

Planning for cooler cities in Ghana: Contribution of green infrastructure to urban heat mitigation in Kumasi Metropolis

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ABSTRACT

This study investigates the spatial variability of some remote sensing indices representing built-up areas, vegetation, bareness, and urban heat island (UHI), based on time-series Landsat TM/ETM+ and OLI/TIRS datasets archived for 1980–2020 period from the US Geological Survey's website for Kumasi Metropolitan Area in Ghana. Modules for Land Use Change Evaluation (MOLUSCE) and Cellular Automata Artificial Neural Network (CA-ANN) algorithms and simulations in QGIS were used to predict future changes (2020–2050) for land-use systems in Kumasi. Findings revealed urbanization/built-up areas (+108.02%) contributed massively to the decline of forest areas (−93.34%) and farmlands/shrubs (−31.53%), thereby making Kumasi lose its once critical green position as the “Garden City of West Africa.” UHI moderately and strongly correlated positively against built-up ($R^2=0.78$, $p < 0.0001$) and bareness ($R^2=0.96$, $p < 0.0001$) indices, respectively. By contrast, UHI showed a statistically significant inverse relationship with the vegetative index ($R^2=0.97$, $p < 0.0001$). Future land-use scenarios revealed more forests, waterbodies, and farmlands/shrubs will be lost, influencing urban temperature and water supply. The multipurpose advantages of urban green space are ingrained in the grand urban model. Contextually, the Metropolis's resilience has been hampered by inconsistency in the performance of institutional roles, competition for land ownership rights over green areas, and little investments or prioritization of green spaces. An integrated collaborative governance framework is proposed to unify actions, address power crisis and factors that influence governance of green infrastructure, UHI and land cover change.

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1. Background and related studies

Land cover change (LCC), according to Stehfest et al. (2019) connotes a change in certain continuous characteristics of the land such as vegetation features, soil properties, and so on, whereas land-use change (LUC) encapsulates the transformation of a natural landscape into other forms. These alterations are accompanied by a host of regional/local and global implications, including variations in climatic conditions, biodiversity loss, health and safety, as well as ecosystem functions and endpoints. Existing literature (Hong et al., 2022; Zhang et al., 2019) have reported the link between Land Use/Cover Change (LUCC) and climate change. Growing concerns on prioritizing LUC amid sustainability concerns emanate from the said mesoscale phenomenon influencing earth and atmospheric processes, sustainable development, food security and public health (Zhang et al., 2019). Evidence of the dire consequences associated with this phenomenon has driven stern initiatives towards promoting sustainable practices, heat mitigation, land-use management (LUM) and social innovations (SI). Notable among undesired climate stressors linked to LUCC consist of urban heat island or amplification of land surface temperature, heat waves and certain forms of diseases. Global warming and UHI effects are interconnected, but ultimately different in horizon. The former is said to have emanated from severe city expansion during the industrial revolution, as observed in the 20th century (Maxwell et al., 2018). The combination of the foregoing factors led to the increasing range and aridity of UHI; a phenomenon where obvious temperatures that are high are mostly found in urban cities, while those in the rural areas are usually low due to atmospheric and surface modifications associated with urbanization (Long, 2022; Twumasi et al., 2021). Zhang et al. (2019) asserted that the effect of the preceding trigger of UHI threatens urban habitability to a great degree. They concluded that this phenomenon in the twenty-first century is viewed as one of the major challenges for humankind.

Urban heat island (UHI) as an existential phenomenon of about 200 years has currently emerged, linked to habitability of urban cities. Presently, this phenomenon is considered as one of the primary issues bedevilling the sustainability of cities. The event was identified over 200 years ago in a study that describes the urban climate of London (Howard, 1818). Fundamentally, this issue has however become significant due to the momentous expansion of urban cities and industrialization at a great scale. The event became noticeable during the past fifty years with devastating effects, considering a host of factors triggering its size and intensity beside the common reasons like rapid population growth, industrialisation and automobiles, deforestation and extensiveness of agricultural activities, among other development parameters. Data shows about 47% of Africa's population live in urban areas. United Nations Department of Economic and Social Affairs (UN-DESA, 2015) estimated the proportion of the world's population living in urban areas amplified from 30% in 1950 to 54% in 2015. They further projected this figure to rise to 66% by 2050, citing rapid population growth in Africa and Asia (UN-DESA, 2015). In this study, the tenets of United Nations Millennium Sustainable Development Goals (SDGs) 11 (*targeted at renewing and planning cities/settlements to adhere to the principle of ensuring equitable distribution and access to basic services, to enhance human welfare and protect the environment*), 13 (*incorporates reactive and anticipatory measures into national policies that enhance adaptive capacity*) and 15 (*facilitate sustainable practices that protect and restore degraded lands*) are drawn. Sustainable development remains a key challenge for the future of most cities, municipalities and metropolises. These guiding concepts are situated in the grand urban model (GUM) which refers to the comprehensive planning and development of urban areas that are designed to be sustainable, eco-friendly and liveable (Hong et al., 2022; Çalışkan, 2012). One of the key concerns in the GUM is the issue of UHI. UHI is a phenomenon where urban areas experience a significant increase in temperature due to rapid urbanization, and changes in land use patterns. UHIs are known to have significant impacts on public health, energy consumption, and the environment. GUM

addresses UHI by promoting sustainable urban planning that prioritizes green spaces and vegetation. Trees, green walls and roofs, among other forms of vegetation have the potential to reduce urban temperature and mitigate UHI effects. Green roofs and walls can also provide additional benefits such as energy conservation, pollution reduction, improve public health and carbon sequestration. According to Teye (2018), climate change threatens systems and processes in major cities.

In Ghana, akin to other nations in Africa, the capital cities are in most instances challenged with the issue of rapid urban sprawl which contributes greatly to the intensity of UHI. Ghana's overall population has grown almost five-fold in size between 1984 and 2021 (Ghana Statistical Survey GSS, 2021). Again, the statistics of urban population overshadowed the rural population growth by an annual percentage of 4.4. Ghana's urbanization rate according to the Ghana Statistical Service (GSS) rose from 30% to 57.35% (Ghana Statistical Survey GSS, 2021). The nation has initiated some socio-economic policies like the Ghana Vision 2020, Renewable Natural Resource Sector Strategy, Comprehensive Development Framework (CDF), Ghana Poverty Reduction Strategy (I & II), Millennium City Initiative, Savannah Accelerated Development Programme, Ghana Youth Employment and Entrepreneurial Agency, National Urban Policy, Planting trees for Food and Jobs, among others. Isoyoye et al. (2020) opined that in least developed nations, the largest, medium and small-sized cities are the economic hubs. Early studies conducted in Kumasi Metropolitan Assembly (KMA) attempted to quantify and spatially (Nero et al., 2017; Abass et al., 2018; Engelhardt, 2012) present the distribution of UGS above and beneath the ground carbon pools, determine the extent of urban heat, effects of green roofs on thermal discomfort in indoor spaces, and the perception of the populace in relation to their immediate settings and prevailing micro-climatic conditions (Koranteng et al., 2021). Studies conducted by Campion (2012) and Mensah et al. (2020) primarily delved into issues related to the sustenance of UGS, land use systems (Toure et al., 2020), urbanisation, extreme events and wetlands. Twumasi et al. (2021) compared land surface temperature and lushness density of two major cities in Ghana. In the same vein, Keith and Meerow (2022) proposed some heat mitigation strategies that improves quality of life in cities. Abulibdeh (2021) posited that the degree of intensity and thermal balance of UHI remain a function of different components which comprise urban design (location of open spaces and spacing between buildings), population growth and density, vertical and horizontal urban expansion, topography, land use cover change attributes, and nature of building materials (Estoque et al., 2017; Cui et al., 2016; Grover and Singh, 2015).

Kumasi Metropolis, earmarked among the major cities under the Millennium City Initiative (MCI), has not received adequate attention on green infrastructure, UHI and its prognosis. The current study moves beyond establishing a link between thermal comfort and vegetation, as well as identifying population growth and poverty as the sole drivers of LUCC and UHI in urban areas, as reported in numerous studies. In spite of a surge in current literature and the guiding concepts highlighted in the previous paragraphs, particularly in developed countries, the task of developing reliable predictions of future LUCC in KMA is further complicated by limited accurate baseline data on urban vegetative cover, urban hotspots and barren areas. The application value of this study, specifically the land-use predictions will play a crucial role in creating alternative futures and policy options, geared towards social, economic, institutional and environmental considerations. The outcome of this study is vital in the sense that very few long-term analyses of changes in urban vegetation in African cities have been conducted. Again, examining some remotely sensed indices for deeper and clearer insights for major cities remain an arduous challenge, coupled with allaying feasible and proactive strategies that addresses UHI effects and urban green issues within the context of the grand urban model. Standpoints reported in this study will be essential to urban communities more widely amid climate concerns, both within and beyond the developing world. Therefore, we attempted to:

1. Analyze the spatial distribution of land use systems in Kumasi Metropolis between 1980 and 2020.
2. Examine the spatial variability of urban vegetative cover, urban hotspots, barren areas and UHI.
3. Identify green and non-green hotspots that could be factored into sustainable urban planning.
4. Identify historical shifts in Normalized Difference Vegetative Index (NDVI), Normalized Difference Built-up Index (NDBI) and Normalized Difference Bareness Index (NDBaI), and how they influence UHI.
5. Create future LUCC scenarios (2020-2050) and propose policy options that address heat mitigation concerns.

2. Study area and methods

2.1. Study setting

The Kumasi Metropolis (Fig. 1) lies 270 km north of Ghana’s capital. With latitude 6°40.664’N and longitude 1°37.397’W. It occupies an area of about 214 km². Kumasi Metropolis serves as the administrative capital of the Ashanti region.

The GSS (2021) estimates that KMA’s current population stands at 3, 490, 030 (Fig. 2). It links major areas to the northern and southern parts of Ghana, characterized by two main seasons (rain and dry seasons) with a transitional forest zone.

2.2. Data acquisition and image classification

In this study, five Landsat images with a resolution of 30 m, archived for the given period (1980–2020), were acquired from the United States Geological Survey’s (USGS) website (<http://earthexplorer.usgs.gov/>). ArcGIS 10.8, ENVI 5.0 and 5.3 were used for the image pre-processing and enhancement. Table 1.

2.2.1. Data processing

Other image pre-processing procedures (Fig. 3) which were performed include image calibration, layer stacking and supervised classification (Table 2). Bands 7, 4 and 2 were used for various classifications, specifically for LANDSAT 4 (1980 s) and 5 TM (1990 s), as well as LANDSAT 7 ETM+ (2000 s and 2010), whilst LANDSAT 8 OLI/TIRS (2020) used bands 5, 5 and 3 with 055/194 as row/path. We employed Landsat satellite imagery for this study due to its high level of standardization, accessibility or provision of free datasets to individuals and the global community, and its optimal ground resolution capacity to detect and monitor changes in landscapes and other ecosystems driven by biophysical and other human-induced factors.

2.3. Change detection analysis

Change detection analysis was run to ascertain the regularity of land use systems and its drivers in KMA, based on the following formulations:

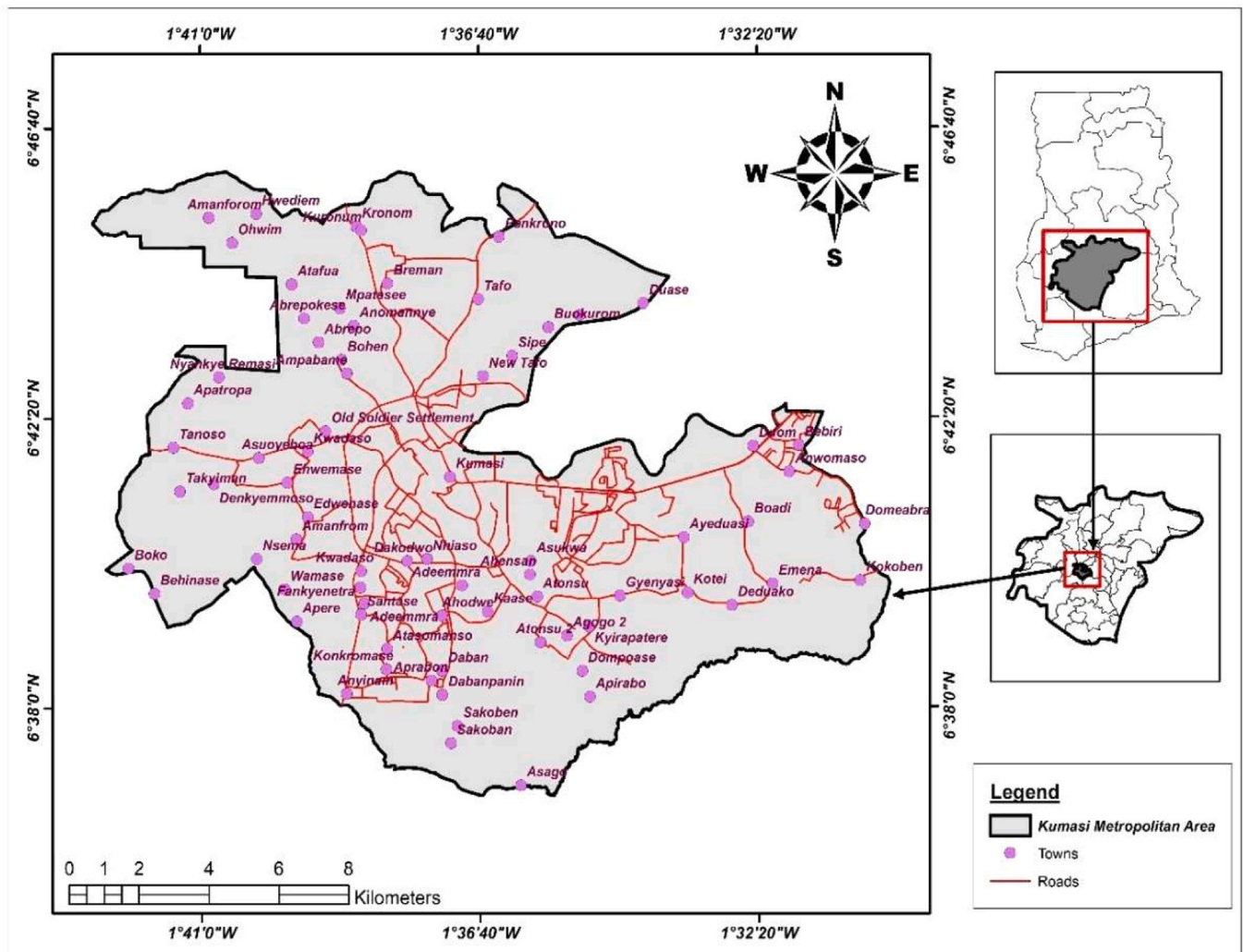


Fig. 1. Geographical location of Kumasi Metropolitan Area.

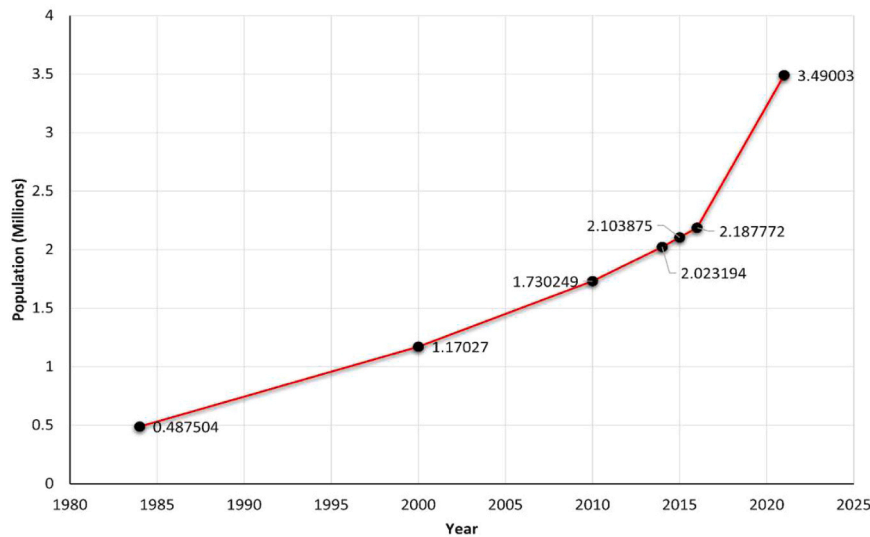


Fig. 2. Total Population (millions) for Kumasi Metropolis (1984–2021).

Table 1

Description of land cover types identified in KMA.

Feature	Definition
Forests	Closely interwoven trees and lush vegetation dominate these areas. It also includes all vegetative regions with no exposed soil.
Built-up	Urban, business, and industrial regions. This category also includes community green spaces, playing fields, and truck terminals.
Bare land	Bare sections of soil or rocks that haven't been covered by greenery. In and around built-up regions, barren areas are noticeable. It constitutes terrains that have been cleared in preparation for redevelopment or cultivation.
Farmlands and shrubs	Widely distributed trees, hedges or bushes, secluded thickets, and non-tree crops.
Waterbodies	Rivers, lagoons, lakes, and other bodies of water are all part of this ecosystem.

$$\text{Change in LUCC}(x^2) = \frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}} \quad (1)$$

$$\% \text{ Change in LUCC}(x^2) = \frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}} \times 100\% \quad (2)$$

$$\text{Rate of change in LUCC per year} = \left[\left(\frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}} \right) \times 100\% \right] \div 40\text{years} \quad (3)$$

Where;

$\text{LUCC}_{\text{Current year}}$ denotes the final year under study, thus, the year 2020 within the context of the present study; $\text{LUCC}_{\text{Past year}}$ denotes the initial year being studied, thus, the year 1980. The rate of change in LUCC per year was estimated to ascertain the gains/expansion and losses/reduction in areas covered by the given land use classes over the past 40 years per the study duration. This provides detailed information on how changes occurred annually to ascertain the major events, transitions and underlying mechanisms that drove such changes in order to inform policies.

2.4. Spatial autocorrelation

The value range for UHI, NDBI, NDVI and NDBaI was classified into twenty classes (Table 3) each using ArcMap 10.8. The relationship analysis was conducted to show whether there is a direct (positive) or inverse (negative) relationship between the given variables quantified in Table 3. The georeferenced or values generated for each of the under-studied variables were exported to Statistical Package for Social Sciences (SPSS) version 26 for further analysis.

2.4.1. Coefficient of determinant

Degree of proof or substantiation described as insignificant, relatively weak, or weak; least reasonable, or reasonable; and significant, or substantial connection was determined through this research. R^2 justified the level of variation in a model. Thus, a model's capacity to forecast or justify an event in a logistic regression scenario. Maximum R^2 score mean the deviation in an outcome may be clarified by estimation, using the specified parameters. R^2 solely delves into magnitude of the association, and not ascertaining one variable as the cause of the other.

$1 \leq R^2 \geq 0.8$ means substantial or significant association between the given parameters.

$0.7 \leq R^2 \geq 0.5$ indicates reasonable or least reasonable association.

$0.49 \leq R^2 \geq 0.2$ indicates weak or relatively weak association.

Less than 0.2 indicates insignificant or no association.

2.5. Land use prediction and validation

Predictions for 2030, 2040, and 2050 were made using Modules for Land Use Change Evaluation (MOLUSCE) in QGIS software version 2.18.24. This plug-in uses Cellular Automata and Artificial Neural Network (CA-ANN) techniques and simulations to forecast or make predictions for KMA. The analysis primarily constitutes Evaluating Correlation (EC), area changes, Transition Potential Computation (TPC) modelling and validation based on four (4) iterations. Digital Elevation Model (DEM) and a road raster georeferenced image of KMA were used as reference data for the predictions. The main predictor variables used as reference for future projections, based on the three (3) iterations constitute *built- environment* (i.e., likelihood of change, density of developed lands and crop land and transportation), *socio-economy* (i.e., population density, number of households, urban population density, urbanisation and industrialization), and *natural environment* (i.e., climatic variables-temperature, precipitation and moisture; ecology and topography).

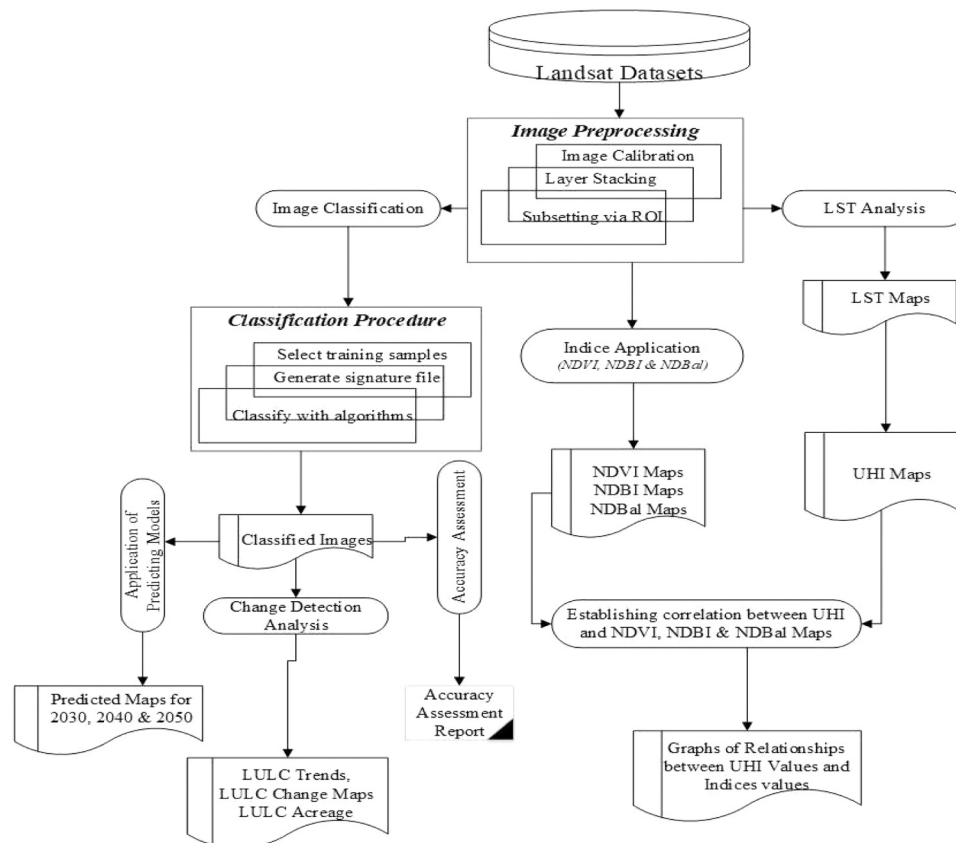


Fig. 3. Flow diagram of image-processing and post-classification for the study.

In predicting LULC in Kumasi Metropolis (Fig. 4), the model’s first stage integrates LULC maps for the base periods (2010 and 2020) for predicated 2030, 2040 and 2050. Inputs are incorporated in the model to generate LULC map, from which the changing trends for the study setting between 2010 and 2020 are generated. These parameters constitute DEM, distance from roads, and built-up density. Using Pearson’s correlation, Cramer’s coefficient and Joint Information uncertainty, the link between geographic variables between the two raster images, employed for this relationship is examined. Various classifications for KMA along with the region’s dynamics are computed between the base period (2010) and the final year (2020). The TPC plug-in applies some machine learning algorithms like artificial neural networks (ANN), logistic regression (LC), weights of evidence (WoE), and some multi-criteria evaluation (MCE) to create TPC maps. These techniques or procedures draw on geographic information and LULC data to construct and calibrate changes in the region. ANN was applied to make predictions for 2030, 2040 and 2050. A confusion matrix that merges and improves the user and producer accuracy assessments were used to gauge accuracy rates.

2.5.1. Accuracy assessment

In order to assess the accuracy of each study period, ground truth sample points were generated using ENVI and ArcGIS software. These points were overlaid on Google Earth Pro for verification. Twenty sample points were generated from each class in the classified images for the accuracy assessment (see Fig.A.1). The expression or confusion matrix below was used to estimate the accuracy assessment:

$$\text{Accuracy Assessment(A.A)} = [(\text{ASP/TSP}) \times 100] \tag{12}$$

Where:

A.S.P = Number of sample points that accurately fall on each required feature (ASP=94).

3. Results

3.1. KMA’s change detection analysis

Statistics (Tables 4–5) presented indicate land cover conversion for the five classes during the last four decades. Built-up and barren areas were the main land features that increased dramatically over the study period. Conversely, farmlands and shrubs, forests and waterbodies experienced massive reduction in area coverage over the same period (Fig. 5).

3.2. Urban Heat Island (UHI) analysis

The mean temperature for the given study period (1980–2020) ranges between 31.62 °C to 20.79 °C. An upswing in UHI in Kumasi Metropolis as presented in Fig. 6 is primarily due to anthropogenic influence, which is driven largely by population growth and distribution (increasing settlements due to high birth/fertility rates and migration, urban sprawl, and so on), infrastructure development, and conversion of forest resources into other land cover forms. Tables 4–5 and Fig. 5 show a remarkable rise in barren areas indicating the natural vegetation or forests have been altered, with these areas cleared for development purposes. More specifically, between 2010 and 2020, there was a considerable rise (i.e., by 3.1 °C in maximum temperatures) in urban heat, which could be attributed to the alarming rate of forest and land degradation (declension rate of 2.3% between 1980–2020), and escalating settlements (+108.02%), resulting in a significant increase in bare land (+924%), which influenced rising temperatures (i.e., 9.01 °C and 5.2 °C as differences in maximum and minimum temperatures over the past four decades) (Fig. 6) in the KMA. UHI effects influence morbidity and mortality of several ecosystems.

Table 2
Quantification of remote sensing variables.

Indices	Formulation	Source
NDVI	$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (4)$ <p>where; NIR= Near-infrared, RED= Red visible bands</p>	Abu Bakar et al. (2016)
NDBI	$NDBI = \left(\frac{SWIR - NIR}{SWIR + NIR} \right) \quad (5)$	Xu (2007)
NDBaI	$NDBaI = \left(\frac{Band5 - Band6}{Band5 + Band6} \right) \quad (6)$ <p>For Landsat 8 data:</p> $NDBaI = \left(\frac{Band6 - Band10}{Band6 + Band10} \right) \quad (7)$	Chen et al. (2006)
UHI analysis	$L_{\lambda} = \frac{(LMAX_{\lambda} - LMIN_{\lambda})}{(QCALMAX - QCALMIN)} \times (DN - QCALMIN) + LMIN_{\lambda} \quad (8)$ <p>Where L_{λ} is cell value as radiance in $W/(M^2 * sr * \mu m)$; $LMAX_{\lambda}$ is the sensor spectral radiance (L_{λ}) scaled to ($QCALMAX$) in $W/(M^2 * sr * \mu m)$; $LMIN_{\lambda}$ is the sensor spectral radiance that is scaled to ($QCALMIN$) in $W/(M^2 * sr * \mu m)$. ($QCALMAX$) is the maximum quantized calibrated pixel value to $LMAX_{\lambda}$ [D.N], ($QCALMIN$) is the minimum quantized calibrated pixel value corresponding to $LMIN_{\lambda}$ [D.N]; and $QCAL$ is the quantized calibrated pixel value [D.N]. The $LMIN$ and $LMAX$ are the spectral radiances for each band at D.N 1 and 255 for Landsat 7 ETM+, 1 and 65535 for Landsat 8 OLI/TIRS. λ is the wavelength. -Conversion of L_{λ} to Kelvin (K) with emissivity value:</p> $T = \frac{K_2}{\ln\left(\frac{K_1 * E}{L_{\lambda}} + 1\right)} \quad (9)$ <p>Therefore, k_1 and k_2 become coefficients determined by effective wavelength of a satellite sensor.</p> $BT = \frac{K_2}{\ln[(K_1/L_{\lambda}) + 1]} \quad (10)$ <p>Since temperature is required in Degree Celsius ($^{\circ}C$) (T_C), results for various temperatures must be converted from (K) satellite brightness temperature (T_B) to ($^{\circ}C$) (T_C).</p> $T_C = T_B - 273.15 \quad (11)$	Avdan and Jovanovska (2016).

Table 3
Autocorrelation analysis for the given indices and UHI.

UHI	NDBI	NDBaI	NDVI
36.02	0.99	0.96	-0.77
35.79	0.89	0.88	-0.72
35.43	0.69	0.78	-0.67
34.88	0.59	0.68	-0.63
34.52	0.49	0.58	-0.57
33.73	0.39	0.48	-0.47
32.98	0.29	0.38	-0.39
31.73	0.19	0.28	-0.27
30.87	0.09	0.18	-0.02
29.77	0	0	0
28.52	-0.002	-0.09	0.09
28.12	-0.009	-0.19	0.19
27.73	-0.013	-0.29	0.29
27.34	-0.044	-0.39	0.39
26.85	-0.059	-0.49	0.49
25.47	-0.065	-0.59	0.59
23.77	-0.18	-0.69	0.69
21.72	-0.2	-0.79	0.79
19.33	-0.21	-0.89	0.89
18.38	-0.22	-0.99	0.99

3.3. Green space and urban hotspot analysis

Over the research period, ArcMap was used to reclassify and assign lushness and non-greenness symbologies to vegetative and non-vegetative regions in the Kumasi Metropolis. Urban green studied in KMA, as shown in Fig. 7, shows a constant decline in greenery. The city that was once dubbed the "Garden City of West Africa" because of its beautiful view of people living in harmony with nature has lost its identity to socio-economic growth and development. A close observation for the less density or concentration at the heart of KMA between 1990–2000 (Fig. 8) is attributed to the decongestion policy/exercise that took place for the effective implementation of Renewable Natural Resource Sector Strategy between 1996 and 2000, redevelopment of the city, and concerns over decline of KMA's lushness due to high influx of migrants from nearby or other regions in such of greener pastures, among other institutional and policy-driven factors.

Urban hotspot analysis (Fig. 8) was also performed to spatially depict areas and the magnitude of urbanization between 1980 and 2020. Based on the evidence presented in Tables 5–6, as well as Fig. 8, settlements within the Metropolis have amplified drastically. The quest of bridging housing deficit gaps, enhancing capital expenditure, as well as industrialization substantially support the spatial results generated by this study. KMA is Ghana's second most populated and largest city, and a

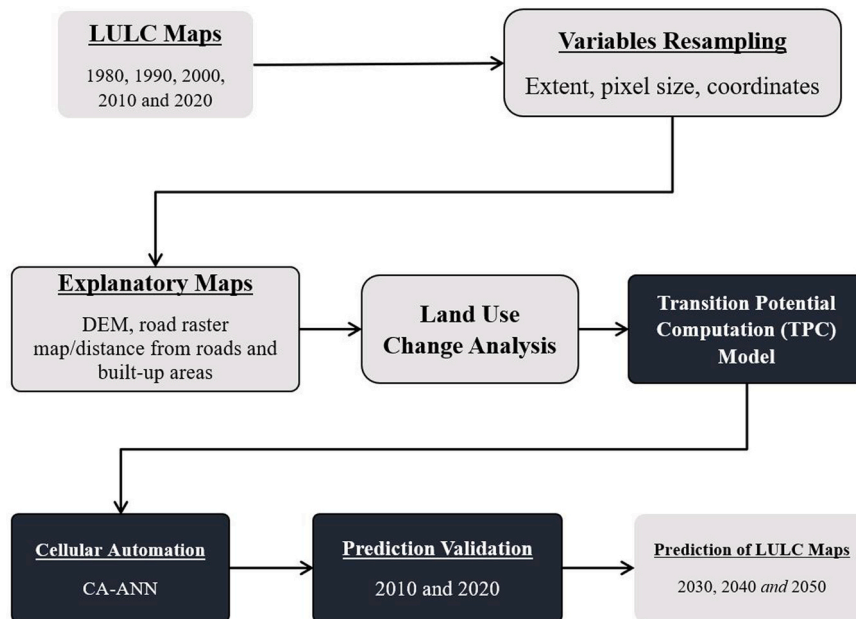


Fig. 4. Evaluation procedure for land-use change predictions.

Table 4

Area coverage for each class (km²) (1980–2050).

Class/Period	1980 s	1990 s	2000 s	2010	2020	2030	2040	2050
Built-up	120.4	170.91	193.19	237.67	250.46	262.66	275.45	287.57
Farmlands & shrubs	30.1	65.68	19.58	20.35	20.61	19.33	12.52	5.13
Forests	146.32	50.11	74.12	36.68	9.75	5.42	4.21	2.57
Waterbodies	0.44	0.57	1.15	0.41	0.36	0.29	0.25	0.19
Bare land	1.74	11.73	10.96	3.89	17.82	11.3	6.57	3.54

***Total area coverage (Km²) (Absolute) = 299

Table 5

KMA’s temporal variations of land cover changes (LCC) in windows (1980–2050) (%).

Class/Period	1980-1990	1990-2000	2000-2010	2010-2020	1980-2020
Built-up	+41.95	+13.04	+23.02	+5.38	+108.02
Farmlands & shrubs	+118.21	-70.19	+3.93	+1.28	-31.53
Forests	-65.75	+47.92	-50.51	-73.42	-93.34
Waterbodies	+29.55	+101.75	-64.35	-12.19	-18.18
Bare land	+574.14	-6.56	-64.51	+358.09	+924.14
Future Estimations (2020-2050)					
	2020-2030	2030-2040	2040-2050	2020-2050	1980-2050
Built-up	+4.87	+4.87	+4.4	+14.82	+138.85
Farmlands & shrubs	-6.21	-35.23	-59.03	-75.11	-82.96
Forests	-44.41	-22.33	-38.96	-73.64	-98.24
Waterbodies	-19.44	-13.79	-24	-47.22	-56.82
Bare land	-36.59	-41.86	-46.12	-80.14	+103.45

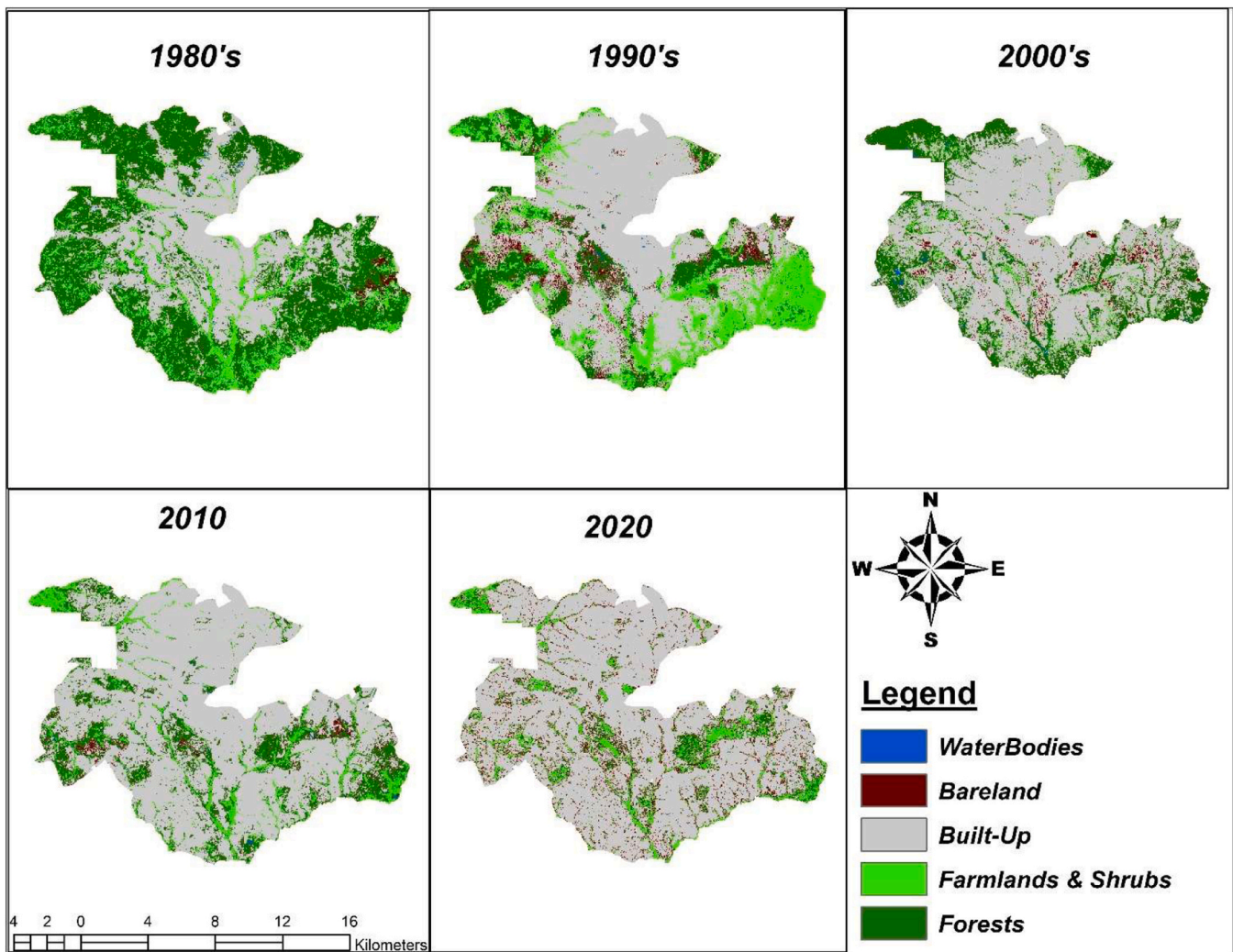


Fig. 5. LUCC over the past four decades in KMA.

commercial hub for production and business transactions (commerce and services) after Accra Metropolitan Area. Since the population of KMA is expanding at an annual rate of 2.3% between 1984 and 2021 (Fig. 3), demand for housing, infrastructure, food and employment, among others, continuously increases. These persistent expansionary forces exerted on the natural environment to meet the growing demands or needs of the populace is what has resulted in the massive decline of forest or natural vegetation over the years with undesired consequences like UHI.

3.4. LUCC prediction for Kumasi Metropolitan

The distribution (Tables 5–6) shows built-up will increase at a rate of 14.82% (with 0.5% increment each year), farmlands and shrubs will decline at a rate of 75.11% (with 2.5% decrease each year), areas covered by waterbodies will decrease by 47.22% (with 1.6% declension each year), bare land will expand by 80.14% (at 2.7% decreasing rate each year) whilst forests over the study period (2020–2050) will decline by 73.64% (at a declension rate of 2.5% each year). Considering current trends of immense changes in KMA, the projected statistics or scenarios (Fig. 9) could occur if strategic and results-oriented measures are not designed to avert or regulate current anthropogenic activities driving these changes. The highlighted drivers and trends without regulation defeat the purpose of developing a sustainable or a resilient city that enhances social well-being and quality of life.

A close observation of Fig. 2, considering the spike in KMA's population over the past few decades is in tandem with Abass (2018) standpoints. In his study dubbed "Peri-urbanisation and loss of arable land in Kumasi Metropolis in three decades", he asserted that urban population across the globe are expected to grow by more than two thirds. According to the GSS (2021) report on "Population projections/prospects", the Ashanti region of Ghana which has Kumasi Metropolis as its administrative capital projects the population of the region to hit 9,607,389 by 2050. The region currently has a population of 5,924,294, with 3.49 million residing in KMA. Similarly, a study conducted by PricewaterhouseCoopers (PricewaterhouseCoopers PwC, 2022), a multinational accounting and auditing firm in the United Kingdom, stipulates that "the current urban-rural split in Ghana which is 54% in urban areas and 46% in rural areas is likely to expand in favour of urban areas in the next three decades." According to PwC (2022) and GSS (2021) reports, Ghana's population is expected to surpass 50 million by 2050. Out of this total, 36 million are expected to live in urban areas, thus, 73% of the total population are projected to be living in urban areas by 2050. Results from the present study's land use predictions (2020–2050), which anticipates a continuous increase in built-up aligns with the reports and assertions of PwC (2022) and GSS (2021).

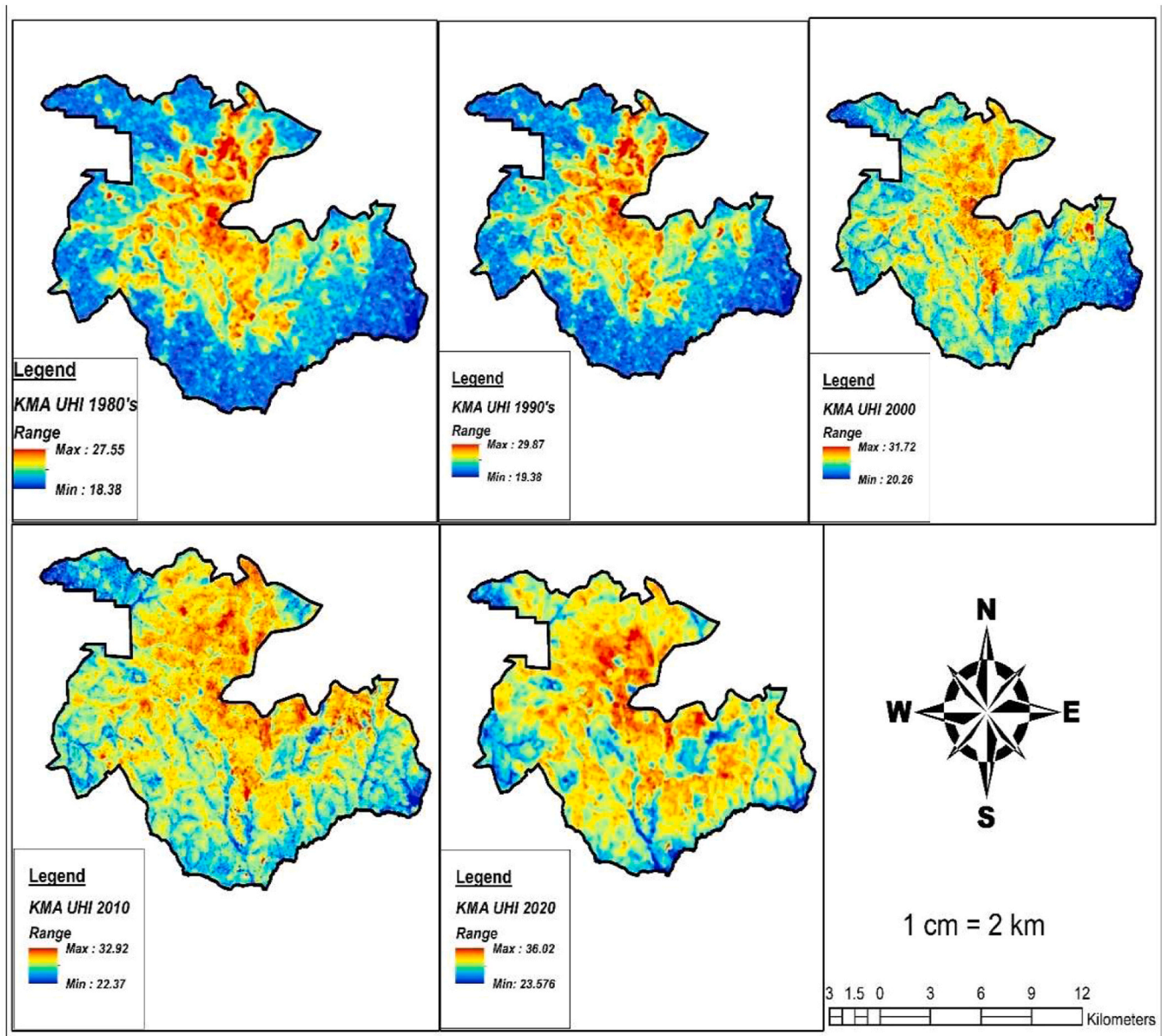


Fig. 6. UHI variations in KMA (1980–2020).

3.5. Assessment of the various indices in KMA

3.5.1. Vegetative-index

Fig. 10 illustrates a remarkable decline in vegetative index over the study period. Forest regions have higher NDVI values due to enhanced green biomass of trees and other plants. Forest and wildlife reserves/parks, closed (dense) and open canopies make up the greenish regions. Reduction in NDVI based on study findings could be attributed to urbanization (increase in human settlements, migration and so on), government policies, programs and projects, initiated between 1980 s-1990 s (i.e., 1983 Economic Recovery and Stabilization Program; Vision 2020 (1996–2020); Ghana Poverty Reduction Strategy I and II ((2003–2005, 2004–2007)/Ghana Shared Growth Development Agenda (2015–2020); National Urban Policy (2013 till date); Comprehensive Development Framework (1999–2001); Renewable Natural Resource Sector Strategy (1996–2000), as well as infrastructure development. Reddish regions indicate a significant negative change in greenery throughout the research period. Built-up environments and barren

terrain are examples of such regions. Yellow or light yellowish regions indicate less plant cover.

3.5.2. Built-up index

There is substantial evidence of settlement growth over the study period (Fig. 11). Magenta denotes areas where the built-up environment has undergone significant positive change (presence). Natural vegetation (forests) and farmlands/shrubs, respectively, are depicted by dark brown and yellowish sections. Light green zones are locations with few human populations and vast stretches of undeveloped land.

3.5.3. Bareness-index

The significant variations in bareness index across the research period are illustrated in Fig. 12. Regions with minimal bareness (less exposed patches) are represented by deep-blue areas, which are covered by natural flora. Reddish zones depict barren regions, left empty or unoccupied in order to be developed for infrastructure or farming. Built-up regions are represented by yellow patches and light red/yellow areas.

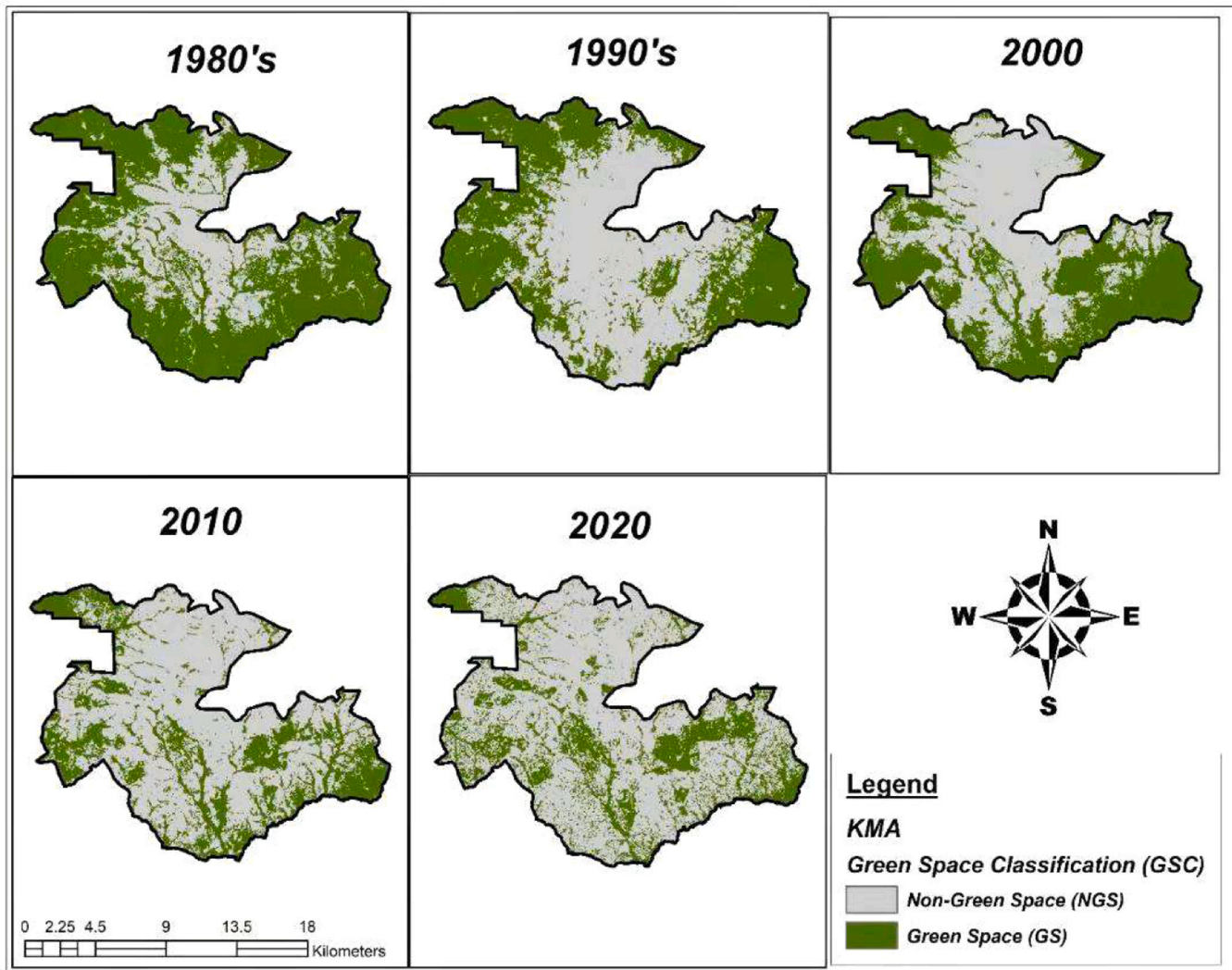


Fig. 7. Green and non-green space zones in KMA.

3.6. Relationship between the given study variables

The necessity of creating a relationship (Figs. 13(a)-13c) between UHI and the specified remote sensing indices is critical in acquiring a thorough understanding of land use and climate research. Identifying and tracking changes linked with historical land use system evolution validates strategic and results-oriented actions focused at reversing these unfavorable happenings. Global environmental change is the outcome of a combination of these changes at the local and regional levels throughout the world.

Generally, UHI and NDBI as reported in most studies have a positive correlation. The degree of correlation or association varies spatially from one geographical location to the other. In the context of KMA, a statistically significant moderate positive correlation was identified ($R^2=0.78$, $p < 0.0001$). Here, $R^2=0.78^2 \times 100\% = 60.84\%$. This indicates 60.84% of the variation in UHI is explained by NDBI (Fig. 13a). Here, the moderate positive correlation generated connotes the study identified enough evidence in relation to the link between the two variables. Contextually, geographic analysis revealed a significant and consistent rise in built-up (Fig. 11) and UHI (Fig. 6), respectively. Considering the growth in human settlements among other socio-economic activities in the study area, previous studies (Buo et al., 2021; Qin et al., 2020; Amos-Abanyie, 2009) have reported a direct

relationship between NDBI and UHI. Findings reported in this study is in tandem with the results mentioned by the studies above.

Plotting UHI values against the NDVI depicted a statistically significant strong inverse relationship ($R^2=0.966$, $p < 0.0001$). Here, $R^2=0.966^2 \times 100\% = 93.3\%$. This means that NDVI accounts for 93.3% of the variance in UHI. The study found robust evidence in relation to the link between the two variables. The inverse relationship in Fig. 13(b) suggests as NDVI decreases, UHI increases. Geospatial analysis based on LUCC and UHI proves drastic decline in forests, and a significant change in surface temperature (Fig. 6). Furthermore, unlike forests or thick vegetation, which substantially influence microclimatic conditions, farmlands and shrubs, despite their greenness, have little impact on surface temperature.

UHI and NDBAI plots in Fig. 13 (c) presents a strong positive relationship ($R^2=0.957$, $p < 0.0001$). Here, $R^2=0.957^2 \times 100\% = 91.59\%$. NDBAI is responsible for 91.6% of the variance in UHI. Bareness index increases with urban heat in KMA, according to representations (Figs. 6, 12 and 13c). According to Mensah (2015), green zones within the KMA have been encroached or removed for socio-economic gains.

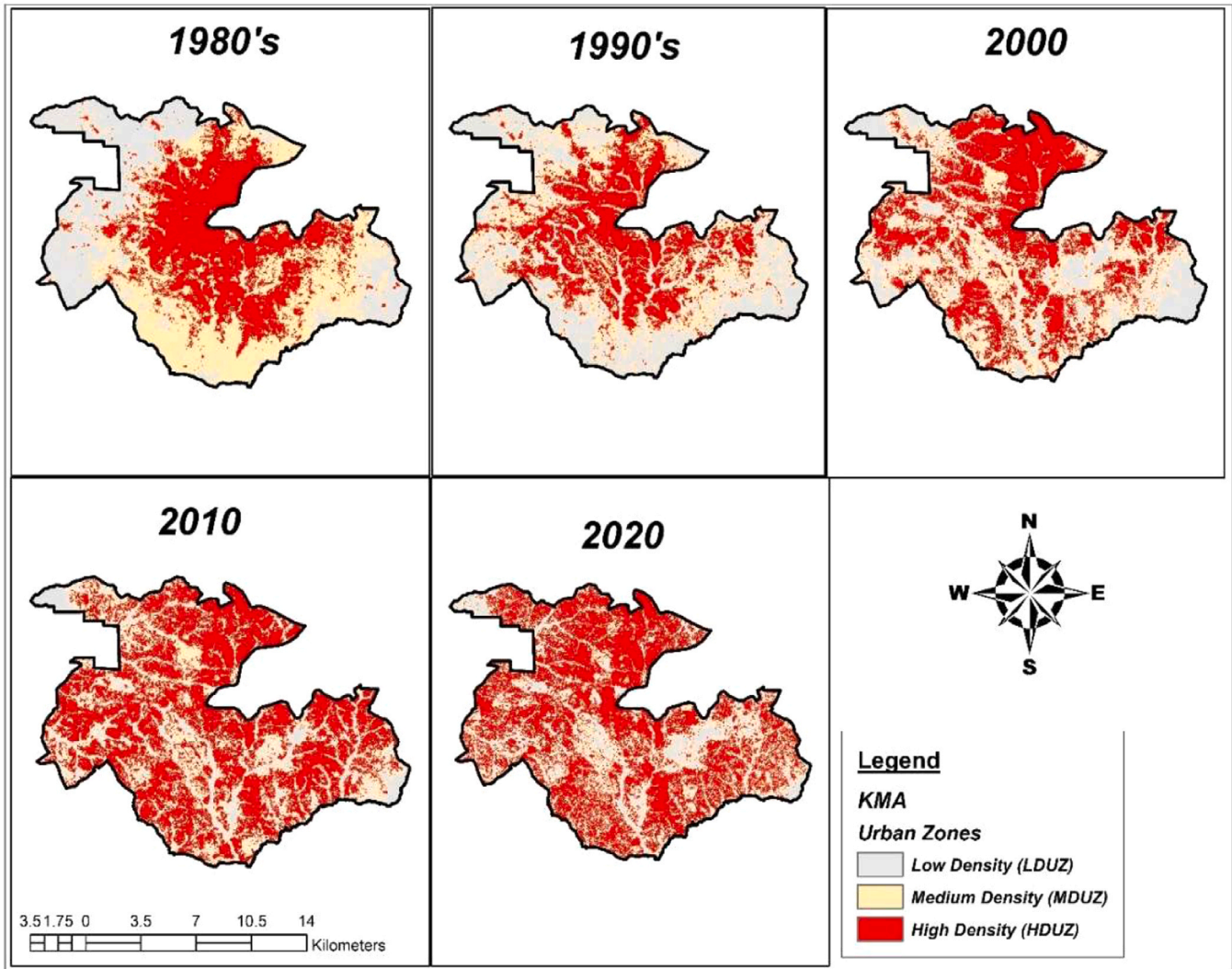


Fig. 8. Urban concentration hotspots in KMA.

Table 6
Rate and magnitude of change (sq.km) in LCC of Kumasi Metropolis.

Class/Period	1980	2020	2050	1980-2020			2020-2050		
				Magnitude of Δ (km ²)	Rate of Δ /Yr (%)	Magnitude of Δ (km ²)/Yr	Magnitude of Δ (km ²)	Rate of Δ /Yr (%)	Magnitude of Δ (km ²)/Yr
Built-up	120.4	250.46	287.57	+130.06	+2.7	+3.251	37.11	+0.5	+1.237
Farmlands & shrubs	30.1	20.61	5.13	-9.49	-0.8	-0.237	-15.48	-2.5	-0.516
Forests	146.32	9.75	2.57	-136.57	-2.3	-3.414	-7.18	-2.5	-0.239
Waterbodies	0.44	0.36	0.19	-0.08	-0.5	-0.002	-0.17	-1.6	-0.0057
Bare land	1.74	17.82	3.54	+16.08	+23.1	+0.402	-14.28	-2.7	-0.476

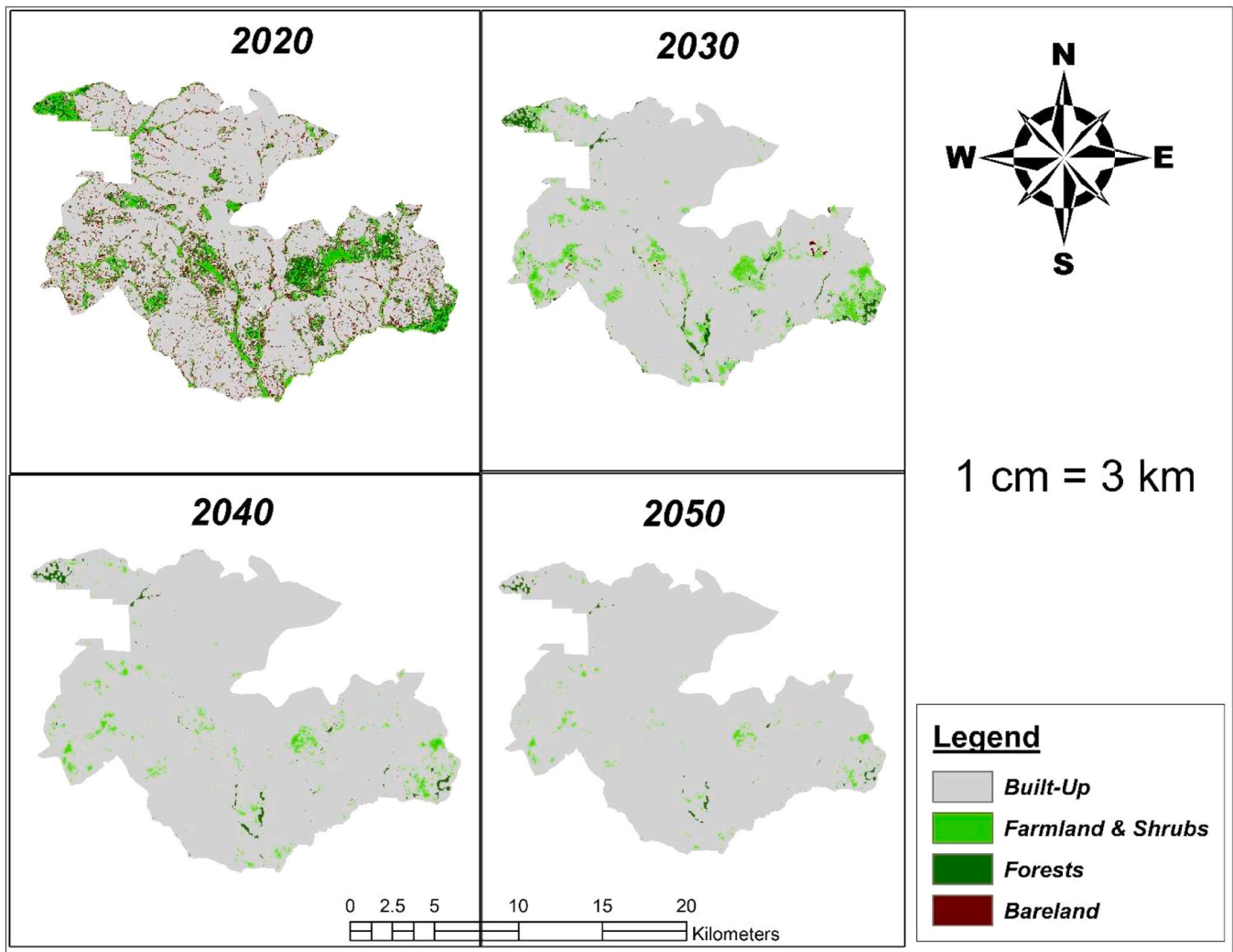


Fig. 9. Predicted future LUCS scenarios for KMA (2020–2050).

4. Discussion

4.1. Drivers and temporal variations of KMA's LUCS

We identified over six major factors (proximate/ underlying) that influence LUCS in KMA based on reports from other studies, major events and the spatial results generated. Taking into account the overall conversions of LUCS systems (as shown in Table 5 and 6), built up expanded at a rate of 108.02% (with 2.7% increment each year), farmlands and shrubs fell at a rate of 31.53% (with 0.8% decrease each year), waterbodies reduced by 18.18% (with 0.5% declension each year), bare land increased by 924.14% (at a rate of 23.1% increment each year) whilst forests over the study period (1980–2020) declined by 93.34% (at a declension rate of 2.3% each year). Results presented in Tables 4–6 show an area coverage (sq.km) for each class and evidence of considerable LUCS patterns in KMA between 1980–2020 and 2020–2050. The main land use features that increased progressively over the study period were built-up and barren areas. Forests, waterbodies and farmlands and shrubs experienced gradual decline over the given periods.

Presently, the major drivers of LUCS in KMA, identified in this study moves beyond identifying population growth and distribution (caused by migration and high birth/fertility rates) and poverty alleviation as the sole or critical drivers driving LUCS. Infrastructure development, weak institutional structures in the formulation, implementation and

monitoring of sustainable policies and projects, deforestation, attitudes of individuals and private developers, lifestyles and cultural issues (issues linked to conflict of power and ownership of assets, due to the cultural setting or monarchical system in the region), and state driven policies or governance systems tilted towards neo-liberalism and capitalism allay some economic and socio-political factors driving these undesirable changes. These six key issues, based on previous studies (Frimpong and Molkenthin, 2021; Abass et al., 2018; Nero et al., 2017) drove massive changes in land use systems in Kumasi. The Metropolis once known as the “Garden City of West Africa” has lost its once critical ‘green position’, mainly as a result of these direct or underlying factors.

4.2. Factors influencing the development of green spaces in Kumasi Metropolis

After exploring existing studies and policies, our study presents seven key factors impeding the development of green spaces in Kumasi. These foregoing barriers are situated in global discourse and the GUM.

- a. *State policies, governance systems and technological advancement:* The government of Ghana over the past few decades have initiated several developmental policies and governance systems, aimed at enhancing industrialization (transforming the economy from a raw to a highly industrialized/structured economy) like the one district one factory policy initiative, bridging housing deficit gaps,

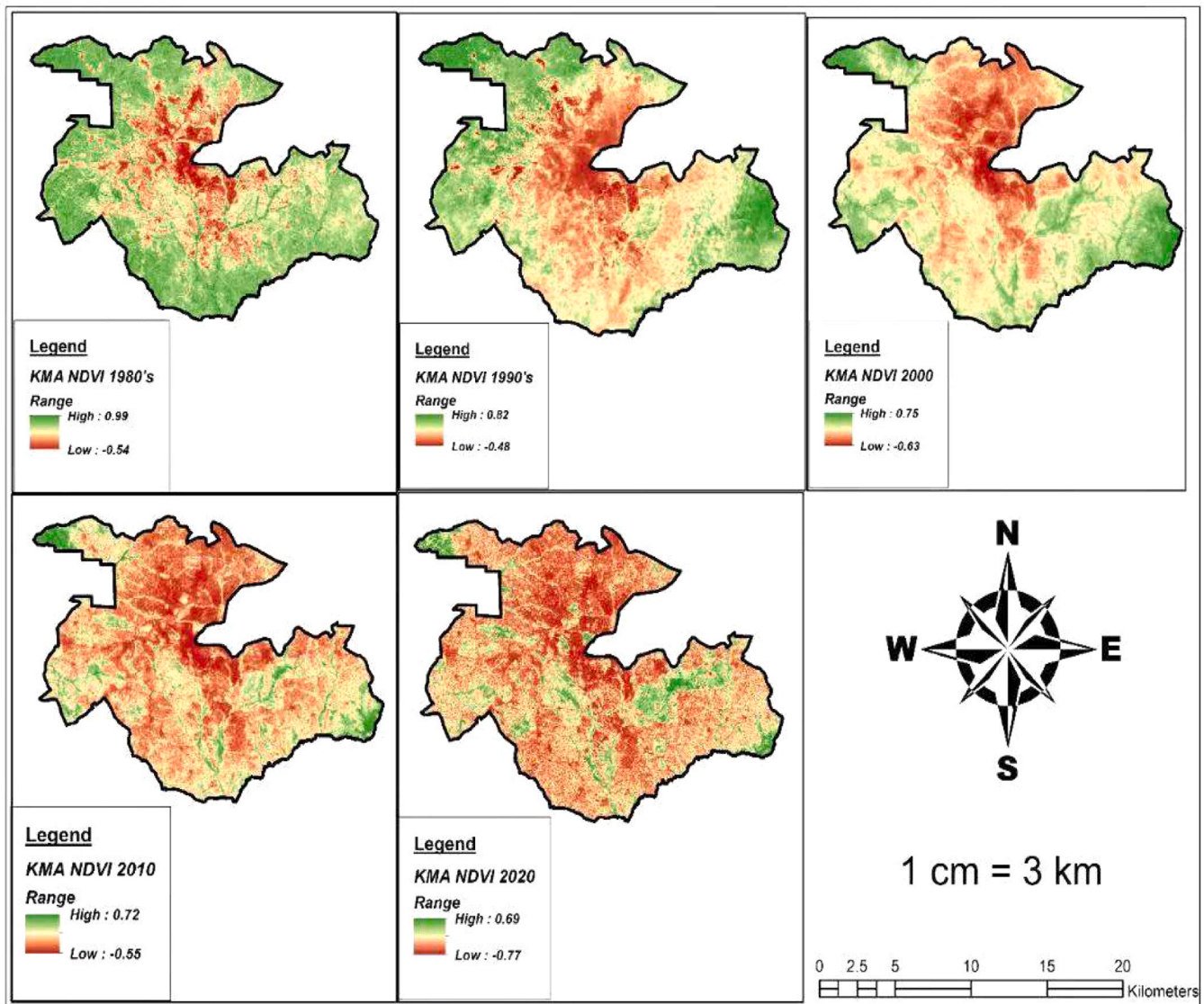


Fig. 10. NDVI variations for KMA (1980–2020).

capitalism and neo-liberalism governance systems initiated after the year 2000, minimum wage threshold and so on. Post-famine period in the 1980 s-1990 s drove the country to set-out an Economic Recovery and Stabilization Program in 1983 that ensured micro-and-macroeconomic stability (Abbam et al., 2018; Teye, 2018; Aryeetey and Kanbur, 2007). These policies welcome or boost foreign or private investments. However, private investors in most scenarios often focus on profit-oriented or natural resource sectors like the minerals, oil and gas, timber, fisheries and aquaculture that deteriorate the natural environment. These initiatives go a long way to increase and prioritize some sectors over the others that end up in the trading of some conservative areas for economic gains.

b. *Laxity in the implementation and monitoring of development controls:* Development controls are instruments used for the planning and management of cities. They are tailored or designed to enhance the populace’s quality of life. In the context of KMA, Mensah (2015) reported this as a predominant factor that hindered the development, and affected the quality of green spaces. He further stated areas demarcated on the city’s layout as natural reserves, parks and wetlands were either non-existent or heavily encroached. In most developing countries, public parks are found to exist on paper, but are found to be non-existent in reality. Likewise, political

interference, nepotism and cronyism were highlighted as key barriers that influenced stringent or stern enforcement of development controls over UGS.

c. *Issue of land tenure systems or administration:* Identifying the departments or individuals who have absolute control over some designated areas for conservation or green space lands was a major constraint. Hammond (2011) and Mensah (2015) presented three forms of land owners operating in the study domain. First delved into “vested lands” thus, lands owned by the government of Ghana; the second linked to “stool lands” (i.e., lands owned by the chiefs who are custodians of the land), and third classified as “public lands” which are acquired by the state for public usage like schools, landfill sites, transportation networks, markets, open spaces and so on. Their study revealed the Lands Commission among other state agencies have the legislative backing to manage lands in the metropolis. However, authorities from this unit opined these only exist on paper and not in reality as their roles are being impeded by the traditional authorities who in some sections of the constitution or local acts have the power to exercise some jurisdiction. The traditional authorities, in most instances, sell out green space lands to private developers without their consent. The cultural set-up of Kumasi (considering its monarchical system) which engulfs the cultural perspective of urban

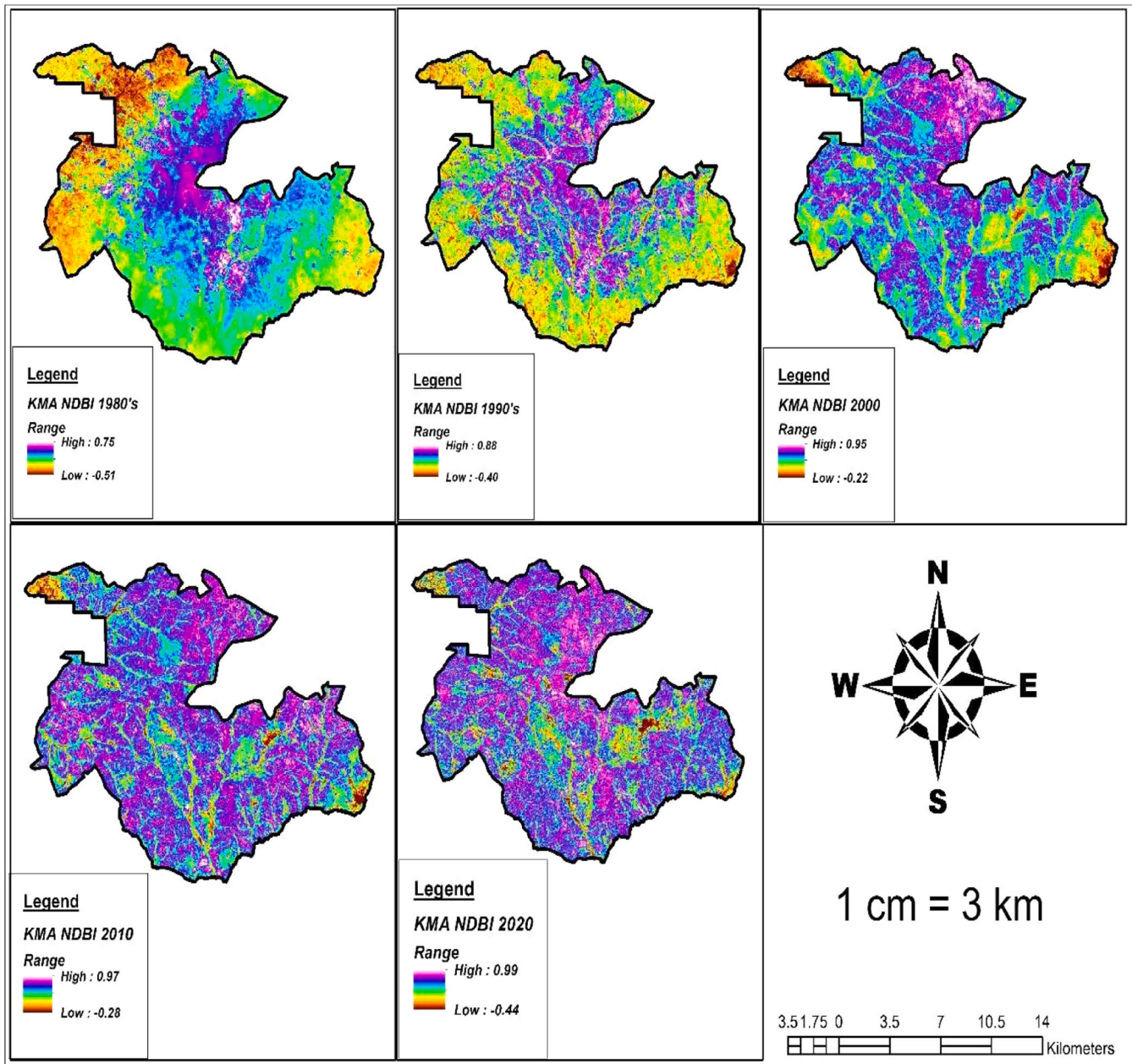


Fig. 11. NDBI variations for KMA (1980–2020).

- governance, is key in the management and planning of such facilities.
- d. **Urbanization:** Based on population and geospatial statistics presented in Figs. 2 and 8, increasing settlements and infrastructure development have resulted in massive encroachment of several green spaces. Likewise, the city’s geographical location (Fig. 1) is equally advantageous, and a major contributory factor. KMA remains a hub for several business transactions and services, hence, attracting several immigrants from the northern and southern zones of Ghana.
 - e. **General public’s attitude:** Development of several parks or green spaces in developed countries have instituted collaborative efforts or inputs from the populace. Sensitizing the public and other relevant stakeholders on the importance of green spaces have fostered some sense of ownership and change in attitudes towards green spaces, limiting encroachment and pollution of these areas. Mensah (2015) reported in the KMA, authorities expressed concerns over the public’s attitude towards the conservation of UGS. Destruction of lawns

- and shrubs meant to beautify the city by the public through using such spots as walkways or for trading, coupled with freely leaving their animals to graze on green spaces. The case of Kumasi could be likened to that of Nairobi city in Kenya, as reported by Makworo and Mireri (2011).
- f. **Low prioritization and investment in green spaces:** Results presented in Fig. 7 show alteration and dynamic ebb in urban greening. A city that was once tagged as the “Garden City of West Africa” has lost its unique status to socio-economic development. Steady decline of green spaces as depicted in Figs. 6 and 9 show UGS development have not been prioritized or had limited budgetary allocations due to its relevance to the city and country, not being realized.
- g. **Power relations, over lapse and poor coordination among state agencies over green spaces:** Effective coordination is an essential tool in the management and planning of UGS, coupled with healthy and positive institutional alliance as observed in Hannover (Germany), Zurich (Switzerland) among other developed cities across the globe as

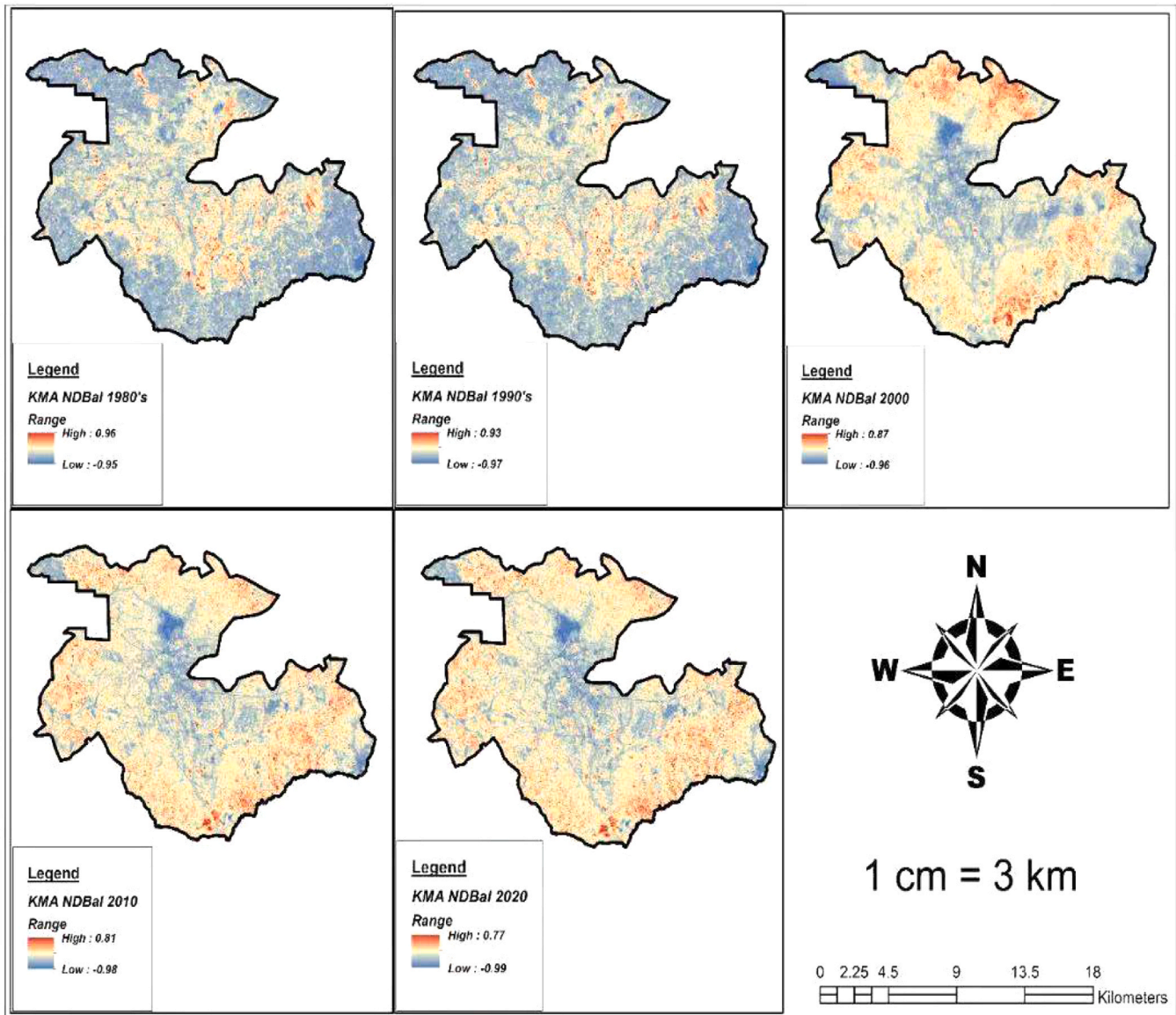


Fig. 12. NDBal variations for KMA (1980–2020).

reported by Carmona et al. (2004). Mensah (2015) reported officials in state agencies that were relevant to the scope of this study rated the level of coordination between them as poor. He ascribed these to undefined and incoherence of responsibilities, limited recognition and over lapse in the execution of roles. This issue has led to destabilization and halting of several green space projects.

4.3. Addressing major constraints impeding the development of green spaces in KMA

We sought to highlight some mechanisms that could be incorporated to address bottlenecks hindering the development and sustenance of UGS in KMA. These measures are developed based on policy recommendations, early studies and deductions from the outcome of the spatial analysis. Here, it is worth noting that the proposed measures are related to the seven factors that impede the development and preservation or sustenance of UGS in Kumasi Metropolis.

1. Prioritisation and provision of more green spaces backed by budgetary allocations and political will, will enhance availability and accessibility to these areas. This, in essence, would integrate

green growth in our development agenda at all levels to attain the multifunctional benefits of green spaces. KMA's available green space currently stands at 4 m² per capita, which is below the World Health Organisation's (WHO) standard threshold of 9 m².

2. State agencies, land use planners and estate developers among other interested parties can organize themselves to work as groups through "an integrated collaborative governance framework" that unifies actions, address power crisis and the driving factors identified. Again, such partnerships could be key in developing heat mitigation strategies in our quest to achieve green or blue footprints (i.e., developing a green economy). Considering the KMA earmarked under the Millennium City project or initiative and in line with the concept of the GUM, KMA through social inclusion and innovation, stakeholder participation through principled engagement and shared motivation/common goal, and involvement/consultation of all key actors including interested parties or international donors and scientific communities, can facilitate the realization of low-carbon, inclusiveness (i.e., in line with Local Agenda 21) and resource efficiency to restore the area's once critical green position and sustainability.
3. Periodic maintenance and expansion of existing green facilities are highly recommended to meet the growing needs of the general public

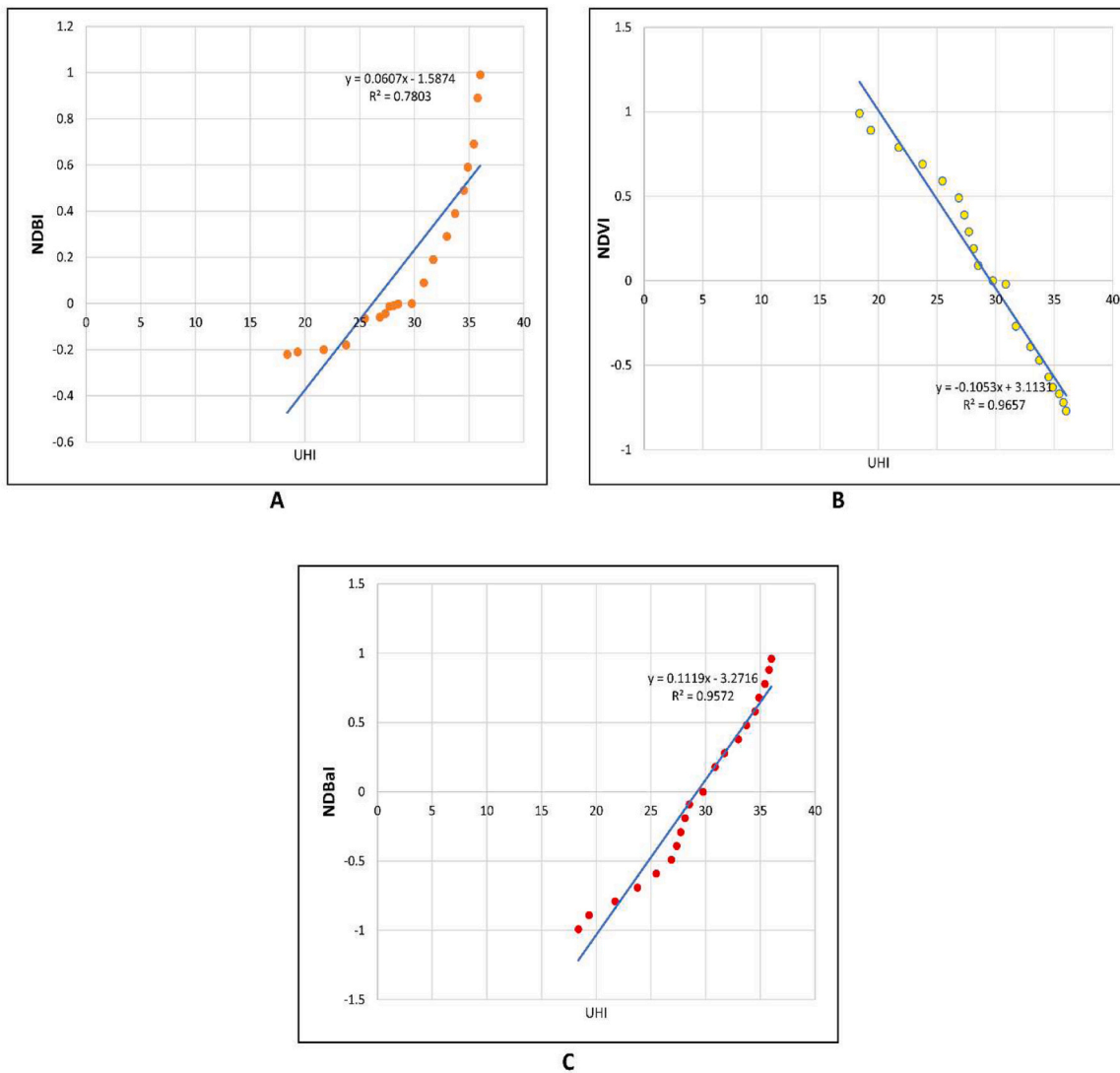


Fig. 13. (a) - (c): Correlation between the given indices and UHI.

- or visitors. Some funds generated from such facilities could be set-aside for such purposes. The government could also intervene to assist through further investments where necessary.
4. Behavioural or mass education on the need to conserve green spaces through public campaigns, research and media outlets. Fig. 14 shows the status of some public green infrastructure engulfed with filth or encroached by others for development and religious purposes.
 5. Public-Private Partnership Agreements (PPPA) could be strengthened between state agencies, private organisations and local communities to enhance maintenance and patronage of these areas (Fig. 15). Award schemes could be designed for green space units to enhance good conditions and quality of services. For instance; The UK and Germany have green flagship awards for well-conditioned facilities, which could be adopted by KMA.
 6. Strengthen institutions with logistics, legislative frameworks, appropriate funds and human resources to monitor and punish encroachers of green spaces. Stringent regulations are needed to ensure effective implementation of development controls imbibed in existing plans and legal frameworks. Creating more green belts will serve as checks for people or private developers not to go against or overextend boundaries.

7. Address issues of land tenure systems, co-management and coordination among state agencies whose functions directly or indirectly influence UGS.
8. Enhance human resource-base of green spaces, coupled with stakeholder participation and involvement at all levels in the decision-making process.

4.4. Contribution of urban greening to heat mitigation in Kumasi Metropolis

Green spaces are placed among the indicators within the SDGs for accomplishment by 2030. Recent studies have reported the critical role, played by green spaces in the actualisation of sustainable cities (Abass et al., 2018; Nero et al., 2017). Green spaces protrude diverse benefits to ecological systems and processes. Notable among these are the quality of life or social well-being, harmonious environmental exchanges and invigoration of economic growth.

The inverse relationship between NDVI and UHI as presented in Fig. 13(b), coupled with earlier reports (Koranteng et al., 2021; Nero et al., 2017) demonstrating the regulation of prevailing microclimatic conditions by green spaces present another advantageous perspective of prioritising the development of green spaces (i.e., tree and vegetative cover) in cities. UHI within KMA has increased substantially between 1980 and 2020, as a result of several conversions of land cover systems.



Fig. 14. The state of some green infrastructure in Kumasi Metropolis. The given frames depict the current state of “Children’s Park at Amakom-Asafo.”, providing evidence of encroachment or misuse of the area for other purposes, limited investments and poor maintenance culture, leaving these areas in a deplorable state, and far from serving its intended purposes.

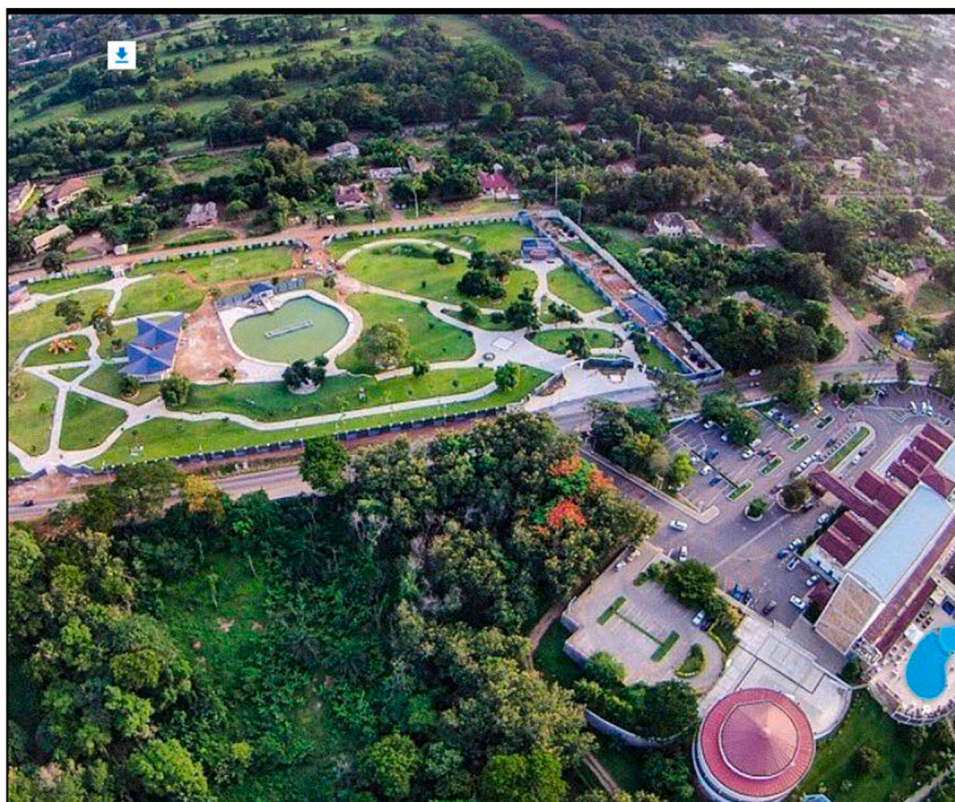


Fig. 15. Image of Rattray Park, Kumasi -A state and a private owned green space infrastructure that serves the general public.

Table 7
Green infrastructure options, their impact and priority locations in terms of heat mitigation in KMA.

Type	Description	Impact on UHI mitigation	Priority locations
Green belts	Medium to large uninterrupted areas of open land around the city, or its districts or neighbourhoods	-They can significantly mitigate UHI effects in KMA by reducing surface temperatures and cooling the surrounding areas through increased vegetation, and evapotranspiration. The presence of green open spaces in urban environments helps absorb heat, lower ambient temperatures, and create conducive microclimatic conditions, thus, counteracting UHI effects caused by the density of buildings, roads, and impermeable surfaces in Kumasi Metropolis.	*High-density housing. *Hotspot zones with medium-to-high heat intensity. *Dead-end streets/spots *Areas with high ecological value and locations near educational, recreational and commercial/centres. *Areas with poor air quality and limited biodiversity.
Urban parks and urban forests	Large parks, pocket parks, neighbourhood green space, botanical gardens, cultivated forests, etc.	-They provide cover, evaporative cooling, and minimizes surface temperatures. They absorb and dissipate heat to create thermal comfort for residents and other ecosystems.	*Areas with high population density and temperatures. *Areas with poor air quality, limited biodiversity and communities with limited access parks. *Under-utilized areas or dead-end streets/spots *Areas with high ecological value and locations near educational, recreational and commercial/centres.
Urban agricultural systems	Meadows, orchards, arable land, grasslands, agroforestry, community horticulture gardens, etc.	-They mitigate UHI effects by expanding green spaces, and enhancing evapotranspiration. Their presence somewhat reduces temperatures, cools surrounding environments and counteracts UHI effects induced by built-up surfaces in cities.	*Rooftop farming *Community and rain gardens *Apartments and condominiums with balconies/terraces. *Academic institutions can incorporate urban agriculture into their systems to teach students about nutrition, environmental sustainability and agriculture. *Sections within public spaces/parks can be allotted for urban agriculture to facilitate strong community engagement.
Small urban green systems	Green canopies, green pavement, vertical greening, green urban furniture, etc.	-They critically influence UHI effects by providing localized cooling effects, and improved air quality.	*Middle of road intersections or along the roads (i.e., traffic islands). *Street corners, installation on building walls/fences, in-between buildings, roofs, along sidewalks, parking lots, etc. *Along the road, pits, walkways, alleyways, bicycle lanes, public spaces, etc. *Underutilized areas -Living plants (i.e., plant resilient species)/facades with living materials such as panels containing growing plants.
Building-integrated green systems	Intensive and extensive green roofs, green facades, green balconies	-They mitigate UHI effects by providing additional vegetative cover to minimize surface temperatures in urban areas. These covers absorb and dissipates heat, which cools down the surrounding or overall ambience based on their extent or coverage in cities.	*The rooftop of buildings *Building facades *Rain gardens *Permeable pavements *Balconies/terraces of buildings *Natural playgrounds or zones -Outdoor learning spaces for environmental education -Living plants (i.e., plant resilient species)/facades with living materials such as panels containing growing plants.
Green water management systems	Rain gardens, green filters, stormwater green streets/catchment and infiltration basins.	-They facilitate natural water infiltration and retention, which aid in cooling down urban surfaces by reducing heat-absorbing impervious areas and increasing evaporation.	*Residential areas, along streets, roadways, public spaces, etc. *Create infiltration basins under stormwater green streets. *Constructed wetlands in open spaces or near waterbodies *Green roofs on buildings to harvest and retain rainwater Creation/sustenance of urban ponds/lakes to serve as natural storage and treatment systems. *Designation of natural drainage channels, detention basins, buffer zones along rivers/streams *Implementation in educational institutions for training and promotion of sustainable practices.
Green-blue infrastructure systems	Lakes, ponds, streams, rivers and small watercourses, and their banks, wetlands, etc.	-They combine green spaces and water features to positively impact or mitigate UHI effects. They enhance cooling by providing shades, and evaporative cooling to enhance carbon sequestration, improve air quality and create more thermal comfort in urban environments.	*Green streets, corridors, green-blue roofs, riverfront/ parks along riverbanks, etc. *Creation and sustenance of wetlands. *Green-blue educational facilities/campuses, alleyways, parking lots. *Coastal green spaces, public playgrounds, urban resilient parks, etc.
Green-grey infrastructure systems	Parking pavements, playgrounds, sport facilities, street/roads greenery (e.g., tree alleys), railroads greenery, etc.	-They synergize green spaces with traditional built materials or vegetation with hard surfaces (i.e., grey infrastructure) to minimize the impact of UHI significantly	-Parking lots with permeable pavements, rain gardens, green roofs, detention basins, etc.

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Table 7 (continued)

Type	Description	Impact on UHI mitigation	Priority locations
Semi-natural infrastructure	Cemeteries, abandoned areas, brownfields, etc.	through shading, and surface albedo improvement that enhances the overall urban climate positively. -They have considerable impact on mitigating UHI effects by enhancing air circulation, the Metropolis's sustainability and reducing heat aggravation.	*Creation of wetland parks -Green-grey institutional designs *Neighbourhoods/community centres *Ecological restoration sites, riparian buffer zones, open spaces, greenbelts, transportation and wildlife corridors. *Reclaimed or degraded lands *Academic/research institutional sites *Cemeteries and barren areas *Semi-natural roofs and facades
Private green infrastructure	House gardens, green fences, ground green walls, etc.	-Initiating vegetation in private zones contribute some level of cooling down effects (i.e., relatively small/limited impact) in urban areas. However, collective presence instead of individual impact of each private green facility has the tendency to reduce the overall heat buildup in KMA.	*Residential, commercial and industrial buildings *Mainstreaming green walls/vertical gardens on the exterior of buildings. -Permeable pavements using permeable materials for walkways, driveways and so on. *Building walls, fences, hedges or roofs with plant resilient/drought tolerant plant species. *Permaculture gardens on private properties. *Private wetlands, backyard structures like sheds, pergolas and greenhouses.

The mean maximum temperature in KMA has risen at a rate of 0.035 °C each year, which is higher than the global warming rate of 0.0150 °C. (Amos-Abanyie, 2009). Given the substantial loss in forest acreage, this is consistent with the conclusions presented in this study.

Major cities in developed countries like Atlanta in the USA, Hong Kong and Singapore where structural change has occurred, draw development strategists, planners, local officials, researchers, and other interested parties to the table to brainstorm, examine and work towards a desired goal (Aflaki et al., 2017; Wang et al., 2013). Action plans and monitoring systems are designed by key stakeholders to develop sustainable strategies that improve the citizenry's well-being and comfort amid UHI concerns. Information presented in this research will serve as impetus in this emerging body of literature that acknowledges the significant role of urban greening in mitigating UHI effects. It is meant to provide the scientific basis for planners, policy-makers and developers to devise innovative means of addressing some local environmental issues which underlie UHI, LUCC among other climatic stressors that could affect major, medium and small-sized cities in future, especially in developing nations.

The morphology of green areas plays a critical role in the regulation of UHI as indicated in Fig. 13(b). Policy documentation, institutional reports and systematic literature reviews based on studies (Twumasi et al., 2021; Koranteng et al., 2021; Buo et al., 2021; Mensah, 2015) conducted in the region were subjected to content analysis. Spatial analysis proved urban green hotspots have been declining in KMA, whilst a fundamental drift in urban density and UHI is observed. Strategies like (i) increasing tree and vegetative cover (Keith and Meerow, 2022; Grover and Singh, 2015) (ii) creation of green roofs, green facades and architectural or building designs for the amplification of solar reflectivity (Arellano et al., 2018) (iii) installation of reflective or cool roofs and pavements (Qin, 2015; Akbari and Matthews, 2012) (iv) Shades and ventilation corridors (Keith and Meerow, 2022) (v) development of ecological and green, blue or grey economies and footprints (vi) use of energy efficient appliances and equipment (Abulibdeh, 2021) and (vii) heat minimization from automobiles and air-conditioning (Keith and Meerow, 2022). These innovative and notable heat mitigation strategies require effective planning, community or public participation/involvement in urban heat governance, coupled with scientific analysis through the use of remote sensing and geospatial techniques to inform decisions about urban climatic maps. Keith and Meerow (2022) and Arellano et al., 2018 have recognised vegetation as one of the key elements of urban space with cooling effects.

Given the amplification of vehicular greenhouse emissions in KMA

(Nero, 2017), where 90% of total emissions were linked to CO₂ and loss of avenue trees along the roads and Central Business District (CBD), green areas could improve air quality and architectural beauty of green building designs (spaces, vertical and horizontal expansions) (Koranteng et al., 2019; Koranteng et al., 2021). They have the potential to increase carbon sequestration, thereby improving climatic conditions and air quality, while preserving tree and animal biodiversity. More so, reflective and cooling pavements/roofs and facades as reported in other studies could be integrated in the urban landscape of KMA, ventilation corridors, efficient equipment and appliances. Presently, other notable heat mitigation strategies such as the development of wind paths (i.e., expansion of cities require novel engineering approaches, landscape planning, capital intensive and policy-driven options to create pathways for winds that significantly minimize high temperatures in some specific locations for KMA based on UHI analysis (Fig. 6)), improvement in road surfaces and public means of water-sprinkling are practiced in Japan and China. Considering the asphaltic nature of roads in KMA, porous concretes/permeable paving materials and systems can be used to replace the asphalts or impermeable concretes which amplifies heat. The water sprinkling effect during summer in some developed countries/cities like Japan/Tokyo (Japan Meteorological Agency (Japan Meteorological Agency JMA, 2018), could be adapted considering KMA characterized by tropical or warm conditions. People across different neighbourhoods can sprinkle water on the streets to regulate evaporation or enhance cooling effects. Similarly, state and private agencies within the Metropolis can adopt novel means sprinkle water on township or major roads to enhance cooling effects. These strategies can inform the Government of Ghana's (GoG) decision and plan to reduce emission rates by 15 to 45%.

Table 7 present some green infrastructure options, their impact and priority locations in terms of heat mitigation that could enhance urban resilience of Kumasi Metropolis.

The proposed green infrastructure options/facilities presented in Table 7 could inform policies and create alternative futures which are area specific or defined to mitigate urban heat concerns in KMA. The proposed measures also go a long way to trickle down other socio-cultural, economic and environmental benefits. It is worth noting that multiple options, regarding the proposed measures can be combined or utilized to address heat concerns in KMA considering the complexity of UHI effects or degree of impacts trickled down by each of these measures.

5. Conclusion

This study uses satellite imagery and current literature to show how urban green space may be used to address UHI effects in major cities, within the context of the grand urban model. Due to the city's unregulated and unplanned expansion, some unfavourable changes in land use and urban systems have occurred in Ghana's Ashanti region, notably Kumasi. Several climatic stressors have been compounded by institutional ineptitude and the inability to adequately manage urban green areas, as well as enforcing land use restrictions. Findings will make meaningful contributions on topics such as integrated collaborative governance, development of sponge, low-carbon and garden cities. The study results can be summarized as follows:

- Kumasi Metropolis has lost its once critical green position as the "Garden City of West Africa."
- Urban heat statistically correlated positively with built-up and bareness indices.
- Land use predictions (2020-2050) show thermal comfort and urban temperatures in Kumasi will be adversely impacted.
- Proposed heat mitigation strategies can facilitate the realization of sponge, low-carbon and garden cities.

The geographical setting and evaluation method used in Kumasi Metropolis could be applied in other major cities across Africa and beyond. Our study toughens conceptual frameworks on the management of green spaces, urban heat mitigation and land use systems. Similarly, it explicitly enriches basic datasets for multiple comparative case scenarios, and influence policy directives about the nature and challenges of green spaces in Ghana to inform the decisions of development practitioners. Health and safety problems, which are critical to UHI related studies, might be further investigated in future works. Future research might focus on converting barren areas into green spaces, as well as incorporating cemeteries, which were not included in our study, into the broader green infrastructure of metropolitan areas. An integrated collaborative governance framework is proposed to unify actions, power crisis and address the factors that influence urban greening, UHI and land cover change.

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CRediT authorship contribution statement

Isaac Sarfo: Visualization, Methodology, Formal analysis, Data curation, Conceptualization, Writing - original draft, Writing - review & editing. **Bi Shuoben:** Validation, Supervision, Resources, Funding acquisition. **Xiuhua Xu:** Writing - review & editing, Supervision, Project administration, Data curation. **Emmanuel Yeboah:** Writing - review & editing, Validation, Software, Methodology, Formal analysis, Data curation. **Clement Kwang:** Writing - review & editing, Validation, Methodology, Formal analysis. **Michael Batame:** Methodology, Data curation. **Foster Kofi Addai:** Validation, Formal analysis. **Umar Wakil Adamu:** Writing - review & editing, Formal analysis. **Emmanuella Aboagye Appea:** Writing - review & editing, Formal analysis. **Michael Atuahene Djan:** Writing - review & editing, Formal analysis. **Henry Bortey Otchwemah:** Writing - review & editing, Formal analysis. **Vanessa Elikem Kudoh:** Writing - review & editing, Formal analysis. **Floribert Vuguziga:** Writing - review & editing, Formal analysis. **Olumide Samuel Olowe:** Writing - review & editing, Formal analysis. **John Ernest Koku:** Writing - review & editing, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.landusepol.2023.106842](https://doi.org/10.1016/j.landusepol.2023.106842).

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