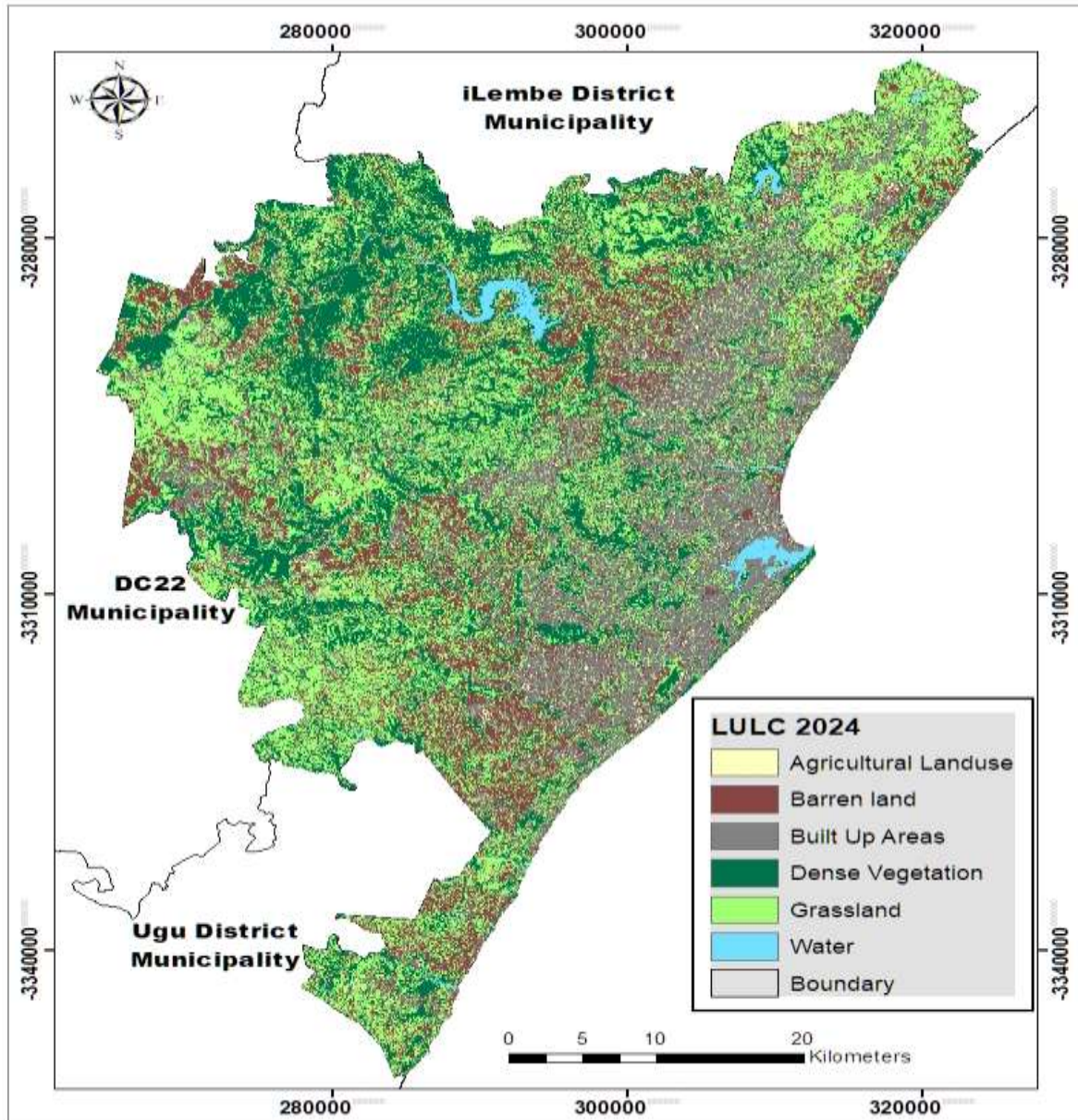


Figure 5: Digitized Map of Durban in 2024

Table 4: Coverage area for each of the 6 classes of LULC (in km<sup>2</sup>) 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.<sup>32</sup> A 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 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<sup>2</sup> with total land coverage of 22.7%. Agriculture will decrease to 51.435 km<sup>2</sup> with 2.24% of the land use. Figure 6 depicts the digitized map of the study area in 2034.

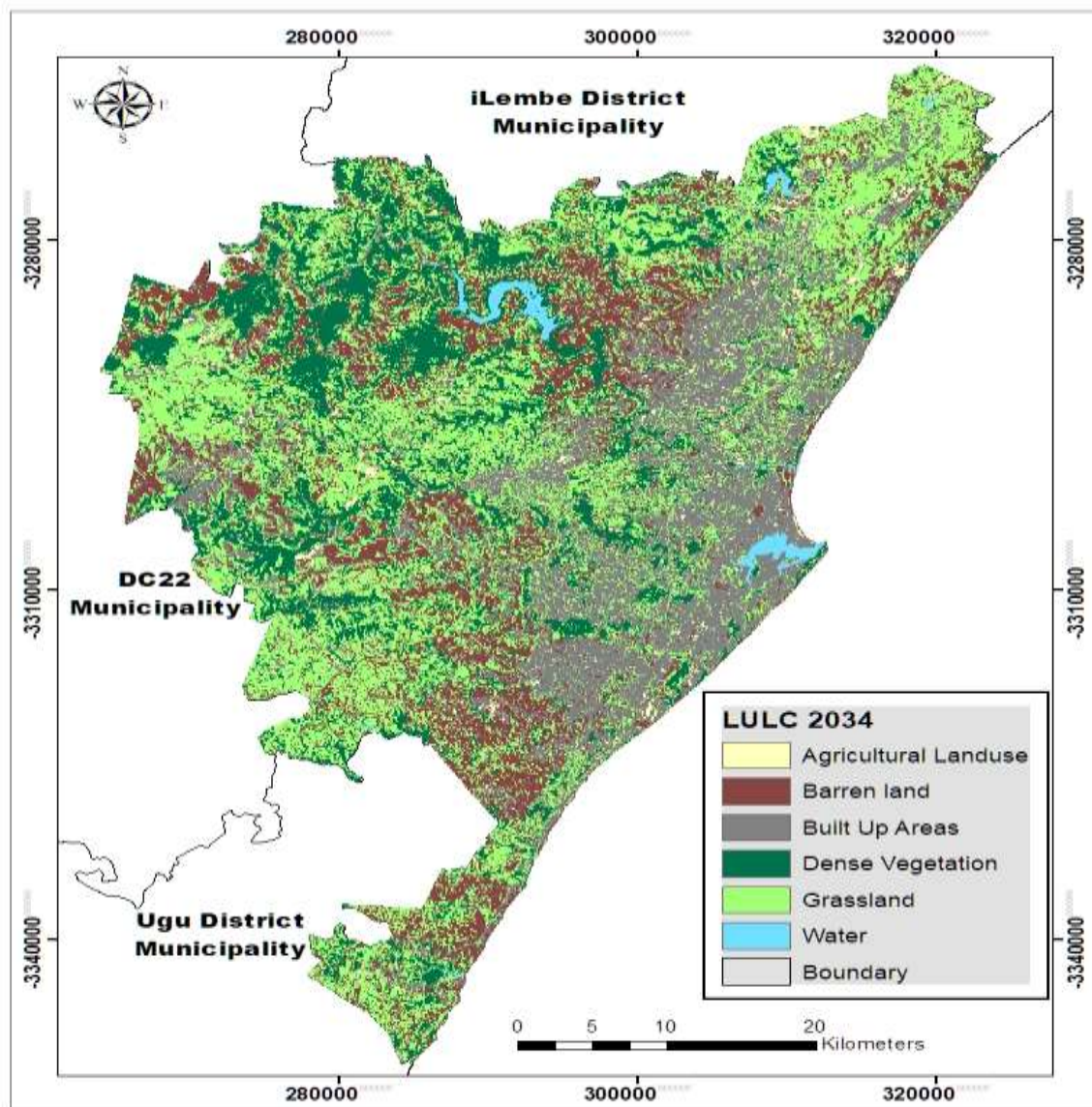


Figure 6: A Projection Map of Durban in 2034

### 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

<sup>32</sup> Rahel Hamad, 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.

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.

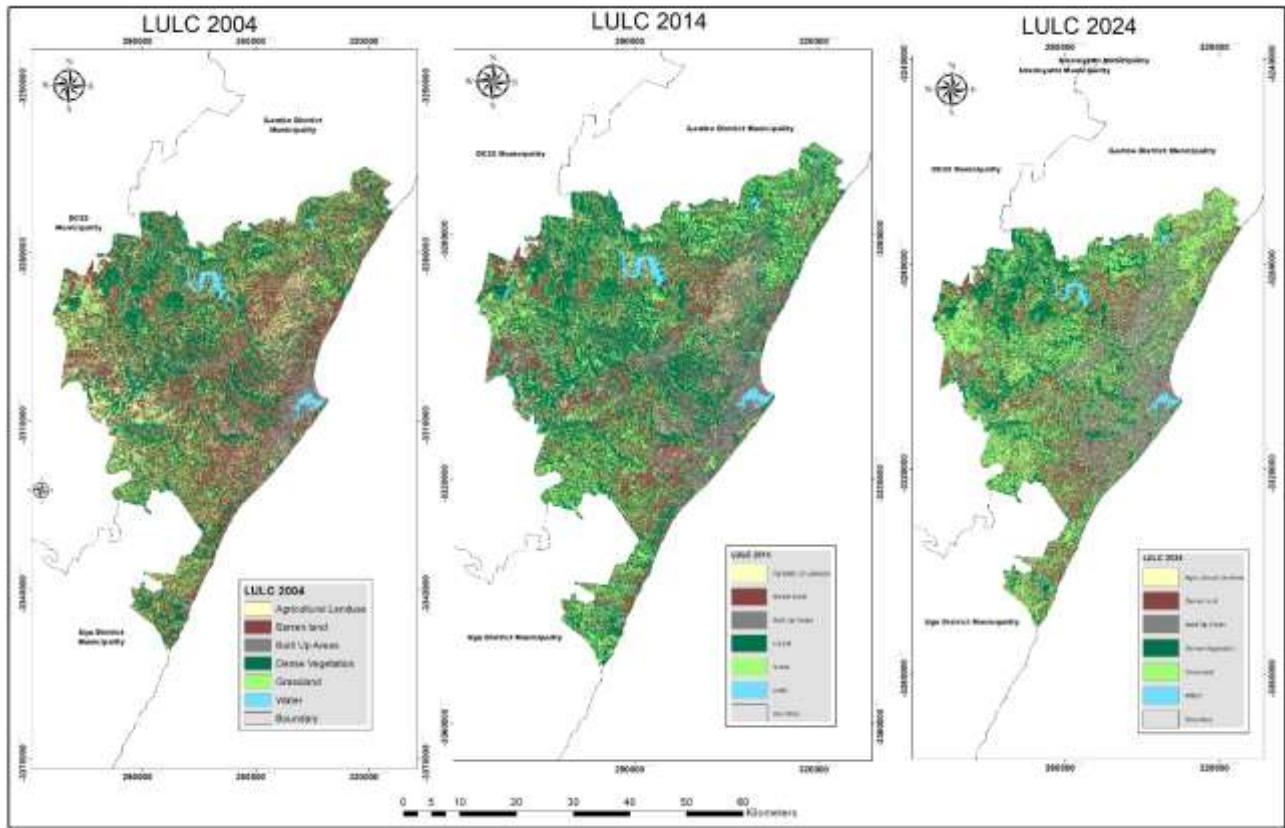


Figure 7. Digitized Overlay Maps of the Study Area from 2004-2024 (Source: Authors)

### Validation of LULC Results of the Study Area

The LULC results were validated using 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.<sup>33</sup> It is calculated based on visible and near-infrared light reflected by vegetation.<sup>34</sup> 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 Explorer). The Landsat images bands 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 band 4 and 3 were used for 2004. The ArcGIS 10.8 Raster Calculator toolbox was used to process the satellite imagery.

$$NDVI = \frac{\text{Near Infrared band} - \text{Red band}}{\text{Near Infrared band} + \text{Red band}}$$

<sup>33</sup> 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.

<sup>34</sup> 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).

In 2004, the vegetation range of -0.113797 to 0.457789, in 2014 from -0.157078 to 0.654621, and in 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 a 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.

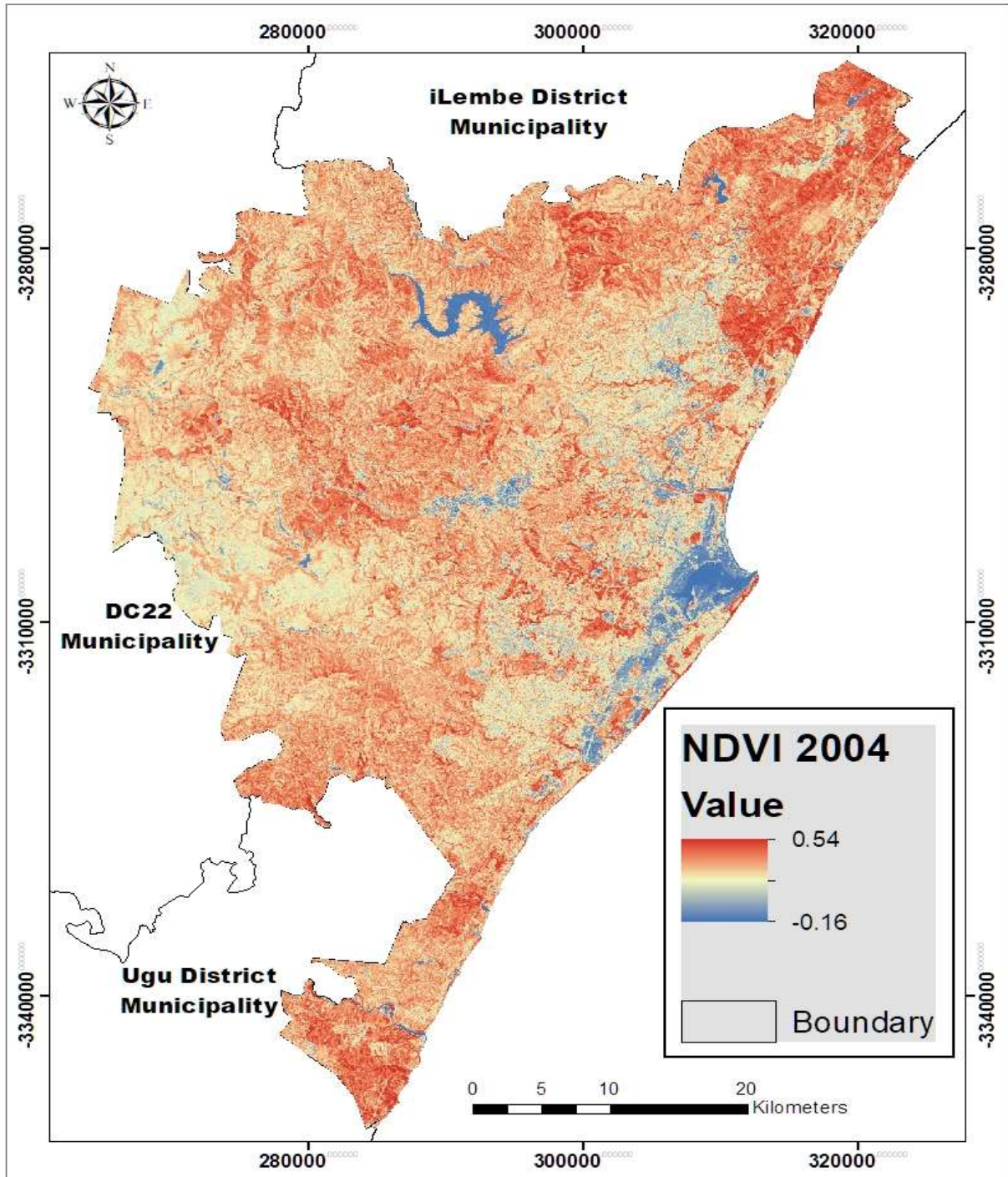


Figure 9. Normalized Difference Vegetation Index (NDVI) for 2004

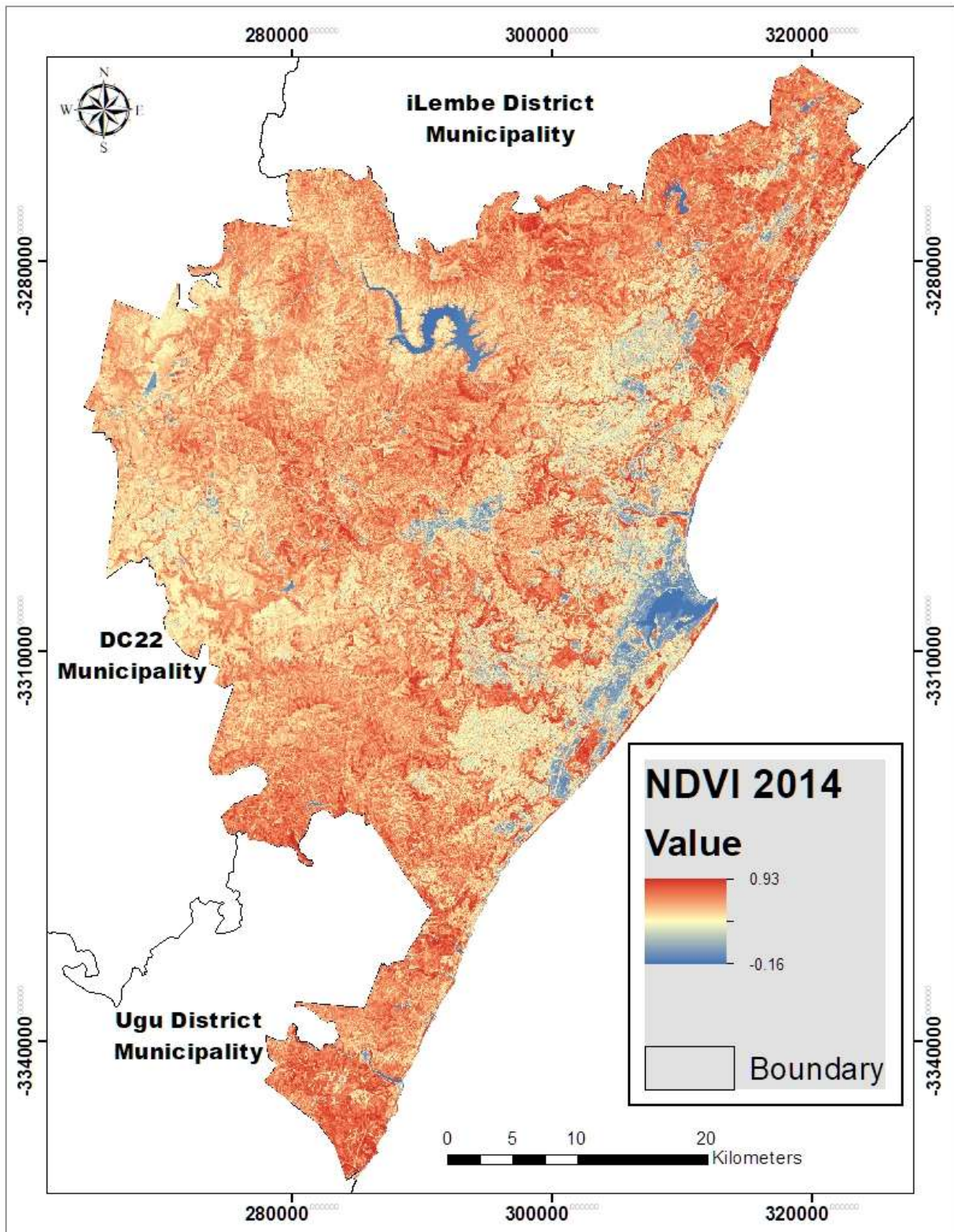


Figure 10. Normalized Difference Vegetation Index (NDVI) for 2014

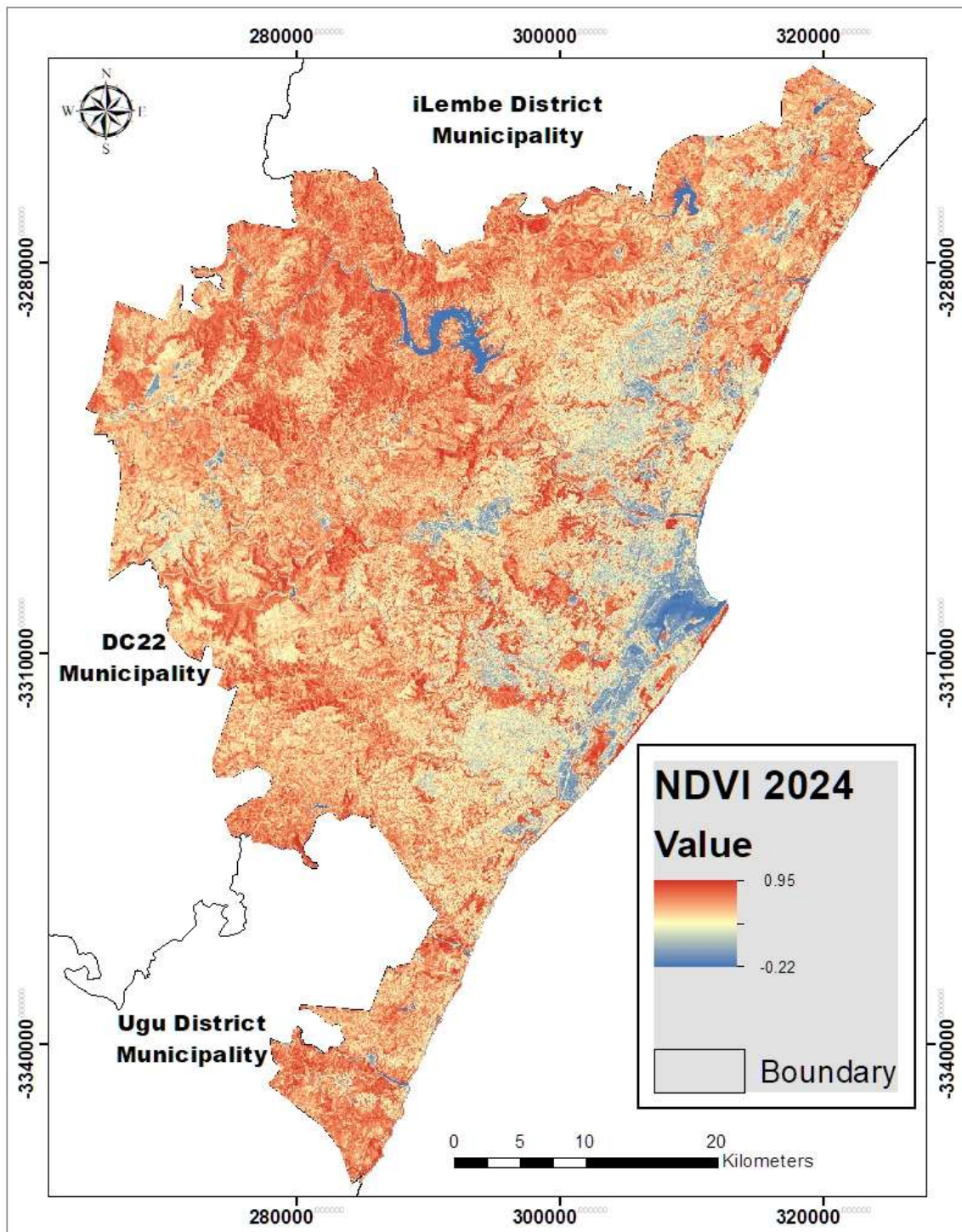


Figure 11. Normalized Difference Vegetation Index (NDVI) for 2014

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

According to Ali et al, NDBI is an indicator used to separate built-up regions from undeveloped land by utilizing the differences in spectral reflectance of urban areas.<sup>35</sup> It provides a quantitative measure of the degree of urbanization in a given area.<sup>36</sup> It is measured as

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

<sup>35</sup> 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.

<sup>36</sup> Karanam and Neela, "Study of Normalized Difference Built-up (NDBI) Index in Automatically Mapping Urban Areas from Landsat TN Imagery."

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

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 or built structure, while the yellow ones show a mixture of built-up with vegetation, and areas with 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.

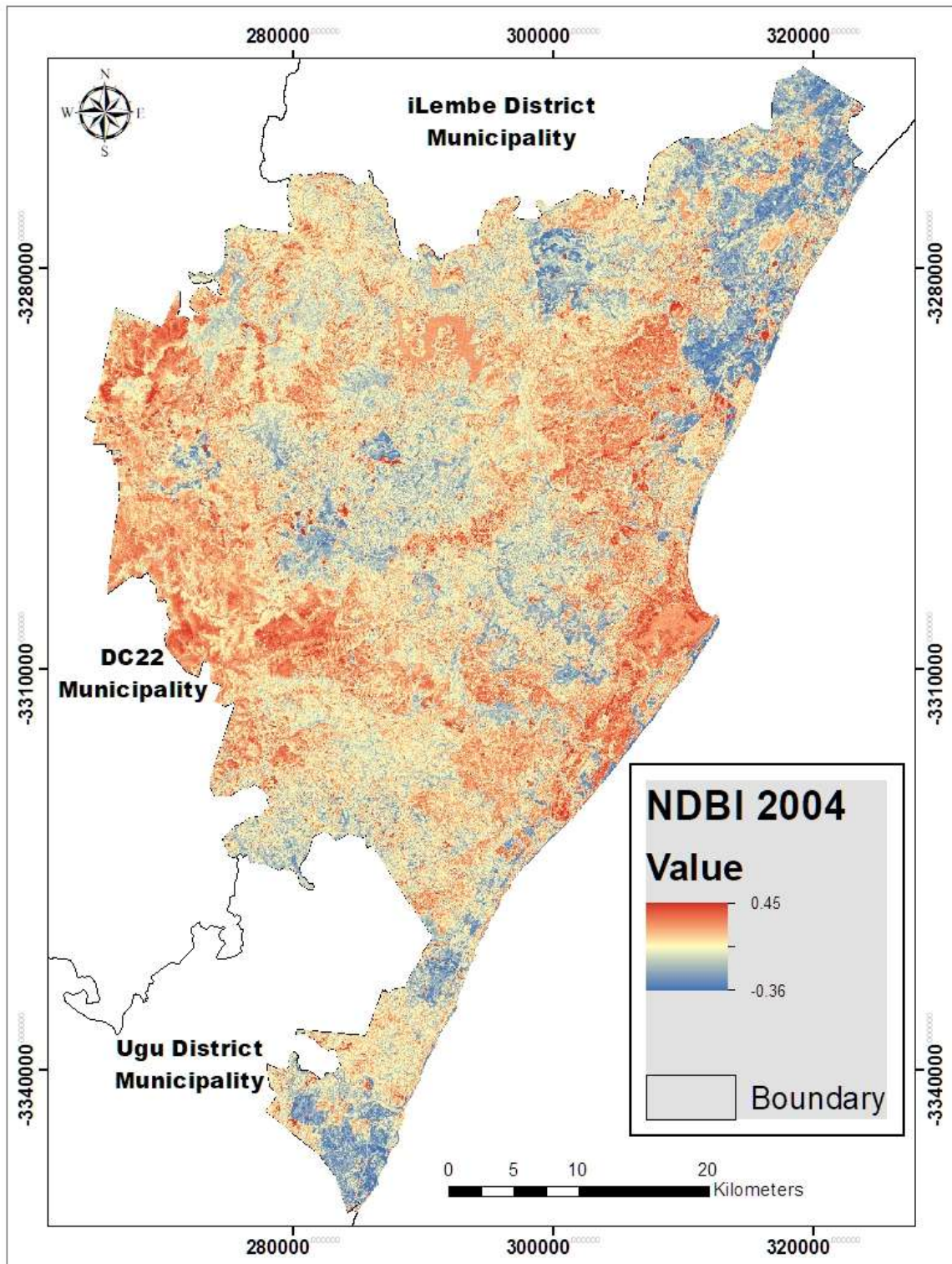


Figure 12. Normalized Difference Built Up Index (NDBI) for 2004

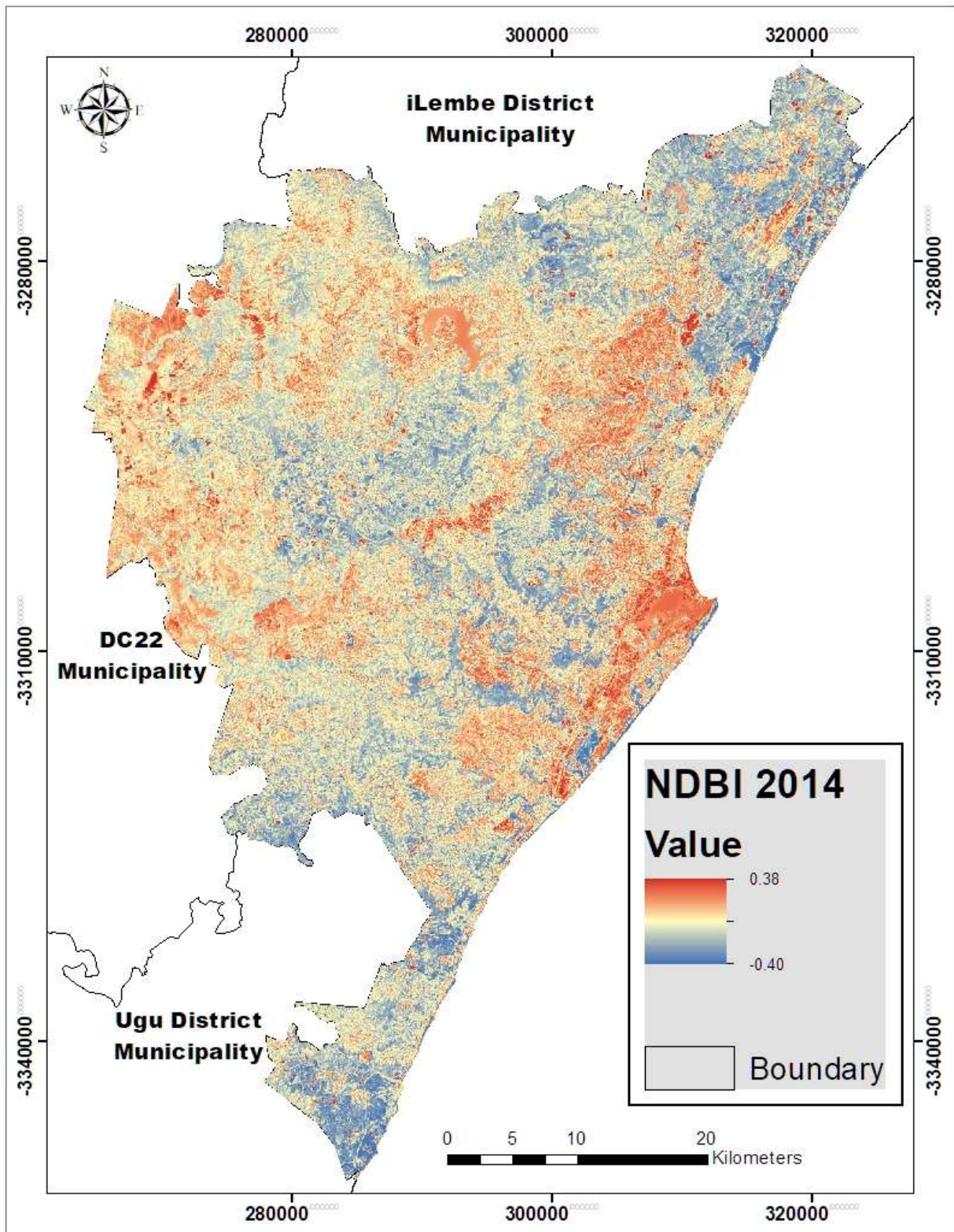


Figure 13. Normalized Difference Built Up Index (NDBI) for 2014

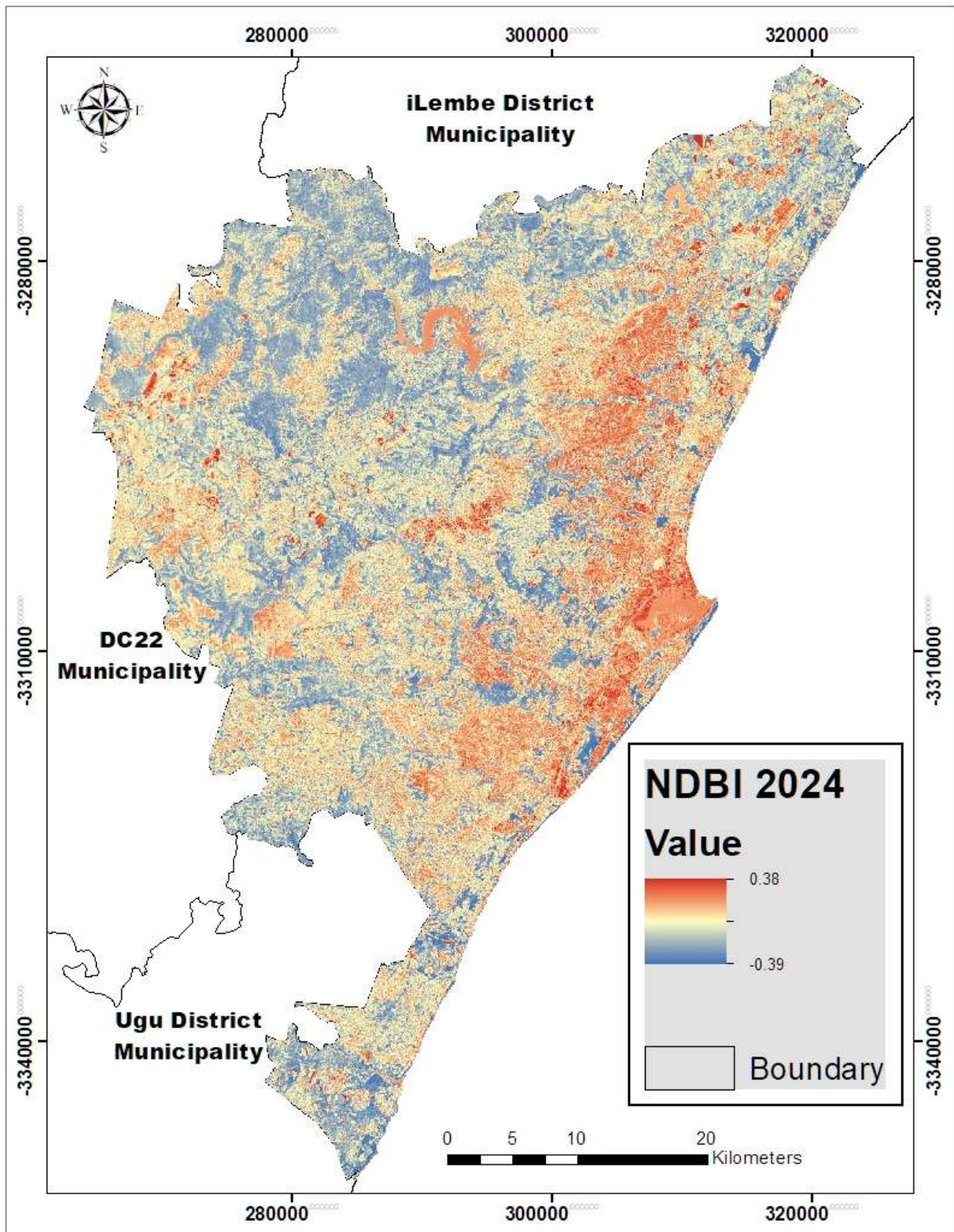


Figure 14. Normalized Difference Built Up Index (NDBI) for 2024

## DISCUSSION OF FINDINGS

The results of this study reveal a profound and accelerating transformation of Durban's urban morphology, reflecting broader trends in African metropolitan expansion. The marked increase in built-up land, from 5.38% in 2004 to 19.32% in 2024, with projections reaching 22.7% by 2034, confirms the intensifying urbanization pressure documented in several South African metropolitan regions.<sup>37</sup> This expansion aligns with global urbanization patterns observed in developing contexts where population growth and infrastructural demand drive land conversion.<sup>38</sup> Consistent with these studies, Durban's shift from vegetation-dominated landscapes to built-up urban fabrics illustrates the characteristic transition from ecological resilience to anthropogenic dominance. The decline in dense vegetation and agricultural land observed in this study corroborates the findings of Ahmed et al., who argue that vegetation loss in coastal cities reflects increased land speculation, informal settlement growth, and municipal development priorities.<sup>39</sup> The NDVI outputs in this study, indicating declining vegetative health between 2004 and 2024, further reinforce the established link between urban expansion and ecosystem degradation. However, this study extends previous literature by providing a 30-year trajectory (past, present, projected), thereby offering unique predictive insights into Durban's future ecological vulnerability. The NDBI results provide additional empirical confirmation of urban intensification, showing increasingly high reflectance values indicative of expanding impervious surfaces. This reflects findings by Guo et al., who note that NDBI coordinates closely with urban heat island formation, stormwater stress, and reduced ecological functionality.<sup>40</sup> While earlier studies recognized the extent of Durban's urban growth, the present study demonstrates through overlay maps and predictive modelling that the rate and spatial patterning of built-up expansion are more aggressive than previously reported. In relation to pedagogy, the findings reinforce the calls by Lee for integrating real geospatial data into urban geography teaching to cultivate spatial intelligence and inquiry-based learning.<sup>41</sup> By linking LULC dynamics to instructional design, this study affirms the argument that contemporary geography curricula must move beyond static content toward data-driven spatial reasoning. The predictive modelling outcomes serve not merely as environmental observations but as pedagogical tools capable of fostering critical spatial citizenship, analytical thinking, and applied problem-solving among students.

Notably, the findings partially refute earlier claims that Durban's green infrastructure is resilient enough to absorb urban pressures.<sup>42</sup> In contrast, this study provides strong empirical evidence of long-term vegetative decline, even in previously stable ecological zones, indicating that the city may be approaching a critical ecological threshold. The projected decrease in dense vegetation to 18.95% by 2034 suggests that current conservation interventions may be insufficient without more stringent urban planning reforms. Furthermore, the results illuminate significant socio-environmental implications. Urban growth concentrated along transport corridors and peri-urban zones reflects the uneven spatial development patterns described by Biegańska et al., where infrastructural access and economic opportunity shape city expansion.<sup>43</sup> The reduction in agricultural land, in particular, presents risks to Durban's food system resilience, echoing the concerns of Steenkamp et al., about the vulnerability of South African urban food security amid land conversion.<sup>44</sup> Hence, the findings confirm several prevailing scholarly positions while offering new empirical depth and temporal range. The study

<sup>37</sup> Channing Arndt, Rob Davies, and James Thurlow, "Urbanization, Structural Transformation, and Rural-Urban Linkages in South Africa," *South African Urbanisation Review, Cities Support Programme (CSP) of the National Treasury* 35, no. 1 (2018): 1–24; David Samuel Williams et al., "Vulnerability of Informal Settlements in the Context of Rapid Urbanization and Climate Change," *Environment and Urbanization* 31, no. 1 (2019): 157–76.

<sup>38</sup> Zeyang Li et al., "Relationship between Urban Construction Land Expansion and Population/Economic Growth in Liaoning Province, China," *Land Use Policy* 99 (2020): 105022.

<sup>39</sup> David Dodman et al., "Cities, Settlements and Key Infrastructure," 2023.

<sup>40</sup> Guanhua Guo et al., "Impacts of Urban Biophysical Composition on Land Surface Temperature in Urban Heat Island Clusters," *Landscape and Urban Planning* 135 (2015): 1–10.

<sup>41</sup> Lee, "Beyond Geospatial Inquiry—How Can We Integrate the Latest Technological Advances into Geography Education?"

<sup>42</sup> Stephan Pauleit et al., "Urban Green Infrastructure in the Global South," in *Urban Ecology in the Global South* (Springer, 2021), 107–43.

<sup>43</sup> Jadwiga Biegańska et al., "Peri-Urban Development as a Significant Rural Development Trend," 2018.

<sup>44</sup> Jorinda Steenkamp et al., "Food for Thought: Addressing Urban Food Security Risks through Urban Agriculture," *Sustainability* 13, no. 3 (2021): 1267.

contributes to contemporary urban geography debates by demonstrating a clear empirical link between urbanization and ecological decline within a coastal South African metropolis, providing predictive insights that challenge assumptions of green infrastructure resilience, positioning geospatial intelligence as a transformative pedagogical tool capable of modernizing urban geography education, and highlighting the urgent need for policy interventions that reconcile urban development with ecological sustainability. Collectively, the findings underscore that Durban's future urban trajectory, if unmitigated, will likely exacerbate environmental degradation, socio-spatial inequality, and climate vulnerability. This reinforces the imperative for both sustainable urban planning and geospatially enriched pedagogy capable of equipping students to analyze, interpret, and respond to complex urban challenges.

## RECOMMENDATIONS

The study recommends the integration of GIS-based spatial analysis and predictive modeling 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 modeling 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 highlights 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 modeling 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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