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ORIGINAL ARTICLE

Geospatial Analysis of Urban Green Space Dynamics in Matara City: Implications for Sustainable Urban Planning

Jayasinghe, D. B. C. *, Hemakumara, G. P. T. S.

Department of Geography, Faculty of Humanities and Social Sciences, University of Ruhuna, Wellamadama, Matara, Sri Lanka

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ABSTRACT

Green spaces have seen major changes as a result of the fast urbanization and population expansion. Accessible urban green spaces are essential, particularly in view of the Urban Heat Island (UHI) effect and the growing significance of ecological resilience in metropolitan areas. This study investigates the changes in green spaces within the Matara MC from the years 2003 to 2023, occurred by the pressures of rapid urban growth. The primary objectives of the research were to: (a) identify and quantify the extent of green spaces in Matara MC over the past 20 years, (b) analyze and compare the changes in green spaces from 2003 to 2023, and (c) calculate the changes in green space per capita based on the recommended standards. The study utilized geospatial techniques, along with the Normalized Difference Vegetation Index (NDVI), to assess urban green space dynamics. Accuracy of the results was evaluated using a confusion matrix, with an overall accuracy of above 75%. In 2003, the green space cover had an extent of 14.288 km^2, accounting for 73% of the total area. However by 2023, it had decreased to 9.096 km^2, or 48% as a percentage of the area. The central city experienced a considerable loss in green space, while boundary areas also saw reductions. The overall per capita green space decreased from 139 m^2 in 2003 to 120 m^2 in 2023, with several Grama Niladari Divisions (GNDs) now falling below the World Health Organization's (WHO) recommended value as 9.5 m^2 per person. These findings emphasize the urgent need for strategic urban planning to mitigate further green space loss. To address these challenges, recommendations include the implementation of sustainable urban planning practices, the restoration of degraded lands, and active community involvement in green space conservation. These steps will promote future urban growth in the Matara MC while ensuring the protection of natural resources.

1 Introduction

Urbanization is now a worldwide phenomenon due to the rapid expansion of the population and the accelerating shift from rural to urban areas (Withanage and Jingwei, 2024; Withanage et al., 2023). One of the key components of changes in land use is 'urbanization'. This usually results in transforming vegetation (green spaces) and other uses of land in to a more unreceptive surface (Jayasinghe et al., 2024; Mutale et al., 2024; Wijesinghe et al., 2024; Wijesinghe and Withanage, 2021; Withanage et al., 2024).

As a result of the trends of global urbanization accelerating rapidly, it has become increasingly important to integrate green spaces into urban planning (Halder et al., 2022). An 'urban green space' can be defined as any open area in an urban environment which may be covered in vegetation, either fully or partially (Heikinheimo et al., 2020). Theses spaces may consist of parks, public gardens, open fields, trees, green roofs, cemeteries, and even vacant lots (Rahaman et al., 2021). The expansion of cities become an obvious necessity, to accommodate the growing population which inevitably results in the compromise of green areas (Addas, 2023). Green spaces in urban areas supply a number of benefits such as the improvement of air quality, mitigating the heat island effect, enhancing bio diversity and also offering many recreational opportunities (Nawar et al., 2022; Sathyakumar et al., 2020). Furthermore, it also offers pivotal ecological services like the mitigation of noise, filtration of air, management of storm water, and the regulation of microclimatic effects (Escobedo and Nowak, 2009; Namwinbown et al., 2024). Additionally, green areas

* Corresponding author: D.B.C. Jayasinghe, Department of Geography, Faculty of Humanities and Social Sciences, University of Ruhuna, Wellamadama, Matara, Sri Lanka.

E-mail address: chathurikaj@geo.ruh.ac.lk (D.B.C. Jayasinghe).

also provide ecological resilience while maintaining the environmental balance and mitigating the adversarial effects of urban development that may affect the local ecosystems (Nawar et al., 2022).

One of the key factors that contribute to the degradation of green spaces, is the significant human driven factor which is the rapid urban growth (Siddique and Uddin, 2022). With the continued increase of urban population, the demand for resources also increases, which inevitably results in the green areas being fragmented and reduced (McDonald et al., 2013; Nawar et al., 2022). The combined pressures of urbanization, such as the significant growth in population and the shift in the patterns of land use, have contributed further to the intensification of the impact it has on these essential green areas (Zarin and Esraz-Ul-Zannat, 2023). According to the experts, it is recommended that an approximate area of 25% from the total extent should be dedicated to the creation of healthy green areas (Rahman and Zhang, 2018; Sathyakumar et al., 2020). Researchers have identified that the creation and the expansion of green spaces is a significant contributor in the mitigation of effects caused by the Urban Heat Islands (UHIs) (Abulibdeh, 2021; Morar et al., 2022; Siddique and Uddin, 2022). The green spaces possess the ability to regulate and lower the urban temperatures, and thereby helps in the alleviation of the UHI impact (Bowler et al., 2010; Doick et al., 2014). Consequently, larger cities consider green spaces as an essential tool for the control of the heightened air temperature (Abulibdeh, 2021; Morar et al., 2022; Siddique and Uddin, 2022).

Various organizations have defined several standards for the assessment of the sustainability of cities, with a significant focus on the greenery of their respective urban areas. One of the important measures that are considered in these standards is the per capita green space of a city, which is measured in square meters (m^2). This signifies the area of the green space that a single citizen is entitled to, and is calculated by dividing the existent total green area of the respective city by the total population of the said area (Laghai and Bahmanpour, 2012). The World Health Organization (WHO) states that per capita green space should not go below 9.5 m^2, whereas the United Nations has determined that it should be above 30 m^2. However, most of the developed countries have established their respective per capita green space ratios; where for example, USA defines it to be 50 m^2, whereas Germany declared it to be in the range of 30 to 60 m^2, while Switzerland defines the ratio to be between 50 and 60 m^2 (Hosseini et al., 2015).

For the detection and analysis of the changes that occur in the urban land cover and land use, geospatial techniques, combined with the Geographic Information Systems (GIS) and Remote Sensing (RS), are the tools which are generally used for this purpose (Jalayer et al., 2022; Mutale et al., 2024; Selmy et al., 2023; Withanage et al., 2023). Furthermore, the periodic monitoring of the changes that occur in the geographic areas can be conducted through multispectral satellite data (Aljenaid et al., 2022). The integration of the satellite imagery and GIS enables enhancement of the management of natural resources and the tracking of changes in the environment (Tsatsaris et al., 2021). Moreover, GIS and remote sensing are considered to be highly effective tools in the process of assessment and quantification of the dynamics of green spaces (Bai et al., 2022; Nawar et al., 2022). The above techniques have been utilized in a number of researches that have been conducted to assess the changes that have taken place in the green areas (Ghosh and Singh, 2022; Huerta et al., 2021; Kaur et al., 2022; Sathyakumar et al., 2020). For example, Nawar et al. (2022)and Ghosh and Singh (2022) applied the Normalized Difference Vegetation Index (NDVI) to evaluate the green and non-green spaces and classify the vegetation index. In order to identify and categorize different types of green spaces, different researches have applied several image classification techniques, such as supervised classification (Yan et al., 2023), hybrid classification (Byomkesh et al., 2012), and machine learning methods (Yan et al., 2023).

Matara Municipal Council (MC) is one of the largest municipalities in Sri Lanka and experience a significant urbanization expansion as a result of the increased demand for services related to residences, administration, and commercial uses. Presently, Matara MC is undergoing the challenge of a rapid population growth, with the density currently exceeding 3,895 persons/km^2 (Kumara, 2022). The rates in which individuals tend to migrate to urbanized areas are rather noteworthy, and it has certainly impacted the unplanned urbanized process which will inevitably result due to the reduction and fragmentation of the green areas. Hence, Matara area has undergone a significant loss of green space owing to the constructions and the transformation of green spaces to facilitate other land uses. For the creation of policies and strategies to facilitate the maintenance and enhancement of green spaces, it is crucial that the Matara MC constantly assesses and monitors the changes that occur in the urban green areas that are under their purview.

The primary objective of this research was to comprehensively analyze the changes that had taken place in relation to the green spaces within the purview of the Matara MC from 2003 to 2023 by applying geospatial techniques. To better understand the potential long-term effects of urbanization on the city's green infrastructure, the researchers intend to examine data from two decades in order to identify patterns of green space growth, decline, or transformation as well as to calculate the amount of green space per capita. This research was founded on three specific objectives: (a) performing an identification and a quantification of the extent of green spaces under the Matara MC for the past 20 years, (b) conducting an analysis through the comparison of the changes that the green spaces had undergone from 2003 to 2023, and (c) evaluating the changes in green space per capita from 2003 to 2023. The researchers deem that the study findings will facilitate a mechanism which will be more effective in the land use planning process, providing a better protection to the green spaces under the purview of the Matara MC, while also providing constructive recommendations to other land-constrained megacities across Asia.

2 Literature Review

Over the recent years, urban green space planning has obtained a significant amount of attention owing to the crucial role it plays in the promotion of urban sustainability (Addas, 2023; Duku et al., 2023). According to Gelan (2021), it has also become a prominent focus in fields such as research, urban planning, and economics. In urban areas, green spaces must be positioned and planned strategically. Therefore, the assessment of existing vegetation plays an important role in an environmentally sustainable urban development process.

Globally, researches indicate that cities in developed countries generally have more urban greenery compared to cities in developing countries, many of which fail to meet the WHO's minimum standard of 9 m² of green space per city dweller (Kabisch et al., 2015). An extensive study of 386 European cities revealed an average green space proportion of 18.6%, ranging from as low as 1.9% in Reggio di Calabria, Italy, to as high as 46% in Ferrol, Spain (Fuller et al., 2007). Similarly, a survey of 439 Chinese cities found that green space covered 20.1% of urban areas in 1991, with nearly 40% of cities achieving over 30% green cover that year (Ming et al., 1993). In the United States, urban tree cover varies significantly from 0.4% in Lancaster, California, to 55% in Baton Rouge, Louisiana, with an average canopy cover of 27% (Nowak and Crane, 2002). By 2000, China's urban green cover had reached 23%, with a per capita green space of 6.52 m² (Wang et al., 2019). Compared to developed nations, cities in developing countries typically exhibit lower green cover and a limited per capita green space (Singh et al., 2010). However, cities globally renowned for urban greenery maintain a per capita green space of 20 m². In contrast, most Indian cities fall behind this benchmark compared to cities in Europe, Australia, the USA, and China, except for a few examples such as Chandigarh, Gandhinagar, and Bangalore (Chaudhry et al., 2011). Table 1 presents the per capita green space in a few cities in the world.

Urban green space planning and assessment have been made easier by integrating remote sensing and GIS tools, which provide a time- and money-efficient method. These technologies make it possible to gather, store, analyze, and visualize geographical data along with attribute information, significantly enhancing the effectiveness of green space management (Rusli and Ludin, 2009).

Table 1: Account of urban green space (*Source*: Singh et al., 2010).

Region/Country/City	The estimated size of urban green areas and the amount of green space per person	Source
Cadiz, Fuenlabrada, Almeria (Spain), Reggio di Calabria (Italy)	Urban green space: 3–4 m² per person	(Carmona, 2021)
Liege (Belgium), Oulu (Finland), Valenciennes (France)	Urban green space: >300 m² per person	(Carmona, 2021)
Lancaster, California (USA)	Urban tree cover: 0.4%	(Nowak et al., 2006)
Baton Rouge, Louisiana (USA)	Urban tree cover: 55%	(Nowak et al., 2006)
Curitiba (Brazil)	Urban green space: 51.5 m² per person	(Carmona, 2021)
Canberra (Australia)	Urban green space: 80 m² per person	(Banks and Brack, 2003)
Melbourne (Australia)	Extensive network of open spaces harboring >40% nationally listed threatened vegetation	(Carmona, 2021)
Wellington (New Zealand)	Urban green space: 200 m² per person	(Carmona, 2021)
Tokyo (Japan)	Urban green space: 6.1–8.5 m² per person	(Carmona, 2021)
China (Various Cities)	Green space: 32.54% coverage in cities	(Wang et al., 2019)
Nanjing (China)	Urban green space: 44.3 m² per person	(Jim and Chen, 2009)
Wuhan (China)	Urban green space: 10.3 m² per person	(Jim and Chen, 2009)
Beijing (China)	Rich vascular plant diversity, 2,276 species	(Wang et al., 2007)
Delhi (India)	Urban forest cover: 20% of geographical area, 21 m² per person	(FSI, 2009)
Chandigarh (India)	Urban forest cover: 35.7% of geographical area, 55 m² per person	Action Plan, 2009-10 (FSI, 2009)
Jaipur (India)	Urban green space: 1.60 m² per person (current), 8.80 m² per person (target by 2025)	(Pandit et al., 2009)

Many researches have employed the GIS mechanism in the planning processes of green spaces across the regions of Europe, China, Iran, South Korea, and Thailand (Baycan-Levent and Nijkamp, 2009; Faryadi and Taheri, 2009; Tsatsaris et al., 2021).

Misty et al. (2024) undertook a research to assess the changes that had taken place over a period of 30-years in the urban green areas in Dhaka South City Corporation (DSCC), Bangladesh. Using Landsat 4–5 TM satellite imagery from 1991, 2001, and 2011 along with Landsat 8 images from 2021, the study used geospatial tools to investigate the dynamics of green spaces. The research utilized supervised image classification and Normalized Difference Vegetation Index (NDVI) analysis to evaluate the changes that had occurred in the vegetation. Over the course of the 30-year study, the researchers found that the vegetation cover within the DSCC had decreased significantly by 36.5%. Similarly, a study carried out in Lilongwe, Malawi, used NDVI analysis combined with GIS integration to identify regions with low vegetation cover, revealing notable changes in the distribution of green spaces. These results emphasized the urgent need for equitable urban greening strategies, particularly in underprivileged neighborhoods (Nambazo and Nazombe, 2024).

Globally, green space per capita is often used to assess urban livability and ecological sustainability. For example, a study in Melbourne, Australia, combined NDVI data with population density to calculate green space per capita. The research results presented significant dissimilarities between the socio-economic groups, where more affluent areas demonstrated better vegetation cover, highlighting the implementation of policy interventions necessary in addressing green equity (Li et al., 2024). Additionally, a similar study was carried out in Shanghai, China, evaluating the availability of green areas by combining demographic data and NDVI. The findings showed that the average amount of green space per person in the city center was just 5 m^2, far less than the 9 m^2 that the WHO recommends, highlighting the urgent need for urban greening program (Wu, 2008).

In Sri Lanka, studies of this nature are limited. However, one such study by Lin and Pussella (2016) analyzed the changes in green space and per capita green space in the Colombo District between 2008 and 2015 using Landsat images. The research applied NDVI differencing and classification methods to detect land cover changes. The results showed a decline in green space from 629.1 km^2 to 591.16 km^2, representing a 6.03% reduction. Significant decreases were observed in Kaduwela, Moratuwa, and Maharagama Divisional Secretariat Divisions (DSDs), while areas like Avissawella, Homagama, and Padukka performed comparatively better. Additionally, per capita green space dropped from 272.361 m^2 to 248.811 m^2. Although these figures exceed the UN, EU, and WHO standards for the district overall, Colombo DSD failed to meet UN and EU standards.

3 Materials and Methods

3.1 Study Area

Located at 6.10° N and 80.13° E on Sri Lanka's southern coast, Matara City is the district's administrative center and a major regional commercial center. Rapid urbanization has been occurring in the city, as evidenced by the National Physical Planning Department's regional structure plan designating it as a first-order urban center. This rapid urbanization process is a presentation of the vast development in the infrastructure where new roadways, commercial structures and residential compounds have been constructed swiftly.

In 2002, the area of Matara was designated as a municipality by the Urban Development Authority (UDA) of Sri Lanka (UDA, 2019). Matara being one of the significant commercial centers of the southern coast in Sri Lanka, possesses great potential in fulfilling the dynamics of the regional development processes. The Nilwala River, which runs through the city from north to south, is one of the most beautiful natural features. With an average annual temperature of 26.8 °C and 2,147 mm of precipitation, Matara has a tropical climate. This study focuses on the 19.32 km^2 land area under the jurisdiction of the Matara MC. Fig. 1 shows the location map of the study area in the Sri Lankan spatial context.

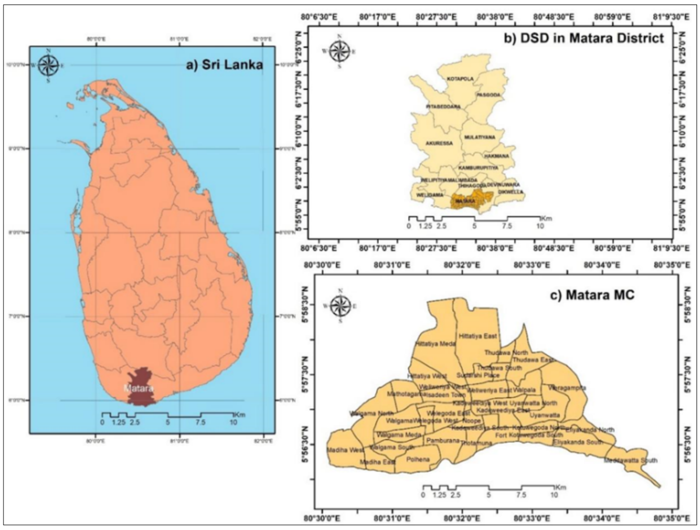

Fig. 1: Location (a) Sri Lanka; (b) Matara District; (c) Matara MC.

3.2 Study Approach

In this research, supervised classification combined with the NDVI was employed to evaluate changes in urban green areas. The analysis concentrated on two main categories: urban regions and green spaces, with data classification done using ArcGIS 10.8 software. NDVI values were obtained from satellite imagery by analyzing the visible red band (approximately 0.6 μm) and the near-infrared band (around 0.9 μm), which are typically reflected by healthy plant life. Supervised classification was subsequently utilized to identify various land use types and examine changes in green space over time. Utilizing population data from the years 2003 and 2023, along with the corresponding green space areas for each year, the researchers will calculate the green space per capita for both years. Fig. 2 depicts the approach used in this research.

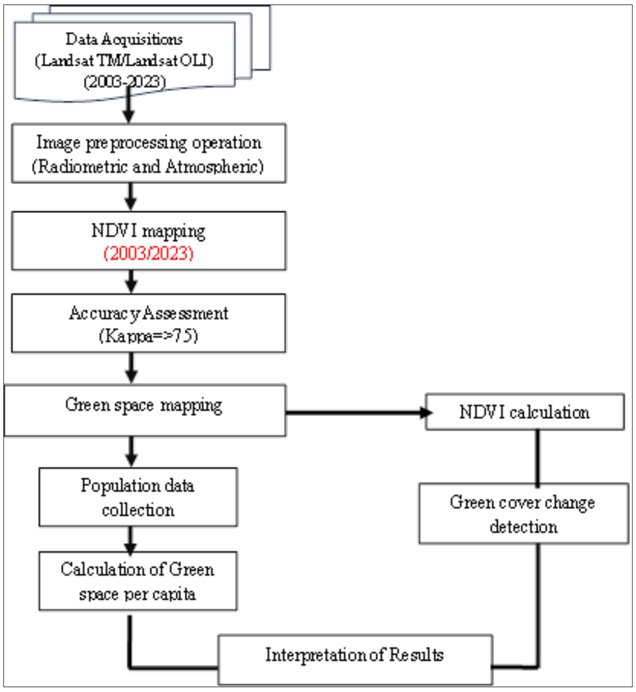

Fig. 2: Flow chart of theresearch methodology.

3.3 Data Sources

The USGS Earth Explorer provided the Landsat data utilized in this research, specifically Landsat Collection 1 Level 1 (USGS, 2018; Landsat8, 2016). Because they offer accurate data that are not available from conventional techniques, Landsat images are frequently employed in remote sensing research. Landsat 8 images from 2003 and 2023 were used in this study. These images were gathered using Landsat 8 and WRS-2 data from the Worldwide Reference System (WRS). The 2003 and 2023 images were chosen so as to have as little cloud cover as possible; all of them had less than 8% cloud cover as shown in Table 2.

3.4 Data Correction, Mapping and Accuracy Assessment

3.4.1 Image Pre-Processing

The data preprocessing process comprised of several necessary steps to ensure the data was accurate, clean, and prepared for analysis. In order to convert raw Digital Numbers (DN) into radiance or reflectance values and account for sensor-specific biases, radiometric calibration was first carried out. To help eliminate atmospheric effects from the reflectance data, the Dark Object Subtraction (DOS) method was applied. For the purpose of applying geometric correction and maintaining spatial integrity, all of the data layers were projected onto the WGS 1984, UTM Zone 44N coordinate system. During the image sub-setting step, the images were clipped to the Areas of Interest (AOI) using the Matara MC border. Finally, the spatial resolution of the Landsat images was adjusted using the closest neighbor resampling technique to ensure a consistent 30 m spatial resolution across all datasets.

3.4.2 Deriving NDVI Maps

This research applied the NDVI technique, which is identified as most common and popular tool for mapping tree cover and vegetation dynamics (Dinda et al., 2021; Zhang et al., 2023). Using ArcMap 10.8, NDVI maps for both years were generated. After deriving NDVI maps, the raster maps were converted into polygons, and the dissolve tool was applied to create a single cohesive polygon for each class. As a result, the two distinct classes were consolidated into a single file. An additional field was added to the attribute table, and the area for each class was calculated in km^2 using the "calculate geometry" function for area calculatiom. The intention of choosing the NDVI for this research was mainly owing to its ability of detecting healthy vegetation through its' widespread application (Dutta et al., 2021; Huang et al., 2021), as it is derived from the reflectance of healthy plant material. The NDVI values were calculated using the red and near-infrared bands from Landsat OLI TIRS images (2003, 2023). Positive NDVI values indicate the presence of vegetation, with values close to 1 signifying high vegetation density. The NDVI values are typically calculated using equation 1 (Jayasinghe et al., 2024; Withanage et al., 2024).

$$NDVI = \frac{NIR_{(Band\ 4,5)} - RED_{(Band\ 3,4)}}{NIR_{(Band\ 4,5)} + RED_{(Band\ 3,4)}} \tag{1}$$

Table 2: Information on the sources and satellite images used in the study.

Satellite	Path/Row	Date	Time (GMT)	Cloud Cover	Thermal Conversion Constants	
					K_1	K_2
Landsat 8 OLI	141/056	2003/01/31	04:54:36	2.00	774.8853	1321.0789
Landsat 8 OLI	141/056	2023/02/23	04:02:02	7.18	774.8853	1321.0789

Note: K_1 is the calibration constant related to the spectral radiance; K_2 is the constant used in the exponential part of Planck's equation to calculate the satellite temperature.

The float command was used to obtain the decimal values used in this formula. Solar radiation reflected from the Earth's surface is taken by the Landsat sensors. Bands 3 and 4 of Landsat 8 record the red reflectance in particular, while Bands 4 and 5 record the near-infrared reflectance. Equation 2 was used to calculate the NDVI (Jayasinghe et al., 2024; Withanage et al., 2024).

$$NDVI = Float(NIR - R)/Float(NIR + R) \quad (2)$$

The NDVI values can be defined in a range from −1 to +1, where values closer to −1 is an indication of the absence of vegetation, and values closer to +1 indicate healthy vegetation. In this study, four NDVI classes were identified based on thresholds found in similar studies (Nawar et al., 2022), as shown in Table 3. Values below zero signify areas with no vegetation, such as water bodies, buildings, and road networks. Values between 0 and 0.33 reflect sparse vegetation, typically consisting of unhealthy or minimal plant cover. Areas with values between 0.33 and 0.66 indicate moderate vegetation, including grasslands, cultivated lands, or areas with moderately dense plants, such as those found in parks and gardens. Finally, values ranging from 0.66 to 1 correspond to dense vegetation, including thick plant growth, large trees, and urban forests, which were classified as "healthy vegetation" in this study.

Table 3: NDVI classes used in the study, classified per the Earth Observation System.

Vegetation Classes	Feature	NDVI Range
No vegetation	Water bodies, built-up areas, road networks	<0
Sparse vegetation	Small plants near roadside, bare land	0 to 0.33
Moderate vegetation	Shrubs and grassland, moderately dense plants in parks	0.33 to 0.66
Dense vegetation	Urban forest, dense plants	0.66 to 1

Sparse vegetation refers to areas where vegetation cover is low, with plants being spread out and not densely packed. This class often includes small plants, grasslands, bare soil, and other land types where vegetation is not abundant. The Moderate vegetation refers to areas with a moderate density of plants. This includes shrub lands, parks, and moderately forested areas where vegetation is present but not dense. It reflects a healthy level of vegetation, though not at maximum density. In satellite images sparse vegetation will appear as areas with noticeable gaps or little plant coverage, whereas moderate vegetation will show more continuous plant coverage but without the dense canopy of forests. Dense vegetation has a high density of plants, often forming a thick, continuous canopy with little bare soil visible beneath (Li et al., 2015).

3.5 Accuracy Assessment

The accuracy of the findings derived from NDVI maps was assessed using a confusion matrix, also known as an error matrix. Historical maps from Google Earth Pro served as the source of the reference data. Using ArcMap, 50 randomly chosen points from each class of green space in the satellite imagery were used to evaluate the accuracy of the classified images; the number of points varied per year. Fig. 3 and Table 4 show the maps with selected random points to check the accuracy. These points were then compared to corresponding reference points from Google Earth Pro. For the 2003 and 2023 data, the comparison was made with Google Earth reference maps. The accuracy of the selected user points was determined by contrasting them with real-world producer points. Finally, the overall user and producer accuracy, along with the Kappa coefficient, were assessed using standard equations 3, 4, 5, and 6 (Jayasinghe et al., 2024; Withanage et al., 2024)Withanage et al., 2024. Table 5 shows the details of the accuracy assessments.

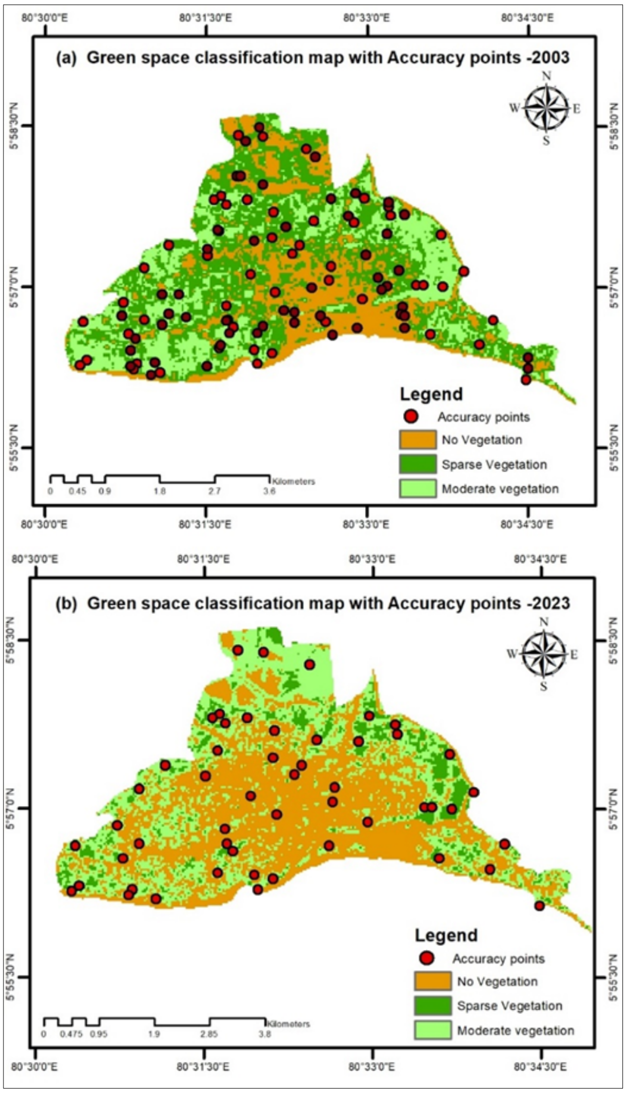

Fig. 3: Sample points used for NDVI accuracy assessment (a) 2003; (b) 2023.

Table 4: X, Y coordinates locations of samples points (a) 2003; (b) 2023.

(a) 2003

FID	Shape *	Classified	Ground Truth	X (m)	Y (m)
0	Point	1	1	173605.8	86598.67
1	Point	2	2	173365.8	86358.67
2	Point	1	1	174565.8	86088.67
3	Point	1	1	173215.8	85758.67
4	Point	2	2	173275.8	85758.67
5	Point	2	2	173665.8	85608.67
6	Point	3	3	174835.8	85368.67
7	Point	2	2	175825.8	85308.67
8	Point	3	3	176095.8	85098.67
9	Point	2	2	175135.8	85068.67
10	Point	1	1	174055.8	84888.67
11	Point	3	1	172885.8	84828.67
12	Point	3	3	175795.8	84768.67
13	Point	2	2	173515.8	84648.67
14	Point	3	3	172705.8	84498.67
15	Point	1	1	175435.8	84408.67
16	Point	2	2	176005.8	84138.67
17	Point	2	2	175645.8	84018.67
18	Point	2	1	175795.8	83868.67
19	Point	1	2	174505.8	83838.67
20	Point	2	2	175705.8	83808.67
21	Point	3	2	171925.8	83718.67
22	Point	3	3	172225.8	83718.67
23	Point	2	1	176065.8	83508.67
24	Point	1	1	174025.8	83448.67
25	Point	1	1	174205.8	83418.67
26	Point	3	2	172045.8	83388.67
27	Point	1	1	176035.8	83388.67
28	Point	3	3	171235.8	83358.67
29	Point	1	1	174655.8	83358.67
30	Point	1	2	176095.8	83358.67
31	Point	2	2	172345.8	83328.67
32	Point	2	2	173035.8	83268.67
33	Point	1	1	174205.8	83238.67
34	Point	3	3	171925.8	83208.67
35	Point	2	2	173665.8	83178.67
36	Point	1	1	175285.8	83148.67
37	Point	1	1	176095.8	83148.67
38	Point	3	3	173095.8	83058.67
39	Point	3	3	173575.8	83058.67
40	Point	1	1	174865.8	83028.67
41	Point	2	2	171475.8	82968.67
42	Point	3	3	172945.8	82848.67
43	Point	3	1	171385.8	82758.67
44	Point	2	2	178225.8	82638.67
45	Point	3	3	171805.8	82548.67
46	Point	2	2	171385.8	82488.67
47	Point	3	3	172705.8	82488.67
48	Point	1	1	178225.8	82458.67
49	Point	1	1	171745.8	82338.67

(b) 2023

FID	Shape *	Classified	Ground Truth	X (m)	Y (m)
0	Point	2	2	173245.8	86463.67
1	Point	1	1	173665.8	86433.67
2	Point	2	2	174415.8	86223.67
3	Point	3	3	172945.8	85413.67
4	Point	3	3	175405.8	85383.67
5	Point	3	3	172825.8	85353.67
6	Point	2	1	173395.8	85353.67
7	Point	2	2	173035.8	85263.67
8	Point	2	2	175825.8	85233.67
9	Point	1	1	173845.8	85143.67
10	Point	2	2	175855.8	85083.67
11	Point	3	3	174535.8	84993.67
12	Point	3	2	175225.8	84963.67
13	Point	2	1	172915.8	84813.67
14	Point	3	3	176725.8	84753.67
15	Point	1	1	173815.8	84693.67
16	Point	3	3	172045.8	84573.67
17	Point	1	2	174295.8	84573.67
18	Point	2	1	174175.8	84423.67
19	Point	1	1	172705.8	84393.67
20	Point	1	1	174835.8	84213.67
21	Point	3	3	171625.8	84183.67
22	Point	3	3	177115.8	84123.67
23	Point	1	1	173455.8	84063.67
24	Point	1	1	174805.8	83973.67
25	Point	3	3	176305.8	83883.67
26	Point	3	3	176425.8	83883.67
27	Point	3	2	176755.8	83853.67
28	Point	1	1	173875.8	83763.67

29	Point	1	1	175375.8	83643.67
30	Point	2	3	171265.8	83583.67
31	Point	1	2	173035.8	83523.67
32	Point	1	1	171625.8	83283.67
33	Point	2	1	173065.8	83283.67
34	Point	2	2	177625.8	83283.67
35	Point	3	3	170575.8	83253.67
36	Point	1	1	174745.8	83253.67
37	Point	3	3	173155.8	83163.67
38	Point	3	2	171355.8	83043.67
39	Point	2	3	176545.8	83043.67
40	Point	1	1	177385.8	82863.67
41	Point	2	2	172915.8	82803.67
42	Point	1	1	173515.8	82773.67
43	Point	3	3	173815.8	82713.67
44	Point	2	1	170635.8	82593.67
45	Point	1	2	171505.8	82533.67
46	Point	2	2	173575.8	82533.67
47	Point	3	3	170515.8	82503.67
48	Point	2	2	171445.8	82443.67
49	Point	2	2	171895.8	82383.67
50	Point	1	1	178195.8	82263.67

$$Overall\ Accuracy = \frac{\sum CCP\ (Diagonal)}{\sum CRP} \times 100 \tag{3}$$

where the corrected reference pixels are CRP, and the corrected categorized pixels are CCP (Diagonal);

$$User\ Accuracy\ = \frac{\sum CCP\ (Category)}{\sum CPC\ (Row)} \times 100 \tag{4}$$

where CCP (Category) is the corrected classified pixels (category) and CPC (Row) is the classified pixels in that category (the row total);

$$Producer\ Accuracy = \frac{\sum CCP\ (Category)}{\sum CPC\ (Column)} \times 100 \tag{5}$$

where CCP (Category) is the corrected classified pixels (diagonals) and CPC (Column) is the classified pixels in that category (the column total);

$$Kappa\ Coefficient = \frac{N\ \sum_{i=j}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+i})} \tag{6}$$

where N is the total samples; r is the number of rows in the error matrix; x_{ii} is the total corrected samples in the ith row and column; N^2 is the square of total samples; x_{i+} is the column total; and x_{+i} is the row total.

3.6 Per capita green space (PCGS)

Per Capita Green Space (PCGS) provides the average allocation of green space per person in a particular region (Shekhar and Aryal, 2019). Equation 7 was used for the calculation of PCGS.

$$PCGS\ i = \frac{Gi}{PNi} \tag{7}$$

where $PCGS_i$, G_i, and PN_i denote PCGS in i, green space in i, and population of i, respectively. In order to calculate the PCGS for each GND, the total green space area (G_i) and total population (PN_i) of the respective GNDs were taken into account.

4 Results

4.1 Green Space in Matara MC

Between 2003 and 2023, there were significant changes in the distribution of green areas within the Matara MC, as shown in Table 6. In 2003, the green space covered an extent of 14.288 km^2, which is approximately 73% of the total area in the Matara MC. Conversely, by 2023, the total area of green spaces had decreased by 48% which is now 9.096 km^2 of the total area. This is an indication of a significant decrease of the amount of green space over the two-decade period, in relation to both total area and its percentage share of the overall land area.

Table 5: Calculated values of the overall accuracy and Kappa coefficient, for the years 2003 and 2023.

Type	2003				2023			
	PA (%)	UA (%)	Overall (%)	Kappa	PA (%)	UA (%)	Overall (%)	Kappa
No vegetation	87.72	86.21	83.33	0.75	84.21	82.76	81.33	0.72
Sparse vegetation	83.33	81.82	83.33	0.75	83.64	82.14	81.33	0.72
Moderate vegetation	76.92	81.08	83.33	0.75	76.32	80.56	81.33	0.72

Note: PA is Producer's Accuracy; UA is User's Accuracy.

Table 6: Temporal changes in green space, and urban built-up and other areas in Matara MC.

	2003		2023	
	Area (km²)	%	Area (km²)	%
Green space	14.288	73	9.096	48
Urban and others	5.135	27	10.188	52

The reduction in the green spaces is a clear indication of the increase in the urbanization since areas that were once utilized for vegetative purposes have been transformed for development purposes like residential, commercial, and other infrastructure projects. This trend is a reflection of the rise in demand for urbanized areas under the Matara MC, and has inevitably caused the grave reduction of the green cover in the Matara area. In summation, it can be observed that though the land area in the Matara MC region still encompasses a substantial portion of green cover, in spite of the proportional figures reducing from 73% in 2003 to 48% in 2023, it is evident that a significant trend towards urbanization is prevalent resulting in the inevitable decrease in the available green spaces in the municipal region.

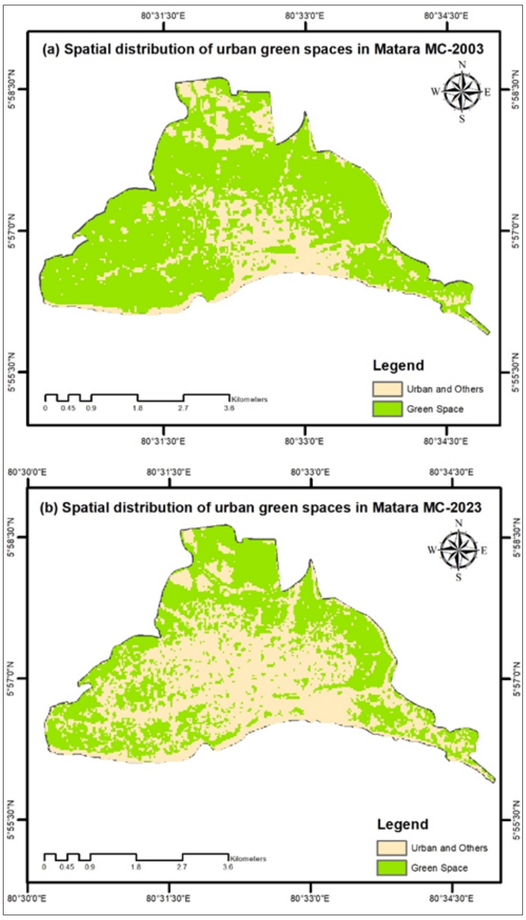

Fig. 4: Spatial distribution of urban green spaces in Matara MC: (a) 2003; (b) 2023.

The spatial distribution of green spaces in Matara MC in 2003 and 2023 is depicted in Fig. 4. It was observed that there was very limited green space in Matara's city center in 2003, although there were more green spaces along the region's borders, particularly in the upper and western areas. However, by 2023, much less green space in the city center and less green space in the surrounding areas were observed as a result of residential development and urbanization. These data imply that urban expansion has resulted in a reduction of green spaces, both within the city center and in the surrounding border areas, particularly in the south-west part of the region, as shown in the spatial distribution maps of green spaces in 2003 and 2023.

4.2 Transformation of Green Spaces in Matara MC

The provided data in Table 7 compares the vegetation classification in Matara MC between 2003 and 2023. The classification categorizes land into areas of no vegetation, sparse vegetation, and moderate vegetation, offering insights into the changes in vegetation coverage over this period. Notably, there is no densely vegetated land in Matara MC indicating the absence of areas with rich, fully developed ecosystems in the city area.

Table 7: Temporal changes in green space in 2003, and 2023 in Matara MC.

Classification	2003		2023	
	Area (km²)	%	Area (km²)	%
No vegetation	5.13	27	10.07	52
Sparse vegetation	8.62	45	7.21	37
Moderate vegetation	5.55	29	2.02	10

In 2003, the area with no vegetation covered 5.13 km^2, which constituted 27% of the total area. By 2023, this figure had significantly increased to 10.07 km^2, accounting for 52% of the area. This substantial increase in the area with no vegetation suggests a possible trend of land degradation or urbanization, where natural vegetation could have been cleared for various activities. The rise in the area without vegetation highlights a shift toward less green space, possibly driven by increased infrastructure development and population growth in the region.

Conversely, the area classified as having sparse vegetation decreased from 8.62 km^2 (45%) in 2003 to 7.21 km^2 (37%) in 2023. Although this is a decline, sparse vegetation still represented a significant portion of the area. The area with moderate vegetation also decreased substantially, from 5.55 km^2 (29%) in 2003 to 2.02 km^2 (10%) in 2023. This marked decrease could point to a reduction in healthy, intact ecosystems, possibly due to human activities like urbanization, and infrastructure expansion. The shrinking of moderate vegetation areas indicates a loss in biodiversity and the potential depletion of land that previously supported more diverse plant life. This decrease is a concerning indicator of ecological changes, as moderate vegetation is often associated with more stable, sustainable ecosystems that offer environmental service like carbon sequestration.

Fig. 5 depicts the spatial distribution of green space classification in Matara MC, and according to the figure, urban areas have expanded outward from the city center. As a result, sparse vegetation has decreased by 1.41 km^2 in 2023 as shown in Table 7. Additionally, the moderate vegetation cover, which was primarily located at the outer boundary of the city, has also been reduced by 2023 to 3.53 km^2.

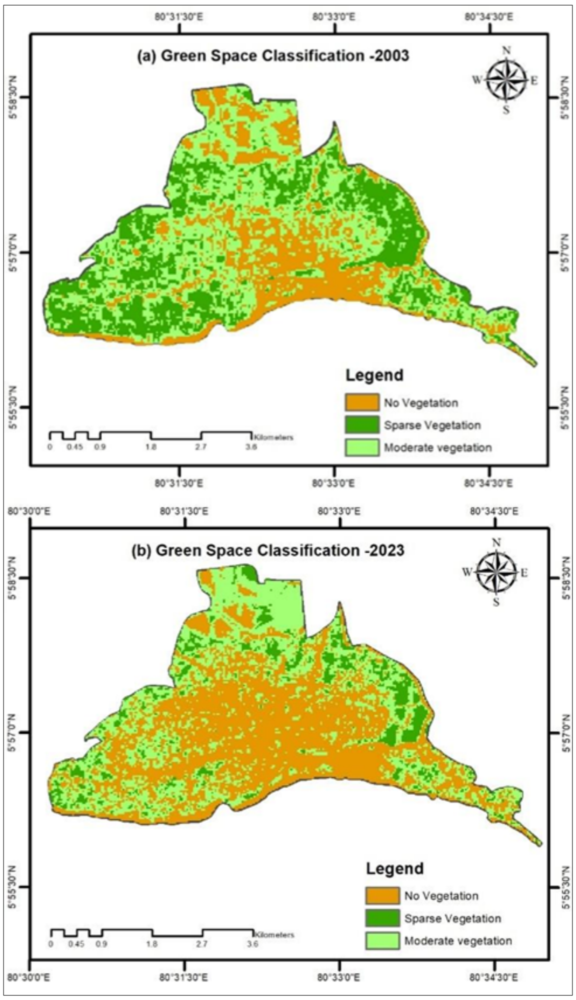

Fig. 5: Green space distribution in Matara MC: (a) 2003; (b) 2023.

Overall, the data suggests a trend of land degradation and environmental stress in Matara MC over the two decades from 2003 to 2023. The significant increase in land with no vegetation, combined with the reductions in both sparse and moderate vegetation, implies that the area may have been subject to intensive land use pressures, such as urbanization. It is noteworthy to declare that this shift from vegetated to non-vegetated areas raises concerns with regard to the local ecology, highlighting the growing need for the implementation of sustainable practices in relation to land management which will enable halting and reversing the above trends.

4.3 GND-Wise Dynamics of Green spaces

The data in Table 8 represents the percentage amounts of the areas with green cover in each Grama Niladari Divisions (GND) for the years 2003 and 2023. The data show how the percentage of green spaces throughout the many GNDs under the Matara MC from the years 2003 to 2023 has changed drastically. It can be observed that certain divisions reveal significant reductions in green cover, for example Isadeen Town shows a substantial drop of 59%, and Kadaweediya West and Kadaweediya East also experience significant decreases such as 21% and 23%, respectively. However, certain improvements can also be observed in some divisions such as Hithatiya West, where an increase of green space by 39% is shown, and Madiha East shows an improvement of 33%. In summary, despite the fact that some areas have managed to maintain or increase their green spaces, many divisions have seen a notable decline in green spaces as a result of the possible environmental impacts of urban expansion. As seen by the average percentage of green space reduction from 74% in 2003 to 47% in 2023, it is clear that the region's green cover is drastically decreasing.

Table 8: Percentage (%) of green space change in GNDs in Matara MC, between 2003 to 2023.

GND	% of Green Space 2003	% of Green Space 2023	Change Green space (%)
Eliyakanda North	69	39	30
Eliyakanda South	85	57	27
Fort	13	13	-1
Hittatiya East	66	79	-13
Hithatiya Meda	76	59	17
Hithatiya West	90	51	39
Isadeen Town	65	6	59
Kadaweediya East	33	10	23
Kadaweediya South	14	5	8
Kadaweediya West	25	3	21
Kotuwegoda North	18	2	16
Kotuwegoda South	12	3	9
Madiha East	85	52	33
Madiha West	91	71	20
Mathotagama	83	42	41
Meddawattha South	75	51	24
Noope	40	9	32

Pamburana	87	38	50
Polhena	87	50	37
Sudharshi place	87	39	49
Thotamuna	39	16	23
Thudawa East	86	76	10
Thudawa North	88	48	40
Thudawa South	94	48	46
Uyanwaththa	76	46	30
Uyanwatha North	74	12	62
Walgama	99	59	40
Walgama Meda	85	20	64
Walgama North	92	62	30
Walgama South	89	54	35
Walpola	79	33	46
Welegoda East	69	13	56
Welegoda West	87	15	73
Weliweriya East	55	13	42
Weliweriya West	45	12	34
Weragampita	93	79	14
Total	**74**	**47**	**27**

4.4 Green Space Per Capita in Each GND

The data presented in Table 9 refer to the PVGS of the Matara MC from 2003 to 2023 and it demonstrates a substantial decrease in the available green areas throughout many of the divisions.

The analysis of per capita green space in the GNDs of Matara MC beween 2003 and 2023 highlights a concerning trend, especially in light of recommendations from the UN and the WHO regarding the minimum green space standards. In the year 2003, the overall average per capita green space stood at 139 m², which surpassed the UN's recommendation of 30 m². However, by 2023, this average has decreased to 120 m², highlighting a decline in the availability of green spaces relative to the growing population. Notably, several divisions fall far below the minimum recommended thresholds; Isadeen Town and Kadaweediya South have extremely low per capita values of 11 m² and 5 m² respectively, failing to meet even the WHO's minimum standard of 9.5 m² per person.

In contrast, divisions like Weragampita maintained a higher standard, with per capita green space decreasing from 304 m² to 212 m² while still remaining well above the recommended limits. One must note that the various discrepancies which can be seen in relation to different GNDs highlight the grave requirement of strategic urban planning and policy interventions to improve the accessibility of the green spaces.

Table 9: Green space per capita in GNDs in the Matara MC in 2003 and 2023.

GND	Land extent (km²)	2003			2023		
		Green space (km²)	Population	PCGS square kilometers (km²) per person.	Green space (km²)	Population	PCGS square kilometers (km²) per person
Eliyakanda North	370896.6	255926.31	1127	227	143267.22	1360	105
Eliyakanda South	773521.8	655252.97	1495	438	443239.42	1650	269
Fort	446660.3	57484.77	1052	55	60258.99	771	78
Hittatiya East	1849186.7	1223816.18	2168	564	1457387.27	2487	586
Hithatiya Meda	1743405.5	1322541.53	3534	374	1028464.05	3931	262
Hithatiya West	514582.3	465250.42	1244	374	262158.25	1529	171
Isadeen Town	395057.9	258578.72	2189	118	25448.19	2348	11
Kadaweediya East	556303.5	182163.27	32132	6	53243.6	2739	19
Kadaweediya South	154694.2	20890.56	1718	12	8108.12	1638	5
Kadaweediya West	176615.7	43451.33	2001	22	5572.62	2065	3
Kotuwegoda North	257351.5	46599.93	1074	43	5794.22	1216	5
Kotuwegoda South	251937.7	29402.15	1224	24	6805.79	1200	6
Madiha East	365188.5	309425.91	1027	301	190704.84	1030	185
Madiha West	830380.8	755696.01	1938	390	588851.49	2144	275
Mathotagama	485632.9	401381.05	2476	162	202968.4	2019	101
Meddawattha South	530326.2	396032.88	1533	258	269906.12	1029	262

Noope	228512.3	91570.67	1162	79	19546.84	965	20
Pamburana	688296.7	601788.71	2732	220	259388.68	3205	81
Polhena	681952.7	592705.26	2601	228	339434.67	2379	143
Sudharshi place	279940.8	243913.62	1606	152	108004.57	1694	64
Thotamuna	375769.3	147596.99	2248	66	60544.81	2285	26
Thudawa East	795729.9	680489.13	1317	517	603134.98	1396	432
Thudawa North	178032.2	155964.15	761	205	84646.74	765	111
Thudawa South	193283.9	180905.7	1686	107	92770.4	1734	54
Uyanwaththa	804740.3	609736.62	3598	169	370697.83	2426	153
Uyanwatha North	197074.2	146298.04	2611	56	23581.79	2727	9
Walgama	567835.8	561017.68	2177	258	336239.04	2856	118
Walgama Meda	386328.2	326785.94	1858	176	79042.34	2066	38
Walgama North	948705.5	871341.29	2669	326	589592.33	3113	189
Walgama South	437224.7	387902.11	1676	231	236063.8	2136	111
Walpola	438809.4	346781.98	2526	137	146460.95	2522	58
Welegoda East	563207.0	388125.22	3536	110	74090.97	3684	20
Welegoda West	231792.9	202606.8	1833	111	33819.99	1944	17
Weliweriya East	461047.7	255747.99	2845	90	60373.56	3005	20
Weliweriya West	175354.3	79042.23	1625	49	20271.99	1551	13
Weragampita	982874.2	916826.83	3013	304	774922.47	3650	212
Total	**19318253.8**	**14211040.95**	**102012**	**139**	**9064807.34**	**75259**	**120**

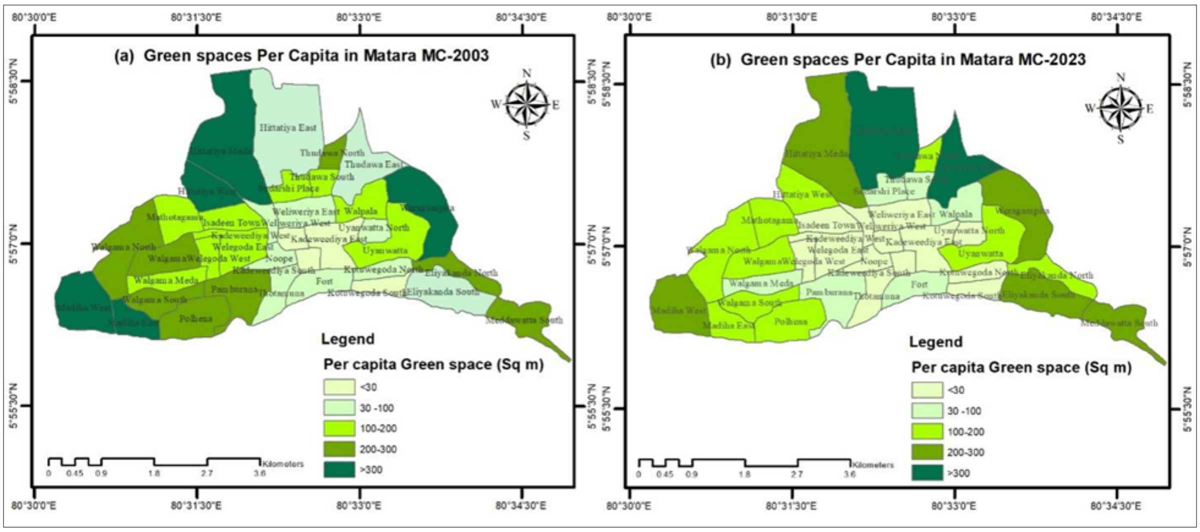

Fig. 6: Green space per capita in Matara MC: (a) 2003; (b) 2023.

This is especially crucial in relation to densely populated areas where the decrease in green spaces highlights the challenges of urbanization and its effect on the well-being of the community and the quality of the environment.

Fig. 6 presents the spatial distribution of per capita green space values across the GNDs of Matara MC for the years 2003 and 2023. The data demonstrates how the GNDs which are located near the city center experience a decrease in the PCGS by 2023, though the area in the periphery have managed to maintain comparatively stable green space values during the same period of time.

5 Discussion and Recommendations

5.1 Discussion

The research results that were gathered in relation to green space, vegetation, and PCGS in the Matara MC spanning two decades demonstrate a disturbing trend of decreasing green areas. It was found that the total extent of green space in Matara MC has diminished from 14.288 km^2 (73% of the total area) in 2003 to 9.096 km^2 (48% of the total area) in 2023, which reflects a marked loss of green cover in relation to both total area and its share of the overall land. This reduction can be mainly due to the rapid urbanization process, as the areas that comprised of natural vegetation have been inevitably transformed to fulfill the requirements of residential, commercial, and infrastructure development. This reduction in the green areas is mainly discernible adjacent to the city center where urban expansion is bound to develop intensely, whereas the areas in the periphery of the cities demonstrate a slower decline in green cover.

Likewise, vegetation classification between 2003 and 2023 also demonstrated a tendency towards land degradation and urban extension. An increase in areas devoid of vegetation which stood at 27% in 2003 to 52% in 2023, implies that larger areas of land were being cleared for developmental and constructional activities. Simultaneously, it could be observed how areas with meager and average vegetation have also diminished considerably, implying a decrease in ecosystems that support biodiversity and environmental services like carbon sequestration and soil stabilization. This modification is rather alarming since it demonstrates the moderate diminution of natural habitat and the degradation of land that once provided substance to a variety of plant lives.

Additionally, the PCGS data ranging through the years of 2003 to 2023 further highlight the general trend of diminished green cover in the Matara MC region. The average PCGS has reduced by an approximate 75%, with divisions adjacent to the city center suffering the most amounts of degradation. The data implies that it is not only the areas adjacent to the city center that is suffering but also the peripheral areas , though it is currently at a slower rate. Unfortunately, this depletion in the green spaces may carry a substantial impact on the local climate, quality of air, and overall quality of life for residents.

The outcomes of this research that was performed in the Matara MC presents marked discrepancies in the availability of the green spaces throughout the different GNDs. This can be considered as an urgent call for attention with regard to strategies pertaining to urban planning. The overall reduction in PCGS from 139 m^2 in 2003 to 120 m^2 in 2023 is a clear indication of the increasing pressures of urbanization, the growing density of populace and the space limitations in relation to urban greenery. Fortunately this figure still ranges above the UN's recommended minimum of 30 m^2 per person. However, the marked drops in the available green spaces cannot be ignored as it is a clear indication of a concerning trend that is on the rise, especially in comparison to the minimum thresholds set by the WHO and the UN.

The situation in the towns of Isadeen and Kadaweediya South is particularly concerning since they have recorded values which are below the WHO's minimum standard. The GSPC values of the towns of Isadeen and Kadaweediya South stand at 11 m^2 and 5 m^2, respectively, which is significanytly lesser than the WHO's minimum standard of 9.5 m^2. These divisions epitomize the challenges posed to areas which are experiencing rapid urbanization processes where the green cover is being compromised for either undervalue or development. A low per capita value such as the above can definitely have a negative effect on both quality of the environment as well as the general well-being of the society. This will undoubtedly contribute to issues such as low air quality, recreational limitations, and heightened stress levels among residents. This disparity is in consistence with the global trends, where generally the cities in developing countries are struggling to provide sufficient green areas to their residents. However the developed countries possess the ability to provide a higher green space coverage, which can be seen in cities like Paris and certain regions in China, where the PCGS is well above the international recommendations, and often exceeding 20 m^2.

Though divisions like Weragampita recorded a reduction from 304 m^2 to 212 m^2 per capita over the same period of time, it also demonstrated a relatively higher availability of green space, but still revealed a broader trend of depleting greenery. In spite of this reduction, Weragampita's green coverage extent continue to exceed the WHO's minimum standard, projecting the potential that can be achieved if better strategies were in place with regard to urban planning and resource allocation in other divisions. The prevalent contrast that exists among the divisions reveals how important it is for green spaces to be distributed equally across Matara's GNDs. Hence, it is critical for urban planners and policymakers to grant more priority to areas with lesser green space, particularly to the areas which are short of the international standards. As enumerated before in the literature, researches across the globe have revealed that more affluent cities benefit from better greenery whereas the less affluent suffer with minimal access. Hence cities like Dhaka, Shanghai, and Colombo signify similar patterns of green space inequity.

Given these differences, it is essential to implement strategic actions to ensure that all residents, particularly those in overcrowded and underdeveloped areas, have equal access to green spaces. As demonstrated by previous researches, the combination of remote sensing and GIS techniques may useful for mapping and assessing the distribution of green spaces, facilitating better decision-making. Furthermore, policies should be formulated to promote sustainable urban development, enhance green infrastructure, and encourage the participation of the community in creating green spaces which could directly contribute to the mitigation of the adverse effects of urban expansion. The study recommends that Matara MC take immediate steps to adopt a more effective and dynamic approach to creating urban green spaces since it will provide all the residents with access to better health and socio-environmental benefits.

5.2 Recommendations

5.2.1 Urban Planning and Green Space Preservation

In order to mitigate the continued decrease in green spaces and the potential negative impacts that it poses to the environment and the general well-being of the public, it is imperative for several strategies to be considered. The research findingss emphasize the urgent requirement for urban planning processes to incorporate green initiatives to their developmental plans. It is recommended that all development initiatives should not only focus on creating new green spaces but should also make it a priority to preserve the existing areas as well. Furthermore, planning regulations must stipulate that all developers make provisions to allocate a section of land to create gardens, parks or roof tops in projects, and residential and commercial areas.

5.2.2 Sustainable Development Practices

Steps should be taken to always balance the urbanization process with sustainable development practices as that would mitigate the environmental damage. This can include the promotion of green infrastructure like green roof tops, rain gardens, and absorptive pavements, which can directly alleviate the negative impact on the of natural vegetation.

5.2.3 Restoration of Degraded Land

It is also important to make restorative efforts to areas of land that had been cleared for construction purposes and the like, particularly in the city's boundary areas. Planting native vegetation, creating ecological corridors and restoring areas with urbanized effects can be some of the measures that can be attempted. Restoration projects can undoubtedly contribute to the revival of the ecosystems, improve biodiversity, and strengthen climate resilience.

5.2.4 Community Involvement and Awareness

Implementation of public engagement and awareness programs is highly important as local communities should be encouraged to contribute to the preservation and expansion of green spaces. This may consist of initiatives such as tree planting activities, creating community gardens, and holding educational campaigns creating awareness about the positive impact that green spaces have for the health and the environment of the city/country.

5.2.5 Monitoring and Data Collection

Green spaces and vegetation cover should be subjected to regular monitoring as that will enable the stakeholders to track changes which will eventually impact the decision-making process. This should include the use of remote sensing technology and it is essential that the status of green spaces and vegetation in the region is regularly assessed. Furthermore, regular data collection is essential as that will enable the identification of trends, measuring the success of conservation efforts, and serve as a guide for future planning initiatives.

6 Conclusion

This research was conducted with the intention of (a) identifying and quantifying the extent of green spaces under the purview of the Matara MC during the period of 2003- 2023, (b) to perform an analysis by comparing the changes that had taken place in the green space sphere from 2003 to 2023, and (c) to calculate the alterations that may have taken place in relation to the green space per capita over the 20 years of 2003 to 2023. The research findings of the green spaces in the Matara MC between 2003 and 2023 signify a substantial decrease in both the total green space and PCGS over the past two decades. According to the findings, in 2003, the green space extent was at 14.288 km^2 which is 73% of the total area. However by 2023, the green cover had reduced to 9.096 km^2, which is 48% of the total area. The adjacent areas of the city center, which comprised of a lower green space in 2003, was seen experiencing a further decrease in the region, while the boundary areas which recorded a more greener coverage previously, could also be seen to experiencing decreases due to urbanization and residential infrastructure development projects. Vegetation classification data also revealed an increase in the areas which were devoid of vegetation where preciously the values were 27% in 2003 but had risen to 52% in 2023. Meanwhile, the areas where vegetation was meager and an average level had also dropped noticeably. Furthermore, areas with dense vegetation were not seen to be present and ultimately the overall percentage of the green areas were seen to fall from 74% to 47%. Additionally, several GNDs, including Kadawediya South, Kadaweediya West, Kotuwegoda South, and Kotuwegoda North, record values which are lower than the WHO's stipulated GSPC. The overall PCGS for Matara MC has reduced from 139 m^2 in 2003 to 120 m^2 in 2023, with the highest declines being recorded in the central divisions. These research outcomes highlight the critical requirement of implementing a strategic urban planning process designed to focus on the fast depleting ratio of the green spaces that are currently available, especially in the areas which bear more population.

The fast depleting green space, together with the reductions in the vegetation cover, is forecasting drastic consequences for biodiversity, climate regulation, and the overall well-being of the community. In order for these effects to be mitigated, it is pivotal that steps be taken for the implementation of sustainable urban planning practices, which will enable the restoration of the depleted lands, and the active involvement of the community for the conservation of the green spaces. If implemented, these actions will undoubtedly contribute to the better facilitation of the Matara MC's ability of accommodating growth while enabling the preservation of its natural resources for future generations.

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Author Contributions

Conceptualization, methodology, analysis, writing - original draft preparation and writing -review and editing, D.B.C.J., G.P.T.S.H.. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

Abulibdeh, A., 2021. Analysis of urban heat island characteristics and mitigation strategies for eight arid and semi-arid gulf region cities. Environmental Earth Sciences. 80, 1-26. https://doi.org/10.1007/s12665-021-09540-7.

Addas, A., 2023. The importance of urban green spaces in the development of smart cities. Frontiers in environmental Science. 11, 1206372. https://doi.org/10.3389/fenvs.2023.1206372.

Aljenaid, S. S., Kadhem, G. R., AlKhuzaei, M. F., Alam, J. B., 2022. Detecting and assessing the spatio-temporal land use land cover changes of Bahrain Island during 1986–2020 using remote sensing and GIS. Earth Systems and Environment. 6, 787-802. https://doi.org/10.1007/s41748-022-00315-z.

Bai, H., Li, Z., Guo, H., Chen, H., Luo, P., 2022. Urban green space planning based on remote sensing and geographic information systems. Remote Sensing. 14, 4213. https://doi.org/10.3390/rs14174213.

Banks, J. C., Brack, C. L., 2003. Canberra's Urban Forest: Evolution and planning for future landscapes. Urban Forestry & Urban Greening. 1, 151-160.

Baycan-Levent, T., Nijkamp, P., 2009. Planning and management of urban green spaces in Europe: Comparative analysis. Journal of Urban Planning and Development. 135, 1-12. https://doi.org/10.1061/(ASCE)0733-9488(2009)135:1(1).

Bowler, D. E., Buyung-Ali, L., Knight, T. M., Pullin, A. S., 2010. Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and urban planning. 97, 147-155. https://doi.org/10.1016/j.landurbplan.2010.05.007.

Byomkesh, T., Nakagoshi, N., Dewan, A. M., 2012. Urbanization and green space dynamics in Greater Dhaka, Bangladesh. Landscape and Ecological Engineering. 8, 45-58. https://doi.org/10.1007/s11355-010-0147-7.

Carmona, M., 2021. Public places urban spaces: The dimensions of urban design. Routledge. https://doi.org/10.4324/9781315158457.

Chaudhry, P., Bagra, K., Singh, B., 2011. Urban greenery status of some Indian cities: A short communication. International Journal of Environmental Science and Development. 2, 98.

Dinda, S., Chatterjee, N. D., Ghosh, S., 2021. An integrated simulation approach to the assessment of urban growth pattern and loss in urban green space in Kolkata, India: A GIS-based analysis. Ecological Indicators. 121, 107178. https://doi.org/10.1016/j.ecolind.2020.107178.

Doick, K. J., Peace, A., Hutchings, T. R., 2014. The role of one large greenspace in mitigating London's nocturnal urban heat island. Science of the total environment. 493, 662-671. https://doi.org/10.1016/j.scitotenv.2014.06.048.

Duku, E., Mensah, C. A., Amadu, I., Adzigbli, W. K., 2023. Changes in urban green spaces in coastal cities and human well‐being: The case of Cape Coast Metropolis, Ghana. Geo: Geography and Environment. 10, e00119. https://doi.org/10.1002/geo2.119.

Dutta, S., Rehman, S., Chatterjee, S., Sajjad, H., 2021. Analyzing seasonal variation in the vegetation cover using NDVI and rainfall in the dry deciduous forest region of Eastern India. Forest Resources Resilience and Conflicts. 33-48. https://doi.org/10.1016/B978-0-12-822931-6.00003-4.

Escobedo, F. J., Nowak, D. J., 2009. Spatial heterogeneity and air pollution removal by an urban forest. Landscape and urban planning. 90, 102-110. https://doi.org/10.1016/j.landurbplan.2008.10.021.

Faryadi, S., Taheri, S., 2009. Interconnections of urban green spaces and environmental quality of Tehran.

FSI, 2009. Forest Survey of India. State of forest report. Ministry of Environment and Forests, Government of India. Retrieved from http://fsi.nic.in.

Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., Gaston, K. J., 2007. Psychological benefits of greenspace increase with biodiversity. Biology letters. 3, 390-394. https://doi.org/10.1098/rsbl.2007.0149.

Gelan, E., 2021. GIS-based multi‐criteria analysis for sustainable urban green spaces planning in emerging towns of Ethiopia: the case of Sululta town. Environmental Systems Research. 10, 1-14. https://doi.org/10.1186/s40068-021-00220-w.

Ghosh, P., Singh, K. K., 2022. Spatiotemporal dynamics of urban green and blue spaces using geospatial techniques in Chandannagar city, India. GeoJournal. 87, 4671-4688. https://doi.org/10.1007/s10708-021-10524-0.

Halder, B., Bandyopadhyay, J., Al-Hilali, A. A., Ahmed, A. M., Falah, M. W., Abed, S. A., Falih, K. T., Khedher, K. M., Scholz, M., Yaseen, Z. M., 2022. Assessment of urban green space dynamics influencing the surface urban heat stress using advanced geospatial techniques. Agronomy. 12, 2129. https://doi.org/10.3390/agronomy12092129.

Heikinheimo, V., Tenkanen, H., Bergroth, C., Järv, O., Hiippala, T., Toivonen, T., 2020. Understanding the use of urban green spaces from user-generated geographic information. Landscape and urban planning. 201, 103845. https://doi.org/10.1016/j.landurbplan.2020.103845.

Hosseini, M. I., Anjomshoa, E., Abdollahi, A. A., 2015. Standardizing green space capitation of Kerman City, emphasizing on the environment and sustainable development. Mediterranean Journal of Social Sciences. 6, S2. https://doi.org/10.5901/mjss.2015.v6n5s2p654.

Huang, S., Tang, L., Hupy, J. P., Wang, Y., Shao, G., 2021. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. Journal of Forestry Research. 32, 1-6. https://doi.org/10.1007/s11676-020-01155-1.

Huerta, R. E., Yépez, F. D., Lozano-García, D. F., Guerra Cobian, V. H., Ferrino Fierro, A. L., de León Gómez, H., Cavazos Gonzalez, R. A., Vargas-Martínez, A., 2021. Mapping urban green spaces at the metropolitan level using very high resolution satellite imagery and deep learning techniques for semantic segmentation. Remote Sensing. 13, 2031. https://doi.org/10.3390/rs13112031.

Jalayer, S., Sharifi, A., Abbasi-Moghadam, D., Tariq, A., Qin, S., 2022. Modeling and predicting land use land cover spatiotemporal changes: A case study in chalus watershed, Iran. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 15, 5496-5513. https://doi.org/10.1109/JSTARS.2022.3189528.

Jayasinghe, C. B., Withanage, N. C., Mishra, P. K., Abdelrahman, K., Fnais, M. S., 2024. Evaluating Urban Heat Islands Dynamics and Environmental Criticality in a Growing City of a Tropical Country Using Remote-Sensing Indices: The Example of Matara City, Sri Lanka. Sustainability. 16, 10635. https://doi.org/10.3390/su162310635.

Jim, C. Y., Chen, W. Y., 2009. Ecosystem services and valuation of urban forests in China. Cities. 26, 187-194. https://doi.org/10.1016/j.cities.2009.03.003.

Kabisch, N., Qureshi, S., Haase, D., 2015. Human–environment interactions in urban green spaces—A systematic review of contemporary issues and prospects for future research. Environmental Impact assessment review. 50, 25-34. https://doi.org/10.1016/j.eiar.2014.08.007.

Kaur, N., Kaur, M., Padhi, S. S., Singh, K. K., 2022. Geospatial analysis of the distribution of urban green spaces: a study of four Indian cities. Cities & Health. 6, 443-459. https://doi.org/10.1080/23748834.2021.1941722.

Kumara, P. B. T. P., 2022. Socio-economic boom in southern province of Sri Lanka and the role of university of ruhuna. Journal of the University of Ruhuna. 10. https://doi.org/10.4038/jur.v10i1.8003.

Laghai, H.-a., Bahmanpour, H., 2012. GIS application in urban green space per capita evaluation:(Case study: City of Tehran).

Li, M., Chen, T., Li, J., Yang, G., Zhao, L., Cao, Q., Yang, L., Sun, Y., 2024. Advancing Sustainability in Urban Planning by Measuring and Matching the Supply and Demand of Urban Green Space Ecosystem Services. Sustainability. 16, 10306. https://doi.org/10.3390/su162310306.

Li, W., Bai, Y., Zhou, W., Han, C., Han, L., 2015. Land use significantly affects the distribution of urban green space: Case study of Shanghai, China. Journal of Urban Planning and Development. 141, A4014001. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000246.

Lin, L., Pussella, P., 2016. Temporal changes of per capita green space of Colombo District, Sri Lanka. Preprints. 2016, 2016120144. https://doi.org/10.20944/preprints201612.0144.v1.

McDonald, R. I., Marcotullio, P. J., Güneralp, B., 2013. Urbanization and global trends in biodiversity and ecosystem services. Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment. 31-52. https://doi.org/10.1007/978-94-007-7088-1.

Ming, S., Profous, G., Dembner, S., 1993. Urban forestry in Beijing. Unasylva (FAO). 44.

Misty, M. S., Hoque, M. A.-A., Mukul, S. A., 2024. Assessment of Urban Green Space Dynamics in Dhaka South City Corporation of Bangladesh Using Geospatial Techniques. Land. 13, 1426. https://doi.org/10.3390/land13091426.

Morar, C., Lukić, T., Valjarević, A., Niemets, L., Kostrikov, S., Sehida, K., Telebienieva, I., Kliuchko, L., Kobylin, P., Kravchenko, K., 2022. Spatiotemporal analysis of urban green areas using change Detection: A case study of Kharkiv, Ukraine. Frontiers in Environmental Science. 10, 823129. https://doi.org/10.3389/fenvs.2022.823129.

Mutale, B., Withanage, N. C., Mishra, P. K., Shen, J., Abdelrahman, K., Fnais, M. S., 2024. A performance evaluation of random forest, artificial neural network, and support vector machine learning algorithms to predict spatio-temporal land use-land cover dynamics: a case from lusaka and colombo. Frontiers in Environmental Science. 12, 1431645. https://doi.org/10.3389/fenvs.2024.1431645.

Nambazo, O., Nazombe, K., 2024. The spatial heterogeneity of urban green space distribution and configuration in Lilongwe City, Malawi. Plos one. 19, e0307518. https://doi.org/10.1371/journal.pone.0307518.

Namwinbown, T., Imoro, Z. A., Weobong, C. A.-A., Tom-Dery, D., Baatuuwie, B. N., Aikins, T. K., Poreku, G., Lawer, E. A., 2024. Patterns of green space change and fragmentation in a rapidly expanding city of northern Ghana, West Africa. City and

Environment Interactions. 21, 100136. https://doi.org/10.1016/j.cacint.2023.100136.

Nawar, N., Sorker, R., Chowdhury, F. J., Rahman, M. M., 2022. Present status and historical changes of urban green space in Dhaka city, Bangladesh: A remote sensing driven approach. Environmental Challenges. 6, 100425. https://doi.org/10.1016/j.envc.2021.100425.

Nowak, D. J., Crane, D. E., 2002. Carbon storage and sequestration by urban trees in the USA. Environmental pollution. 116, 381-389. https://doi.org/10.1016/S0269-7491(01)00214-7.

Nowak, D. J., Crane, D. E., Stevens, J. C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban forestry & urban greening. 4, 115-123. https://doi.org/10.1016/j.ufug.2006.01.007.

Pandit, M., Bhardwaj, V., Pareek, N., 2009. Urbanization impact on hydrogeological regime in Jaipur Urban Block: a rapidly growing urban center in NW India. The Environmentalist. 29, 341-347. https://doi.org/10.1007/s10669-008-9204-2.

Rahaman, S., Jahangir, S., Haque, M. S., Chen, R., Kumar, P., 2021. Spatio-temporal changes of green spaces and their impact on urban environment of Mumbai, India. Environment, development and sustainability. 23, 6481-6501. https://doi.org/10.1007/s10668-020-00882-z.

Rahman, K. A., Zhang, D., 2018. Analyzing the level of accessibility of public urban green spaces to different socially vulnerable groups of people. Sustainability. 10, 3917. https://doi.org/10.3390/su10113917.

Rusli, N., Ludin, A., 2009. Integration of Remote Sensing Technique and Geographical Information System in Open Space and Recreation Area Evaluation. Proceedings of the 10th Senvar & 1st Conveeesh, Madano, Indonesia. 26-27.

Sathyakumar, V., Ramsankaran, R., Bardhan, R., 2020. Geospatial approach for assessing spatiotemporal dynamics of urban green space distribution among neighbourhoods: A demonstration in Mumbai. Urban Forestry & Urban Greening. 48, 126585. https://doi.org/10.1016/j.ufug.2020.126585.

Selmy, S. A., Kucher, D. E., Mozgeris, G., Moursy, A. R., Jimenez-Ballesta, R., Kucher, O. D., Fadl, M. E., Mustafa, A.-r. A., 2023. Detecting, analyzing, and Predicting Land Use/Land Cover (LULC) changes in arid regions using landsat images, CA-Markov Hybrid Model, and GIS techniques. Remote sensing. 15, 5522. https://doi.org/10.3390/rs15235522.

Shekhar, S., Aryal, J., 2019. Role of geospatial technology in understanding urban green space of Kalaburagi city for sustainable planning. Urban forestry & urban greening. 46, 126450. https://doi.org/10.1016/j.ufug.2019.126450.

Siddique, S., Uddin, M. M., 2022. Green space dynamics in response to rapid urbanization: Patterns, transformations and topographic influence in Chattogram city, Bangladesh. Land Use Policy. 114, 105974. https://doi.org/10.1016/j.landusepol.2022.105974.

Singh, V., Pandey, D., Chaudhary, P., 2010. Urban forest and open green spaces-lesson for Jaipur. Occasional Paper.

Tsatsaris, A., Kalogeropoulos, K., Stathopoulos, N., Louka, P., Tsanakas, K., Tsesmelis, D. E., Krassanakis, V., Petropoulos, G. P., Pappas, V., Chalkias, C., 2021. Geoinformation technologies in support of environmental hazards monitoring under climate change: An extensive review. ISPRS International Journal of Geo-Information. 10, 94. https://doi.org/10.3390/ijgi10020094.

UDA, 2019. Urban Development Authority. Development plan for Matara 2019–2030, Part I. Urban Development Authority: Matara, Sri Lanka.

Wang, G., Jiang, G., Zhou, Y., Liu, Q., Ji, Y., Wang, S., Chen, S., Liu, H., 2007. Biodiversity conservation in a fast-growing metropolitan area in China: a case study of plant diversity in Beijing. Biodiversity and Conservation. 16, 4025-4038. https://doi.org/10.1007/s10531-007-9205-3.

Wang, Y., Chen, X., Zhang, Z., Xue, B., Lu, C., 2019. Cross-city convergence in urban green space coverage in China. Sustainability. 11(17), 4707. https://doi.org/10.3390/su11174707.

Wijesinghe, D. C., Withanage, N. C., Mishra, P. K., Ranagalage, M., Abdelrahman, K., Fnais, M. S., 2024. An application of the remote sensing derived indices for drought monitoring in a dry zone district, in tropical island. Ecological Indicators. 167, 112681. https://doi.org/10.1016/j.ecolind.2024.112681.

Wijesinghe, W. M. D. C., Withanage, W. K. N. C., 2021. Detection of the changes in land use and land cover using remote sensing and GIS in Thalawa DS Division. Prathimana Journal. 14, 72-86.

Withanage, N. C., Jingwei, S., 2024. Evaluating the spatial-temporal dynamics of urbanization in prefecture cities of China using SNPP-viirs nighttime light remote sensing data. Gazi University Journal of Science Part A: Engineering and Innovation. 11, 346-371. https://doi.org/10.54287/gujsa.1466745.

Withanage, N. C., Mishra, P. K., Abdelrahman, K., Singh, R., 2024. Monitoring deforestation, forest health, and environmental criticality in a protected area periphery using Geospatial Techniques. PeerJ. 12, e17714. https://doi.org/10.7717/peerj.17714.

Withanage, N. C., Shi, K., Shen, J., 2023. Extracting and evaluating urban entities in China from 2000 to 2020 based on SNPP-VIIRS-like data. Remote Sensing. 15, 4632. https://doi.org/10.3390/rs15184632.

Wu, J., Toward a landscape ecology of cities: beyond buildings, trees, and urban forests. Ecology, planning, and management of urban forests: International perspectives. Springer, 2008, pp. 10-28.

Yan, J., Liu, H., Yu, S., Zong, X., Shan, Y., 2023. Classification of urban green space types using machine learning optimized by marine predators algorithm. Sustainability. 15, 5634. https://doi.org/10.3390/su15075634.

Zarin, T., Esraz-Ul-Zannat, M., 2023. Assessing the potential impacts of LULC change on urban air quality in Dhaka city. Ecological Indicators. 154, 110746. https://doi.org/10.1016/j.ecolind.2023.110746.

Zhang, H., He, J., Chen, S., Zhan, Y., Bai, Y., Qin, Y., 2023. Comparing three methods of selecting training samples in supervised classification of multispectral remote sensing images. Sensors. 23, 8530. https://doi.org/10.3390/s23208530.