Spatio-temporal analysis of land use and land cover dynamics in a coastal South African metropolis and its implications for pedagogy and rural education

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ABSTRACT

This study investigates the spatio-temporal dynamics of land use and land cover (LULC) changes in the Buffalo City Metropolitan Municipality (BCMM), South Africa, and explores the implications of these changes for pedagogy and rural education. As the first of its kind in the study area, the research underscores the relevance of analysing ecological challenges and coastal vegetation conservation in the context of spatial development. The study collected data from advanced geo-spatial technologies, including satellite imagery and indices, spanning a 20-year period from 1998 to 2018. This comprehensive approach provides an in-depth overview of the extent and drivers of vegetation loss within the area. The analysis focused on establishing the relationship between LULC and two key indices: the Normalized Difference Vegetative Index (NDVI) and the Normalized Difference Built-Up Index (NDBI). LULC classification results were validated using five (5) different accuracy assessment techniques and tests. The results indicated a significant increase in built-up areas from 194 km² in 1998 to 814 km² in 2018, with statistical tests demonstrating high overall classification accuracies ($R^2=0.89$ and $P=0.86$) over the study period. These results indicate that approximately 466 km² of forest vegetation has been lost in BCMM during the study period. The study's findings have practical implications for policymakers, conservationists, educators, and rural communities, providing essential data and insights to inform policies and actions aimed at mitigating BCMM's adverse environmental impacts and contributing to sustainable development.

Keywords*:* Coastal Vegetation Ecosystems; Buffalo City Metropolitan Municipality; Ecological Conservation; Geospatial Technologies; Land Use Land Cover Change; Rural Education.

INTRODUCTION

The rapid urbanization and environmental transformation of coastal regions present significant challenges and opportunities for sustainable development (Chamling and Bera, 2020). In South Africa, the coastal metropolitan areas are undergoing profound changes due to population growth, economic development, and land use alterations. Over the past three decades, the Buffalo City Metropolitan Municipality (BCMM) has experienced considerable shifts in land use and land cover (LULC), driven by factors such as uncontrolled urbanization, deforestation, and agricultural expansion. These changes have resulted in substantial vegetation loss, affecting the region's biodiversity, ecosystem services, and overall environmental health. By integrating data from satellite imagery and various indices such as the Normalized Difference Vegetative Index (NDVI) and the Normalized Difference Built-Up Index (NDBI), this study aims to provide a comprehensive overview of the extent and drivers of vegetation loss. By bridging the gap between scientific research and educational practice, the study also aims to empower local communities with the knowledge and tools necessary to address environmental challenges effectively (Cascante-Campos, 2023).. By doing so, it aims to support the development of informed, proactive communities capable of contributing to the sustainable management of their local environments.

AIM OF STUDY

The aim of this study is to investigate the spatio-temporal analysis of land use and land cover change at Buffalo City Metropolitan Municipality (BCMM), Province of the Eastern Cape, South Africa, and its implications for pedagogy and rural education. The study addresses the following research question:

RESEARCH QUESTION

The research question for the study is as follows:
"What spatio-temporal changes in LULC have occurred at Buffalo City Metropolitan Municipality?

LITERATURE REVIEW

Globally, the monitoring of LULC changes has become a priority due to its profound implications on biodiversity, climate change, and sustainable development (Tariq et al., 2021), and satellite imagery has revolutionized our understanding of these changes. For instance, the

Amazon rainforest has been extensively studied using Landsat data to monitor deforestation rates and their impact on global carbon cycles (Thakur et al., 2020). These studies have been pivotal in shaping international policies and conservation strategies aimed at protecting tropical rainforests. In urban contexts, cities and metropolises such as New York and Beijing have utilized satellite data to understand urban sprawl and its environmental consequences. The insights gained from such studies have informed urban planning policies that aim to balance development with environmental sustainability, ensuring that urban growth does not come at the expense of green spaces and biodiversity (Chen, Xu, & Gong, 2021). On an international level, LULC change detection has been instrumental in addressing global environmental challenges (Mishra et al., 2020). In the same vein, the European Space Agency's Copernicus program, which includes the Sentinel satellites, provides comprehensive data for monitoring land changes across Europe (Jutz and Milagro-Perez, 2020), thereby supporting the European Union’s policies and the United Nations Sustainable Development Goals on biodiversity, agriculture, and climate change (Radočaj et al., 2020).

According to Ruan, Long, Zhang, & Lv, (2021), the integration of LULC study findings into rural educational curricula has significant pedagogical implications. By providing real-world data and case studies, educators can enhance students' understanding of environmental science, fostering a sense of stewardship and critical thinking (Duarte, Teodoro & Gonçalves, 2022). Equipping students with knowledge about sustainable land management practices can empower them to contribute to local conservation efforts and advocate for sustainable development in their communities (Holler, 2020; Mwakoba, 2021). According to Pérez-delHoyo et al., (2020), incorporating LULC findings into environmental science education enriches the curriculum by providing students with concrete examples of how land use changes impact ecosystems (Ruan, Long, Zhang, & Lv, 2021; Banerjee et al., 2022). Additionally, Fleming and Evans, (2021), opined that the use of real-world data in the classroom encourages students to engage in critical thinking and problem-solving and evaluating the effectiveness of different land management strategies (Duarte, Teodoro & Gonçalves, 2022). In addition, Osborne et al., (2020) and Kholoshyn et al., (2021), elucidated that educating students about the consequences of LULC changes fosters a sense of environmental stewardship, and a personal commitment to conservation. Furthermore, Hlatywayo & Manik, (2022). Opined that by understanding how to manage their natural resources sustainably, communities can better withstand the impacts of climate change, deforestation, and other environmental threats (Langran et al., 2020).

This research adds to the global body of knowledge on coastal conservation, supporting international environmental goals such as the United Nations Sustainable Development Goals

(Krauss, 2022; Nabiyeva et al., 2023). Conservation organizations can leverage this data to plan and implement restoration projects, monitor their effectiveness, and engage local communities in conservation activities (Prudente et al., 2022). Although the study is geographically specific to BCMM, the research's emphasis on coastal vegetation conservation and LULC dynamics holds broader implications for other coastal regions grappling with environmental sustainability issues. By drawing attention to the overarching themes of ecological change, spatial development, and pedagogical integration, the study contributes valuable insights that can be adapted and applied in diverse settings. Thus, the findings of this study are not only relevant for policymakers and conservationists but also for educators and rural communities (Cascante-Campos, 2023).

According to Debnath et al., (2023), understanding LULC dynamics is critical for environmental sustainability. In Asia, countries like India have leveraged satellite imagery to manage their agricultural landscapes (Nagendra et al., 2022). The use of remote sensing data helps in tracking crop patterns, managing water resources, and planning for sustainable agricultural practices (Jindo et al., 2021). This approach not only enhances food security but also mitigates the adverse effects of agricultural expansion on natural ecosystems (Benami et al., 2021). Regionally, in Africa, the use of satellite imagery for LULC monitoring is growing (Dzurume et al., 2022), for example Remote Sensing (RS) technology has been used in monitoring the Great Green Wall, which spans across the Sahel region, the initiative aims to combat desertification through reforestation and sustainable land management (Ibrahim, Ahmed, Arodudu, Abubakar, Dang, Mahmoud & Shamaki, 2022; Karelkhan, Kadirbek & Schmidt,2023). In East Africa, countries like Kenya and Tanzania have used Landsat data to monitor LULC changes in their national parks and conservation areas (Komba et al., 2021). In the same vein, this information is vital for wildlife conservation, as it helps in identifying areas that require immediate attention to prevent habitat loss and ensure the survival of endangered species (Mwakoba, 2021). In South Africa, the need for LULC monitoring is germane due to the country's diverse ecosystems and rapid urbanization leading to biodiversity loss and increased vulnerability to climate change (Dzurume et al., 2022; Masiza et al., 2023), and BCMM is a prime example of an area experiencing significant LULC changes. The region's coastal ecosystems are under threat from urban expansion, deforestation, and agricultural activities, which have led to substantial vegetation loss and environmental degradation. According to Musetsho, Chitakira & Nel, (2021), the expansion of cities like Johannesburg and Cape Town has been closely monitored using satellite data to understand the impacts on local ecosystems and inform urban planning decisions.

METHODOLOGY

The methodology for this study involves a detailed spatio-temporal analysis of LULC changes in BCMM over a 20-year period (1998-2018). The ethical clearance number for this study is KUL011SOLA01, and approval for the study was given by Mr A. Sihlahla, the City Manager, BCMM on October 2, 2018. The use of advanced geo-spatial technologies, such as satellite imagery and indices like the Normalized Difference Vegetative Index (NDVI) and the Normalized Difference Built-Up Index (NDBI), provides an accurate and comprehensive assessment of land use changes. The results were analysed using ArccGIS 10.8 software. This study adds to knowledge regarding the effective monitoring of environmental changes and developing strategies to mitigate their impacts.

RESEARCH SITE

BCMM is located relatively centrally in the Eastern Cape Province, which is bounded to the south-east by the long coastline along the Indian Ocean. Covering about 2,536 km2 (979 square miles), BCMM lies on coordinates 32°59′S and 27°52′E, and it is enclosed by the Great Kei, Amahlathi, Raymond Mlaba and Ngqushwa Local Municipalities. The area includes the large townships of Mdantsane as well as Amalinda, East London, Bisho, Schornville, King William's Town and Dimbaza. Buffalo City is the key urban centre of the eastern part of the Eastern Cape (Ntakana et al., 2022), which consists of a corridor of urban areas, stretching from East London to the east, through to Mdantsane and reaching Dimbaza in the west (Seethal, Nel & Bwalya, 2021). East London is the primary node, whilst King Williams Town (KWT) area is the secondary node (Olatotye, 2020). According to Mshumpela, (2020), BCMM is broadly characterised by some identifiable LULC patterns. The first is the dominant urban axis of Dimbaza-KWT- East London – Mdantsane–KWT–Dimbaza, which dominates the industrial and service sector centres and attracts people from the greater Amathole region in search of employment opportunities and better access to urban services/facilities. Another LULC patten in the study area comprises of the fringe peri-urban and rural settlement areas (Khumalo, 2021). Having a mild climate with abundant year-round sunshine, BCMM records 850mm of yearly average rainfall (Mshumpela, 2020). Figure 1 depicts the map of the study area.

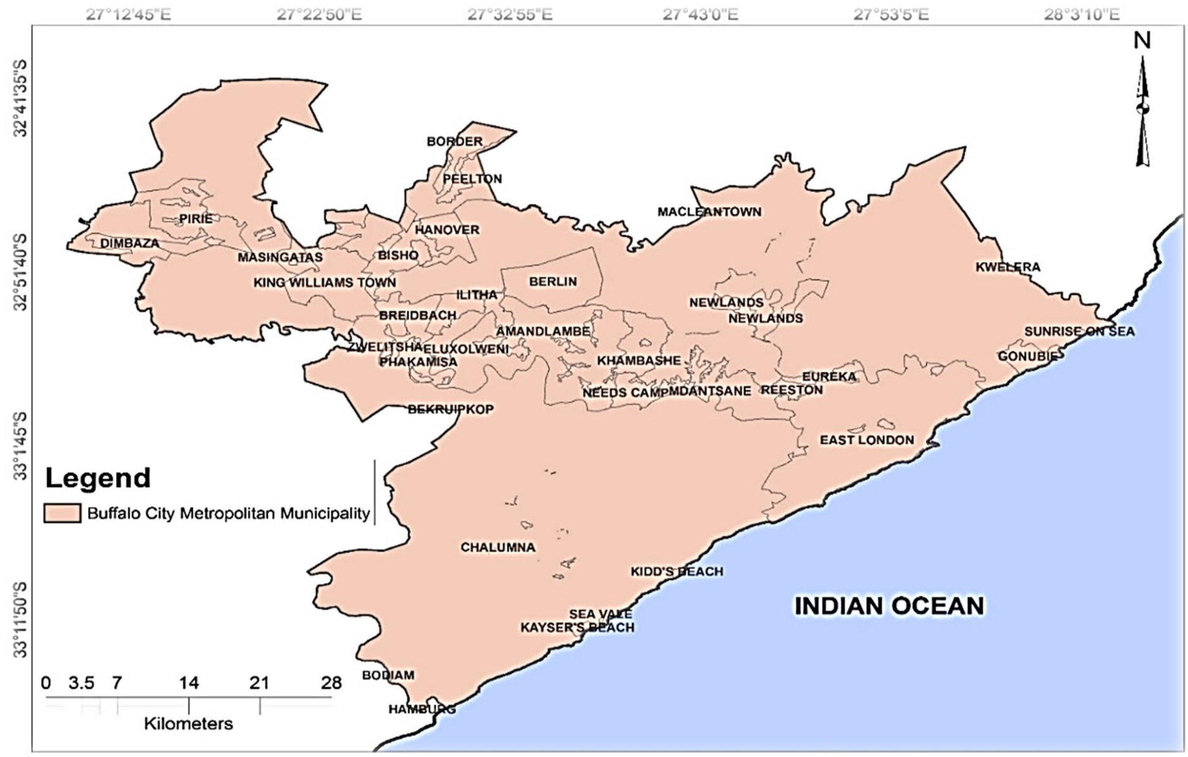


Figure 1: The Study Area (Source: Authors)

RESULTS AND DISCUSSION

This section provides the results of the LULC dynamics of BCMM from 1998 to 2018 and provides a critical analysis of the spatio-temporal changes in the LULC and underscores the importance of integrating these insights into pedagogy and rural education (as supported in the literature by Stout, 2022). Although the study is geographically specific to BCMM, the research's emphasis on coastal vegetation conservation and LULC dynamics holds broader implications for other coastal regions grappling with environmental sustainability issues. While the study had a restricted timeframe of twenty years, it offers valuable insights into the spatial and temporal patterns of LULC at BCMM. The research highlights substantial changes, including significant losses in forest vegetation and expansions in built-up areas, within the studied period. Furthermore, it is important to note that while highlighting the pedagogical significance of the research findings, the study does not neglect the broader socio-economic and policy dimensions of environmental sustainability. By advocating for the incorporation of ecological insights into rural education settings, the research empowers students and communities with the knowledge necessary to address vegetation loss and promote sustainable land management practices within a holistic framework. By drawing attention to the overarching themes of ecological change, spatial development, and pedagogical integration, the study contributes valuable insights that can be adapted and applied in diverse settings. The results and discussions for the study are elucidated in subsequent sections.

Maximum Likelihood Classification (MLC)

The MLC results for the study area in the year 1998 to 2018 is depicted in Table 1.

Table 1: Spatial Distribution of BCMM LULC in 1998, 2008 and 2018

S/N	Feature	Area (km^2) 1998	Area (km^2) 2008	Area (km^2) 2018
1.	Bare Ground	1110.346	56.239836	536.348176
2.	Water Bodies	33.81448	32.14646	22.797197
3.	Forest	804.9369	839.5664	338.012174
4.	Grassland	605.205	1002.948	1735.99065
5.	Built-up Areas	193.8586	817.2702	115.03479
	TOTAL	**2748.161**	**2748.161**	**2748.161**

Table 1 depicts the spatial distribution of LULC at BCMM from 1998- 2018 respectively. From the foregoing, 5 classifications namely bare ground, forest, grassland, water bodies and built-up areas were produced from the LULC image. Grassland recorded an aerial extent of 605.205 km^2 in 1998 occupying 22 per cent of the study area and increased from 605.205 km^2 to 1735.9 km^2 (from 1998 to 2018 respectively), amounting to about 41 per cent increase. Also, forest LULC had diminished in aerial extent from 804.9km^2 in 1998 to 338km^2, which is approximately 17 per cent loss. This loss is due to increasing urbanization that took place in the study area within these years, which resulted in vegetation loss. Also, water bodies in the study area witnessed a decrease from 33.8km^2 in 1998 to 22.7 km^2 in 2018. The results derived from image classification and interpretation, in combination with field authentication, depicts that intensive spatial development initiatives have been executed at BCMM from 1998-2018, and these include land reclamation and urban expansion through the construction of housing, roads, airport projects, and opening of virgin areas in various parts of the metropolis. The MLC images of the study area from 1998 to 2018 are depicted in the Figure 2.

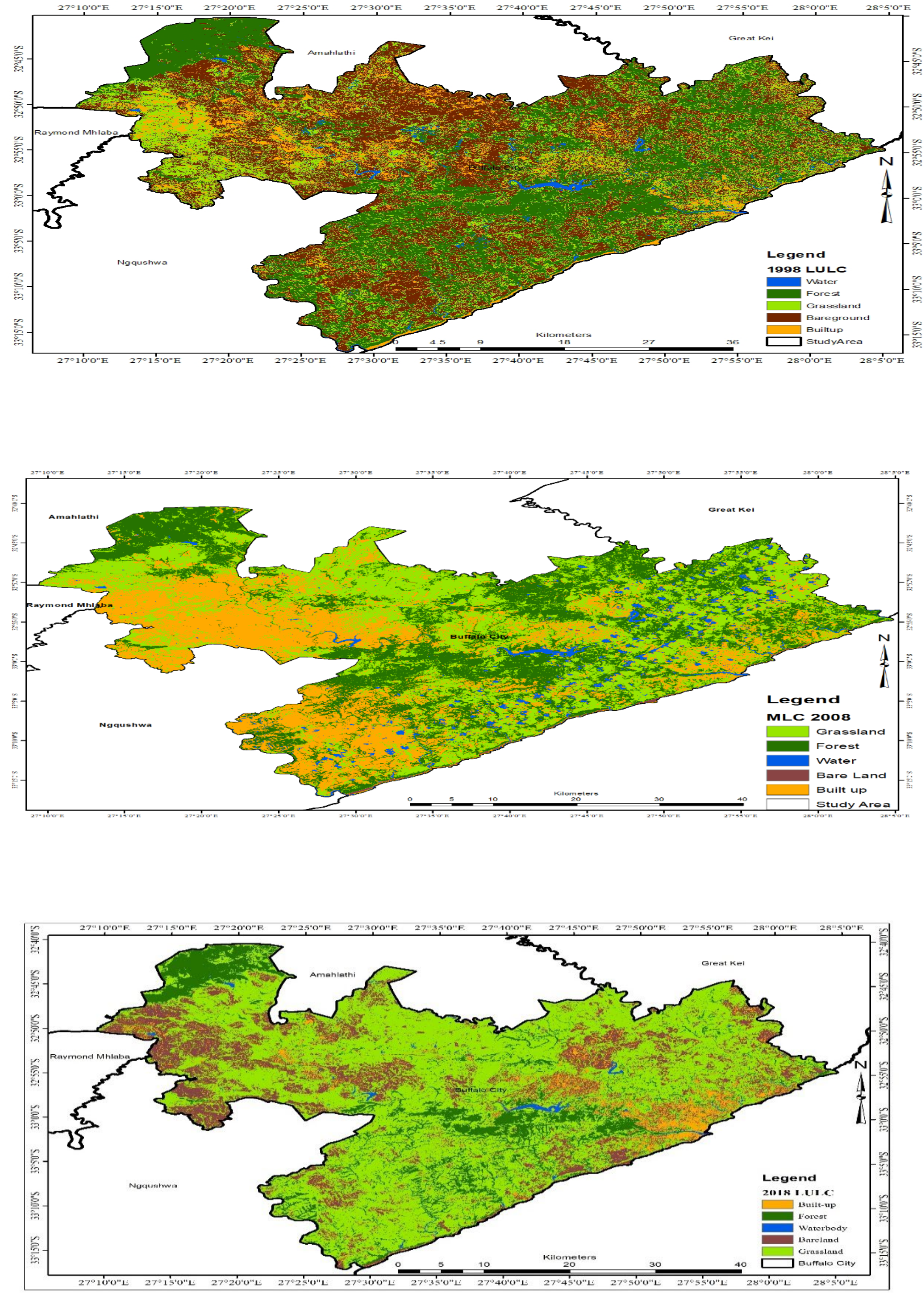


Figure 2: Maximum Likelihood Classification (MLC) of the Study Area (1998, 2008 and 2018) (Source: Authors)

The degree of LULC change in the study area is presented in Figures 3 and 4.

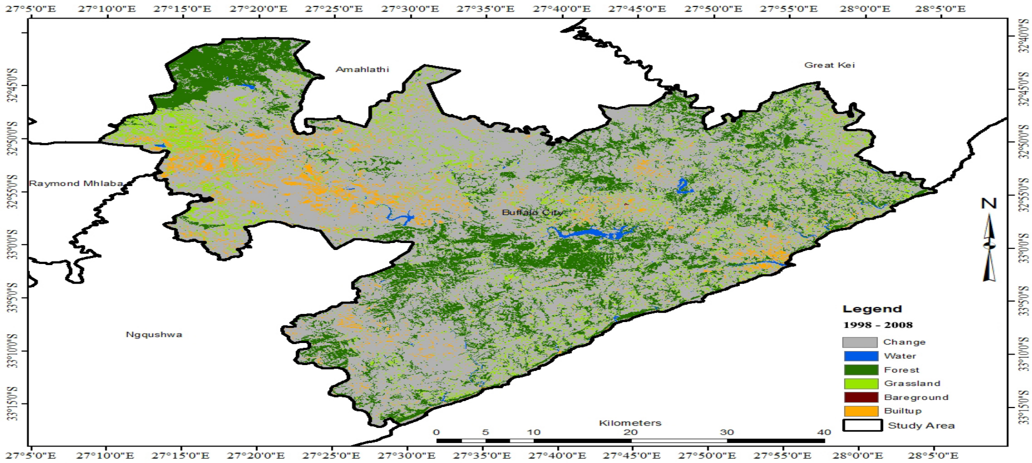


Figure 3: LULC Change Detection Image of Study Area (1998-2008) (Source: Authors)

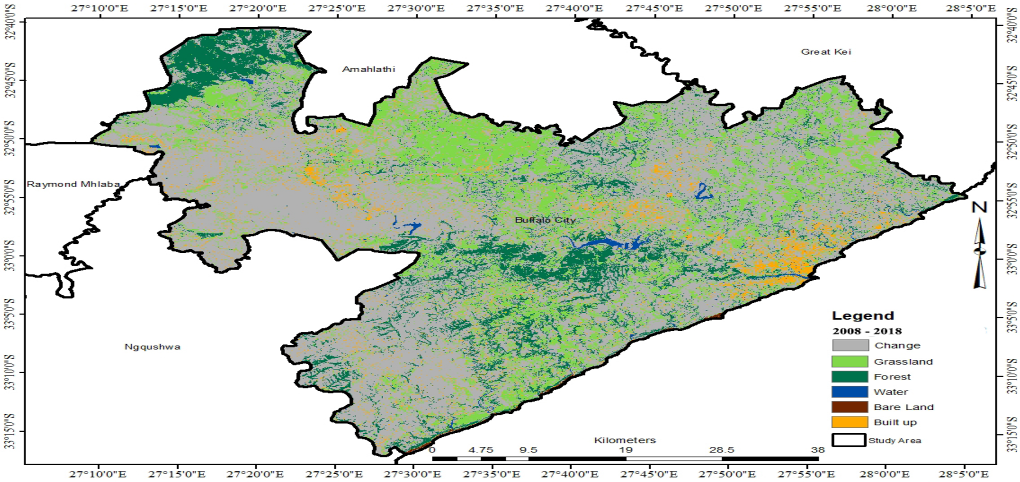


Figure 4: LULC Change Detection Image of BCMM (2008–2018) (Source: Authors*)*

Figures 3 and 4 depict the spatio-temporal LULC changes within the BCMM ecological space, thus indicating increases in urban expansion and decreased vegetation (typified by the reduced vegetation represented as green colour in the imageries) from 1998 to 2018.

Change Detection Algorithms Carried Out at BCMM

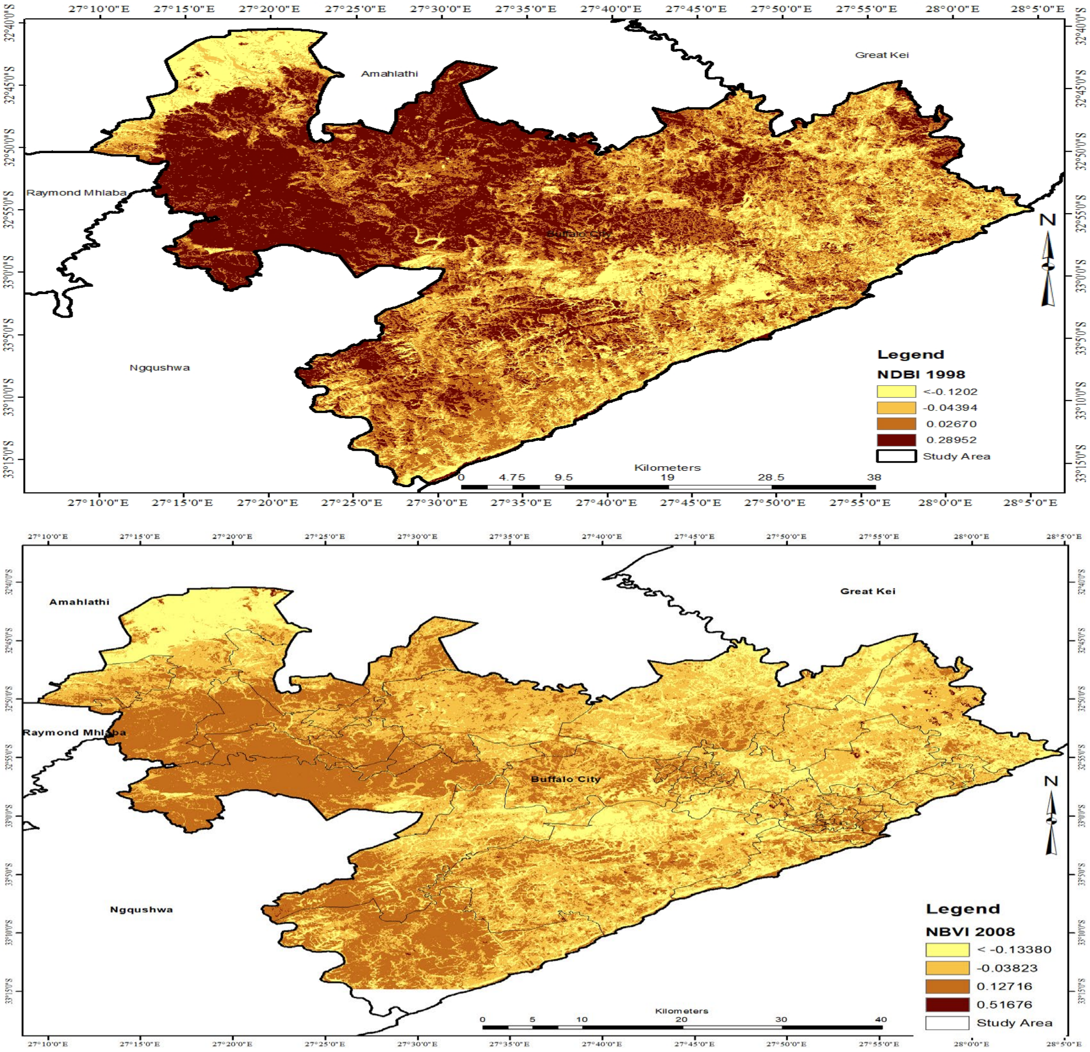
Change detection algorithms were expedited in this study to further validate LULC classification results. From the foregoing, three different change detection algorithms were applied to the three imageries of the study area (1998, 2008 and 2018) respectively, and these were conducted after the processing stage was completed. The change detection algorithms include:

- The Normalized Difference Built-up Area Index (NDBI); and

- The Normalized Difference Vegetative Index (NDVI). These techniques are performed in LULC studies and supported in literature by Prasomsup et al., (2020); Vorovencii, (2020) and Zheng, Tang & Wang, (2021).

The Normalized Difference Built-up Index (NDBI)

NDBI is an effective technique utilized in spatio-temporal LULC mapping of urban landscape/built-up areas over time (Vorovencii, 2020; Prasomsup et al., (2020), the NDBI technique helped to automate the mapping of built-up areas at BCMM, through the exploration of the quantitative correlations between them. Thus, the arithmetic manipulation of re-coded NDBI images derived from Landsat 5 of 1998 and 2008, as well as Landsat 8 OLI TM imageries of BCMM of 2018 were carried out in ArcGIS 10.8 environment. NDBI analysis is calculated with the difference between middle-infrared band (MIR) and Near-Infrared (NIR) bands of RS imageries, and the technique is consistent in literature with Bai et al., (2020); (Zheng, et al. (2021). The NDBI images are depicted in the Figure 5.



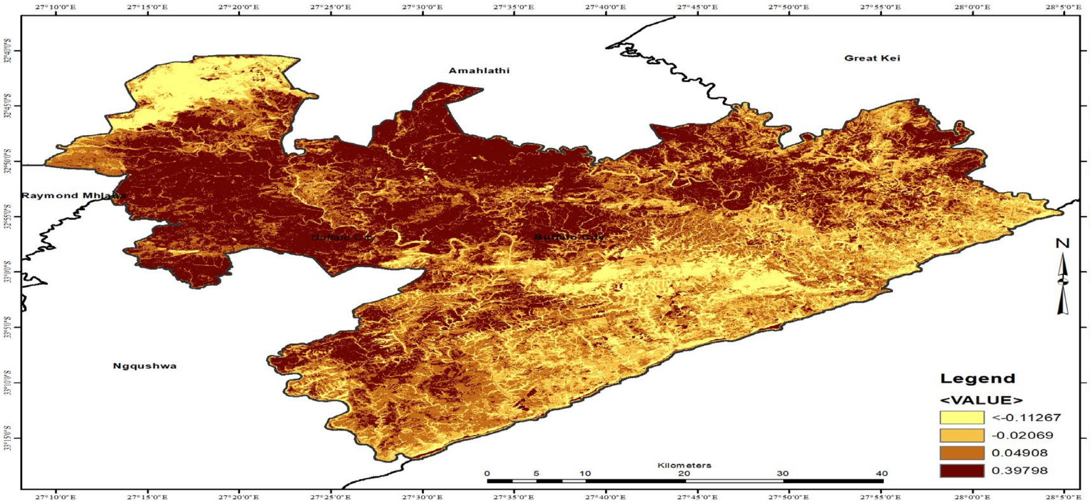


Figure 5: NDBI Images for the Study Area from 1998–2018 (Source: Authors**)**

Figure 5 reveals the NDBI results of the study area for 1998, 2008 and 2018 respectively. The NDBI value lies between -1 to +1. Negative value of NDBI represent water bodies, whereas higher values represent built-up areas. The NDBI value for vegetation is low, revealing a rapid increase in urbanization which spread mainly from the north-western parts of Dimbaza, King Williams Town to the north-western, north-central, north-eastern, south-western and coastal areas of Hanover, Perelton, Berlin, Quigney, Gonubie, Mdantsane and Bisho, with a significant increase over the years. From the foregoing, urban expansion in the study area is manifested by changes in the spatial configuration of landscape characterised with paving, vegetation removal during construction among others.

The Normalized Difference Vegetative Index (NDVI)

According to Huang et al., (2021), NDVI involves the assessment of the red and NIR bands from RS imageries which are derived from Landsat satellite. The NDVI procedure evaluates the degree of robustness or health of the vegetation LULC that is being observed. The signature of different features (that is, training sites) were selected and digitised on the image. The selection of signature was based on field knowledge gathered through ground-truthing exercises as well and features on the ground were confirmed from the satellite imageries. The obtained signatures served as the tool for digital image classification. Thereafter, BCMM was classified into five classes. Subsequently, the classified images were recorded to their individual classes, namely water bodies, barren land, lowly vegetated areas and densely vegetated areas. Thereafter, NDVI was calculated on ArcGIS 10.8 software. The results for the three years were then compared, showing significant LULC at BCMM for the 20-year a period. The NDVI technique conforms with Spadoni et al., (2020), and are depicted in Figure 6.

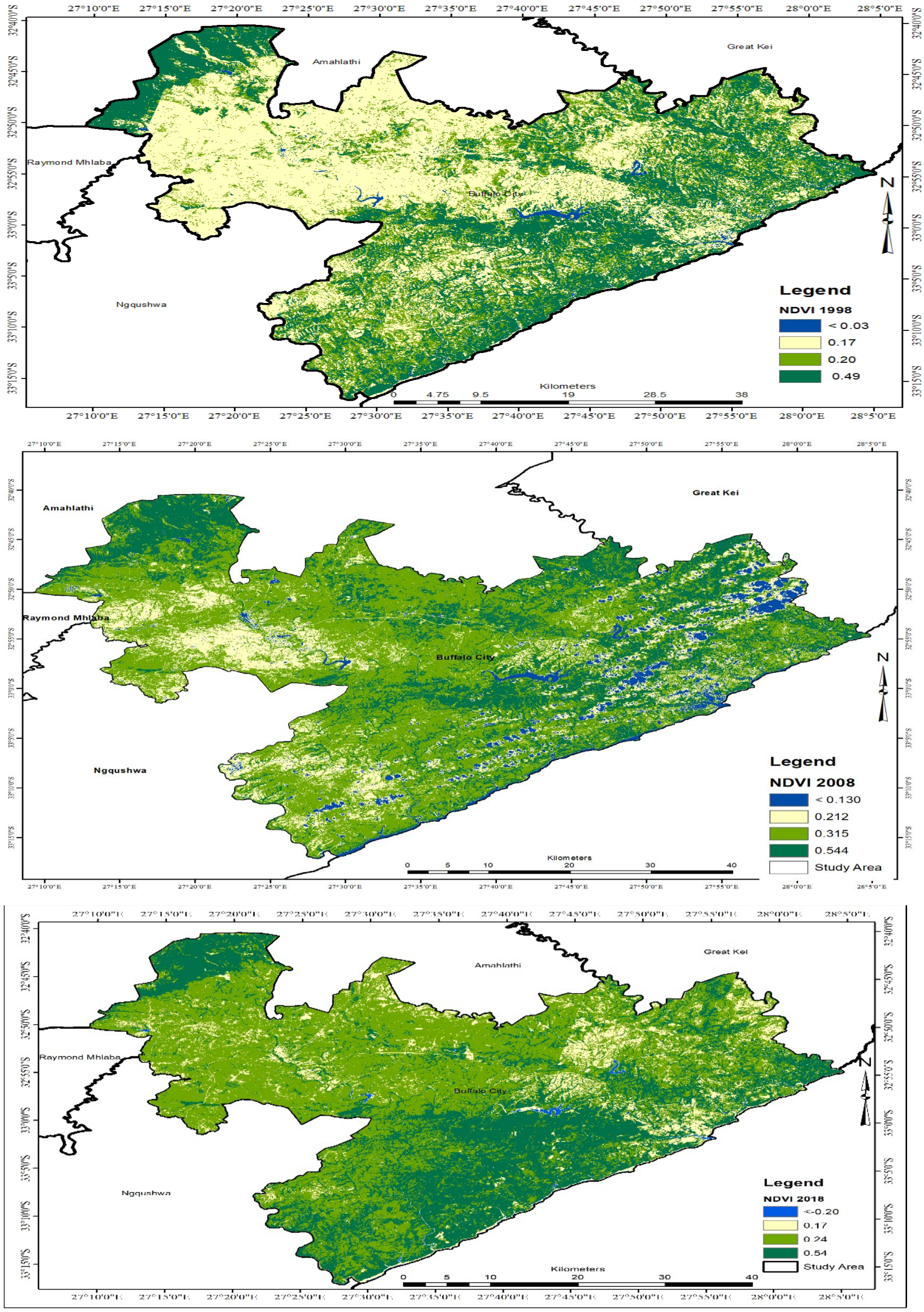


Figure 6: NDVI Images for the Study Area in 1998, 2008 and 2018 (Source: Authors)

Figure 6 reveals the NDVI images for the study area, which depicts values ranging from +1.0 to -1.0. The NDVI technique is a pixel-wise mathematical calculation which indicates plant health, calculated by comparing the values of absorption and reflection of red and near-infrared light. The NDVI values were categorized into four main classes namely water, no vegetation, sparse vegetation and dense vegetation respectively. Consequently, sandy areas, water bodies and barren rock depicted very low NDVI values of 0.1 or less. NDVI values between 0.2 and 0.4 correspond to areas with sparse vegetation; moderate vegetation tends to vary between 0.4 and 0.6, while high NDVI values ranging from 0.6 to 0.9 depict forest vegetation indicate the highest possible density of green leaves, and are at their peak stages of vegetal growth, and these are found around Nahoon, Gonubie, parts of Bisho, etc.

Accuracy Assessment of Land Cover Classification of BCMM

The purpose of accuracy assessment is to measure the correlation between classified imageries and what exists on the ground (Foody, 2020; Homer et al., 2020). While acknowledging the complexity of accuracy assessment in remote sensing studies, the research rigorously evaluates the LULC classification results using multiple validation techniques to ensure the reliability and consistency of the findings. By conducting thorough validation tests, the study enhances the credibility of the identified LULC changes and their implications for pedagogy and rural education. Accuracy measurements were used to verify the exactness for the NDBI and NDVI classified images of BCMM in 1998, 2008 and 2018. To ascertain the validity of the LULC classification results for this study, two accuracy assessment tests were performed, namely:

- Coefficient of determination (R^2);
- Cohen's Kappa Coefficient (k); and
- Pearson's Product Moment Correlation Matrix (*P* Value)

Accuracy Assessment Using Coefficient of Determination (R^2)

According to Chakhar et al., (2020), the Coefficient of Determination (R^2) quantifies the proportion of variance. This coefficient takes values from 0 to 1 and indicates the robustness or strength of phenomena been studied (Anand and Oinam, 2020). The coefficient of determination technique for this study was done by testing the performance and correlation of the landcover types to the NDBI results, and this was carried out in Microsoft Excel environment. The result is presented in Figure 7.

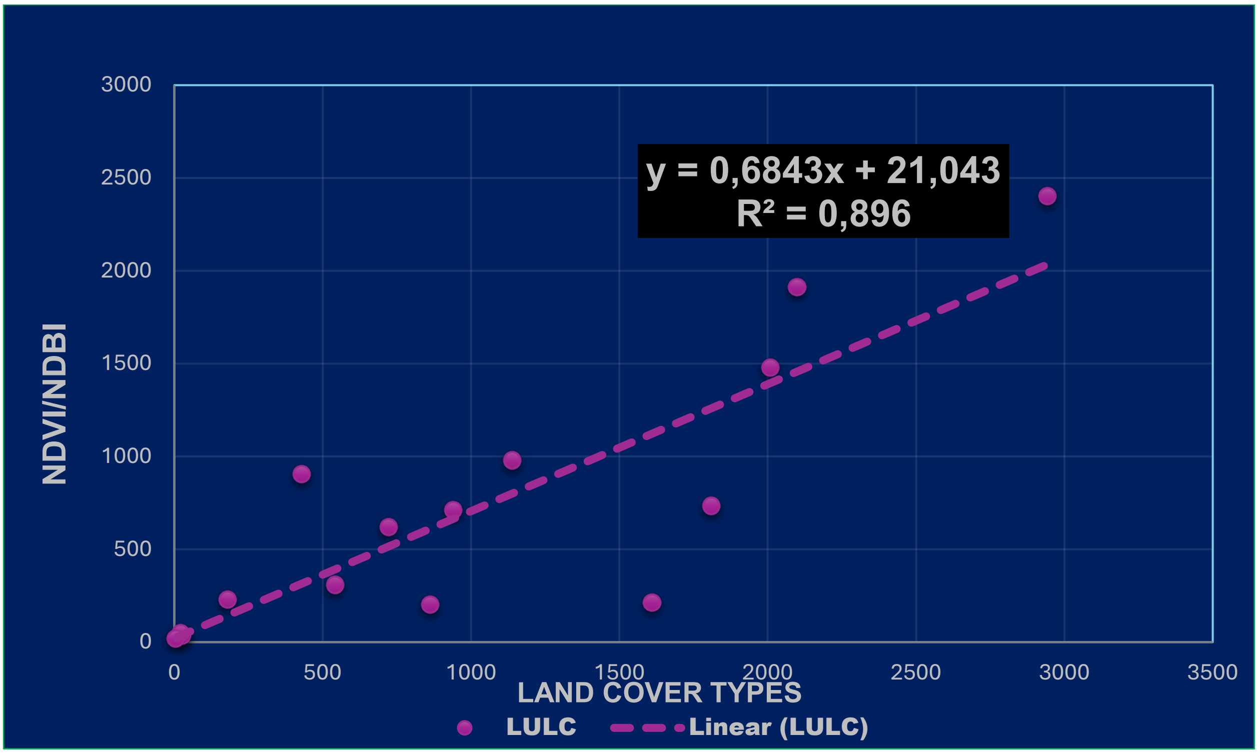


Figure 7: Coefficient of Determination (R^2) Results of BCMM LULC Classification (Source: Authors).

Figure 7 depicts the coefficient of determination (R^2) of the landcover classes (X axis) for 1998, 2008 and 2018 and the NDBI/NDVI results (Y axis). Based on the regression analysis, the result indicates that the relationship between the LULC and the NDBI is significant and strongly correlated at $R^2 = 0.896$ *(89.6%)*. From the foregoing, R^2 is close to 1, which means that the results from this study show very good overall classification accuracy during the study period. This accuracy assessment technique is also supported in literature by Getu-Engida et al, (2021).

Accuracy Assessment Using Cohen's Kappa Coefficient (k)

Cohen's Kappa Coefficient (k) is a statistical technique which was used in the determination of accuracy levels of the five LULC classes of the study area. It is generally thought to be a more robust measure than simple percent agreement calculation, since k considers the agreement occurring by chance. The kappa coefficient measures the agreement between classification and truth values. The Cohen’s Kappa Coefficient was calculated using the ArcMap Raster Calculator in the ArcGIS spatial analyst, and it conforms with the study conducted by Foody, (2020). The results are presented in Tables 2 to 7.

Table 2: Kappa Coefficient Accuracy Assessment (1998)

Class	Waterbody	Built-up Areas	Forest	Bare land	Grassland	Total
Waterbody	42	0	0	0	0	42
Built up Areas	6	44	0	2	0	52
Forest	0	4	41	8	6	59
Bare land	3	2	6	39	14	64
Grassland	2	0	3	7	37	49
Total	50	50	50	50	50	250

Overall Accuracy = (203/250) = 81.2%
Kappa Coefficient = 0.77

Table 3: Producer and User Accuracy Assessment Results (1998)

Classes	Error of Commission (%)	Error of Omission (%)	Producer Accuracy (%)	User Accuracy (%)
Waterbody	0	22	78	100
Built up Areas	18	12	88	84
Forest	31	18	82	69
Bare land	44	34	66	56
Grassland	29	40	60	71

Table 4: Kappa Coefficient Accuracy Assessment (2008)

Class	Grassland	Forest	Waterbody	Bare Ground	Built Up Areas	Total
Grassland	43	0	0	3	1	47
Forest	7	39	10	2	0	58
Waterbody	0	4	37	1	0	42
Bare Ground	0	0	0	27	1	28
Built Up Areas	0	8	3	16	48	75
Total	50	51	50	49	50	250

Overall Accuracy = (194/250) 78%
Kappa Coefficient = 0.72

Table 5: Producer and User Accuracy Assessment Results (2008)

Classes	Error of Commission (%)	Error of Omission (%)	Producer Accuracy (%)	User Accuracy (%)
Grassland	9	14	86	87
Forest	23	12	88	77
Waterbody	02	16	74	93
Bare Ground	04	36	54	96
Built Up Areas	26	04	96	74

Table 6: Kappa Coefficient Accuracy Assessment (2018)

Class	Grassland	Forest	Waterbody	Bare Ground	Built Up Areas	Total
Built-up Areas	42	0	0	5	0	47
Forest	0	42	3	0	6	51
Waterbody	0	0	45	0	0	45
Bare land	8	0	1	40	0	49
Grassland	0	8	1	5	44	58
Total	50	50	50	50	50	250

Overall Accuracy = (213/250) 85%
Kappa Coefficient = 0.79

Table 7: Producer and User Accuracy Assessment Results (2018)

Classes	Error of Commission (%)	Error of Omission (%)	Producer Accuracy (%)	User Accuracy (%)
Built-up Areas	38	06	84	73
Forest	29	12	84	78
Waterbody	21	05	90	82
Bare land	32	11	80	70
Grassland	23	09	88	79

Tables 2 to 7 depict the Cohen's Kappa Coefficient results, as well as the producer/user accuracy assessment results for the five LULC classes calculated for the imageries of the period under review. The Kappa result is interpreted as follows: values ≤ 0 as indicating no agreement and 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41– 0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement. The results indicate substantial accuracy results of 0.77, 0.72 and 0.79 respectively for the three years under review respectively. Further, the producer and user accuracy assessment results (depicted in Tables 3, 5 and 7) were significant. Hence, the user accuracy results for the LULC classifications for this study are significantly reliable.

Accuracy Assessment Using Pearson's Product- Moment Correlation Matrix (PPMC)

PPMC technique is used for investigating the relationship between two quantitative, continuous variables (Njoku and Tenenbaum, (2022). The nearer the scatter of points is to a straight line, the higher the strength of association between the variables. PPMC was performed using the Statistical Package of the Social Sciences (Version 26) software, and the results indicate that the NDBI/NDVI indices is very significant and highly correlated at p= 0.85 (85%). are tabulated in Table 8.

Table 8: PPMC Matrix Validating BCMM Landcover Types and NDBI/NDVI Classification Results

		NDBI/NDVI	LULC
NDBI/NDVI	Pearson Correlation	1	.860**
	Sig. (2-tailed)		.000
	N	15	15
LULC	Pearson Correlation	.860**	1
	Sig. (2-tailed)	.000	
	N	15	15

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the PPMC matrix, the results as shown in Table 8 indicates that the relationship between the LULC and the NDBI/NDVI indices is very significant and highly correlated at p= 0.86 (86%). Hence, a correlation of 1 indicates a perfect positive correlation, hence, the results show excellent overall classification accuracy during the study period. This accuracy assessment technique is supported in literature by Njoku and Tenenbaum, (2022). From the foregoing, the research results depict a significant increase in grassland and forest vegetation loss during the period. Reasons attributable to reduction in forest vegetation in the study area include rapid increases in the provision of urban infrastructure such as housing units, roads, rail and airport. in the industrial, commercial, technological and logistic centres in the study area such as Mdantsane, Bisho, KWT, East London, Duncan Village, as well as the enactment of regional policies attempted to divert population and growth. Hence, policies such as the Integrated Development Plan (IDP) and the Spatial Development Framework (SDF) have led to increased urbanization has led to the removal of vegetation on account of providing basic infrastructure to meet the needs of the ever-increasing citizenry. This is also in conformity with other studies that rapid urbanization and land cover changes have occurred in many parts of the study area such as East London metropolis, and these have contributed significantly to drastic change in the natural land surface characteristics (as well as increased land surface temperature and surface solar radiation), thereby culminating into vegetation cover decline in East London area by about 358.812km^2 while built-up areas increased by 175.473km^2 from 1986 to 2006. Further, urban expansion has culminated in rapid population growth in the study area, it is observed that population increase could be an indispensable factor that causes urban expansion. For instance, several peripheral satellite towns (such as KWT, East London, Bisho), related to other commercial centres in the study area in 1998 were joined more closely with the commercial centres in 2018 during the process of urban expansion.

LIMITATIONS OF THE STUDY

Despite extensive global research on LULC changes, specific studies focusing on South African coastal metropolises, particularly BCMM, are limited.

CONCLUSION

This study examined the impact of urban expansion on the coastal vegetation of BCMM using geospatial technologies, focusing on the years 1998, 2008, and 2018. The study concludes that urban expansion has led to reduced biodiversity, degraded watersheds, increased soil erosion, and raised the risk of endangering the fragile BCMM CVEs. Rapid and unprecedented LULC changes in BCMM in recent years have exacerbated negative consequences such as soil erosion, loss of biodiversity, water pollution, and air pollution. Furthermore, the research revealed that urban expansion in BCMM has led to significant threats to the coastal ecosystem, including the extinction of endemic species, loss of wildlife habitats, and disruption of microbial activities and soil metabolism necessary for plant growth. Other effects of urban expansion on BCMM's CVEs include changes in micro-climatic conditions, soil erosion, environmental pollution from illegal dumping of solid waste, and the loss of vegetation to other land use types. Consequently, this study urges municipality administrators to urgently address these critical environmental issues. The implications for rural education and pedagogy are significant; integrating these findings into educational curricula can enhance students' understanding of sustainable practices and environmental stewardship. Specifically, rural education can benefit by equipping students with knowledge about the environmental impacts of LULC changes and empowering them to engage in local conservation efforts, thereby contributing to sustainable development and improved quality of life in their communities. Hence, the integration of findings on LULC changes into environmental education curricula, especially in rural settings, can foster a deeper understanding of ecological changes, promote sustainable land management practices, and empower students and rural communities with the knowledge needed to address and mitigate vegetation loss. Additionally, understanding LULC changes and their impacts on ecosystems is critical for fostering environmental awareness and stewardship among students. The insights generated by this study have broader implications beyond BCMM, thus contributing to global efforts to monitor and manage LULC changes, particularly in coastal regions. Moreover, the study finds that urban expansion has led to significant threats to the coastal ecosystem, including the extinction of endemic species, loss of wildlife habitats, and disruption of microbial activities and soil metabolism necessary for plant growth. Despite potential criticisms related to methodological limitations, generalization challenges, and the perceived overemphasis on environmental education, this study contributes valuable insights into the spatio-temporal dynamics of LULC at BCMM and their implications for pedagogy and rural education and promoting ecosystem resilience.

In discussing the potential challenges and limitations of implementing these educational recommendations for this study, poses several potential challenges and limitations. Firstly, there may be a lack of adequate funding and resources to effectively integrate land use and cover dynamics into the rural education curriculum. This includes the need for updated textbooks, digital tools, and trained educators proficient in geographic information systems (GIS) and remote sensing technologies. Secondly, rural schools often face infrastructural deficits, such as limited access to electricity and the internet, which are critical for utilizing modern educational tools and resources. Additionally, there may be cultural and linguistic barriers, as educational materials and methods developed for urban contexts might not be directly applicable or relatable to rural students. Furthermore, the existing disparity in teacher quality and student-teacher ratios in rural areas could hinder the effective dissemination of new pedagogical approaches. Resistance to change from educators and communities accustomed to traditional teaching methods may also impede the adoption of innovative educational practices. Hence, it is germane to note that the dynamic nature of land use and environmental changes necessitates continuous updating of educational content, posing a challenge in maintaining relevant and current curriculum materials over time.

RECOMMENDATIONS

Considering the environmental degradation and uncontrolled urbanization challenges in the study area, it is crucial to improve conservation strategies and foster communal ventures aimed at innovative solutions to these environmental issues. Enhancing the development and implementation of programs that align with green infrastructure strategies is also imperative, as green spaces significantly enhance human health and well-being. Incorporating these recommendations into educational curricula can significantly benefit both urban and rural communities. By integrating conservation strategies and green infrastructure concepts into classroom teachings, students can develop a deeper understanding of sustainable practices. In rural education, specifically, equipping students with knowledge about environmental laws and holistic management of natural resources empowers them to advocate for and engage in local conservation efforts. This approach fosters environmental stewardship and prepares students to address the unique challenges of their communities, ultimately contributing to sustainable development and improved quality of life.

FUTURE RESEARCH

Future research will focus on the restoration of degraded coastal ecosystems by offering actionable solutions to achieve environmental sustainability and optimize ecosystem services. Conservation organizations can leverage the data generated by this study to plan and implement restoration projects, monitor their effectiveness, and engage local communities in conservation activities. Additionally, the integration of conservation strategies and green infrastructure concepts into educational curricula is recommended to enhance students' understanding of sustainable practices and environmental stewardship.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

USE OF AI

AI was used in the initial stage of the research for language editing.

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