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Assessment of Urban Green Space Dynamics in Dhaka South City Corporation of Bangladesh Using Geospatial Techniques

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Abstract: Green spaces play a critical role in enhancing the urban environment, improving livability, and providing essential ecosystem services. A city should have at least 25% green space from an environmental and health point of view. However, quantitative estimation is required to assess the extent and pattern of green space changes for proper urban management. The present study aimed to identify and track the changes in urban green spaces within the Dhaka South City Corporation (DSCC) of Bangladesh over a 30-year period (i.e., 1991–2021). Geospatial techniques were utilized to analyze green space dynamics using Landsat 4–5 TM satellite images from 1991, 2001, and 2011 and Landsat 8 images from 2021. Supervised image classification techniques and Normalized Difference Vegetation Index (NDVI) analysis were performed to assess the urban green space dynamics in DSCC. The results of our study revealed a significant 36.5% reduction in vegetation cover in the DSCC area over the study period. In 1991, the green area coverage in DSCC was 46%, indicating a relatively healthy environment. By 2001, this coverage had declined sharply to 21.3%, further decreasing to 19.7% in 2011, and reaching a low of just 9.5% in 2021. The classified maps generated in the study were validated through field observations and Google Earth images. The outcomes of our study will be helpful for policymakers and city planners in developing and applying appropriate policies and plans to preserve and improve urban green spaces in DSCC in Bangladesh and other Asian megacities with high population density.

Keywords: urban green space; geographic information system; remote sensing; normalized difference vegetation index; supervised classification; Dhaka; Bangladesh

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1. Introduction

Urban green space refers to any open area that is partially or entirely covered in vegetation within urban settings [1]. These spaces include parks, public gardens, open fields, trees, green roofs, graveyards, and even vacant land [2]. In recent decades, the global trend toward urbanization has accelerated significantly [3]. As cities develop and expand to benefit their residents, the need for green spaces is becoming increasingly important [4]. Various benefits, such as improved air quality, reduced effects on the cities' heat islands, and increasing biodiversity and recreational activities, can be gained from parks, gardens or town green areas [5,6]. Green spaces offer various ecological types of assistance, including decreased sound pollution, air filtering, precipitation water waste, and microclimate regulation [7,8]. Additionally, green space contributes to ecological integrity, controls the microclimate, and lessens adverse environmental consequences [6].

Rapid urban growth is one human-related issue that frequently contributes to the degradation of green places [9]. As urban populations increase, the demand for resources intensifies, leading to the fragmentation and reduction of green areas [8,10]. Urbanization, population growth, and changing land use patterns further exacerbate this strain on green spaces [11]. An ideal city requires at least 25% healthy green space out of its total land area [6,12]. In recent years, urban green space planning has gained significant attention due to its recognized value in urban sustainability [4,13]. It has also acquired popularity as an increasingly important topic in research, urban planning, and economics [14]. Expanding green spaces is a widely adopted strategy to mitigate the impacts of urban heat islands (UHIs) [9,15,16]. Green spaces help regulate and lower urban temperatures, thus reducing the UHI effect [17,18]. Consequently, in large cities, green spaces are recognized as essential tool for controlling excessive air temperatures [18,19].

Dhaka South City Corporation (DSCC) is one of two municipal corporations in Dhaka, a city with a rich history that includes European colonization. Today, DSCC faces the challenges of a rapidly growing population, with a current density of over 39,371 people per square kilometer [20]. The rate at which people are migrating to urban areas is concerning. This has an impact on the process of unplanned urbanization [9], which reduces and fragments green spaces. Despite the recommendation that cities maintain at least 25% of their land as green space, Dhaka currently has only 8% remaining [6]. The development of built-up areas and the conversion of green spaces into other land uses were the main causes of the significant loss of green spaces in Dhaka city [21,22].

Dhaka city has only 54 green areas, including open spaces and public parks [12]. Given the large population, these 65,283.49 hectares of green space equate to just 0.039 hectares per 1000 residents [6,12]. To create policies and strategies for maintaining and enhancing green spaces, it is crucial to assess and monitor changes in the urban green areas managed by the DSCC [12].

Geospatial techniques, a combination of Geographic Information System (GIS) and remote sensing, are widely used to identify changes in urban land cover and land use [23–25]. Multispectral satellite data allow for periodic assessments of land use changes across large regions [26]. GIS, when integrated with satellite data, significantly enhances the management of natural resources and the monitoring of environmental changes [27]. GIS and remote sensing are the best methods for assessing and quantifying green space dynamics [6,28]. Geospatial techniques were used in several studies to evaluate the dynamics of green spaces; see [5,24,29–31] for some examples. Nawar et al. [6] and Ghosh and Singh [30] used the normalized difference vegetation index (NDVI) to assess green space and non-green areas and carry out vegetation classification. Some studies used image classification approaches, such as supervised classification [32], hybrid classification [31], and machine learning [33], to identify various types of green space.

To assess the recent changes in green spaces within DSCC of Bangladesh, a comprehensive, long-term study is essential. Although several previous studies have analyzed the green spaces of Dhaka city using geospatial techniques, none have especially focused on the DSCC area over an extensive period. For instance, Byomkesh et al. [32] employed supervised classification to quantify green spaces in Dhaka city, analyzing data from 1975 to 2005. Similarly, Dewan and Yamaguchi [34] used supervised classification to map land use in Dhaka city, focusing on the years 1989 to 2009. More recently, Nawar et al. [6] examined the changes in green space across the entire city of Dhaka through vegetation analysis. However, the study did not address the categorization of green spaces, such as parks, playgrounds, and thick plantations, using supervised classifications.

In the present study, we thoroughly assessed the changes in green space in DSCC over three decades (i.e., between 1991 and 2021) using geospatial techniques. By examining data from 1991 to 2021, we identified patterns of growth, decline, or transformation in green spaces, providing a clearer understanding of the long-term impact of urbanization on the city's green infrastructure. Three specific objectives were addressed in our study and are as follows: (a) to identify and quantify the area of green spaces in DSCC over the past

30 years, (b) to compare and analyze the changes in green space in DSCC from 1991 to 2021, and (c) to validate the outcomes through field verification. We believe our study will contribute to the better protection and effective land use planning in DSCC and in other Asian land-constrained megacities.

2. Materials and Methods

2.1. The Study Area

The study was conducted in Dhaka South City Corporation, located at the center of the country and surrounded by the Buriganga River (Figure 1). DSCC is located between 23.661 °N to 23.7823 °N latitude and 90.3474 °E to 90.5137 °E longitude. With a total population of 4,299,345 and a population density of 39,371 people per km^2 [20], it is one of the most densely populated areas in the country. However, population estimates are dynamic and may differ from these figures due to factors such as migration, birth rates, and death rates [35]. DSCC is divided into 10 regions and covers an area of about 109.25 square kilometers. Despite the challenges of urban living, people continue to migrate here in search of better opportunities and employment, contributing to the city's overcrowding. DSCC possesses only 27 parks, 6 of which are leased out. DSCC has been chosen as a study area for this investigation because it possesses all the factors responsible for the loss of urban green space.

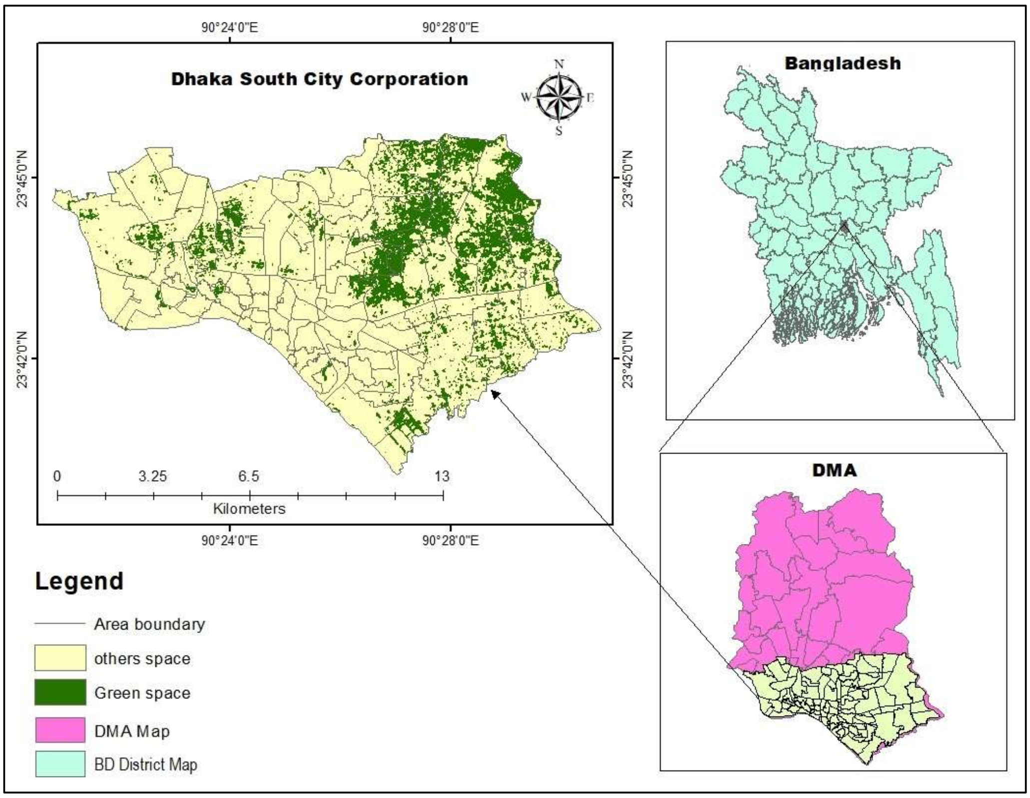

Figure 1. Location of the Dhaka South City Corporation within the Dhaka Metropolitan Area (DMA) and in Bangladesh.

The climate in DSCC is hot and humid, with heavy rain occurring during the monsoon. Dhaka experiences a tropical wet and dry climate, according to the Köppen classification, with an annual average temperature of 25 °C. The monsoon season, which extends from May to the end of September, contributes approximately 80% (1854 mm) of the city's annual average rainfall. However, increasing air and water pollution due to industrial waste and traffic congestion is a major concern, adversely affecting the quality of life and public health in DSCC [35,36].

2.2. Study Approach

In the study, supervised classification and NDVI index were employed to assess changes to urban green space. The analysis focused on two main categories—urban areas and green spaces—using ArcGIS 10.8 software for data classification. NDVI values were calculated from satellite images using the visible red band (approximately 0.6 μm) and the near-infrared band (around 0.9 μm), which are reflected by healthy vegetation. Supervised classification was applied to identify various categories and evaluate changes in green space. Figure 2 provides an overview of the study methodology.

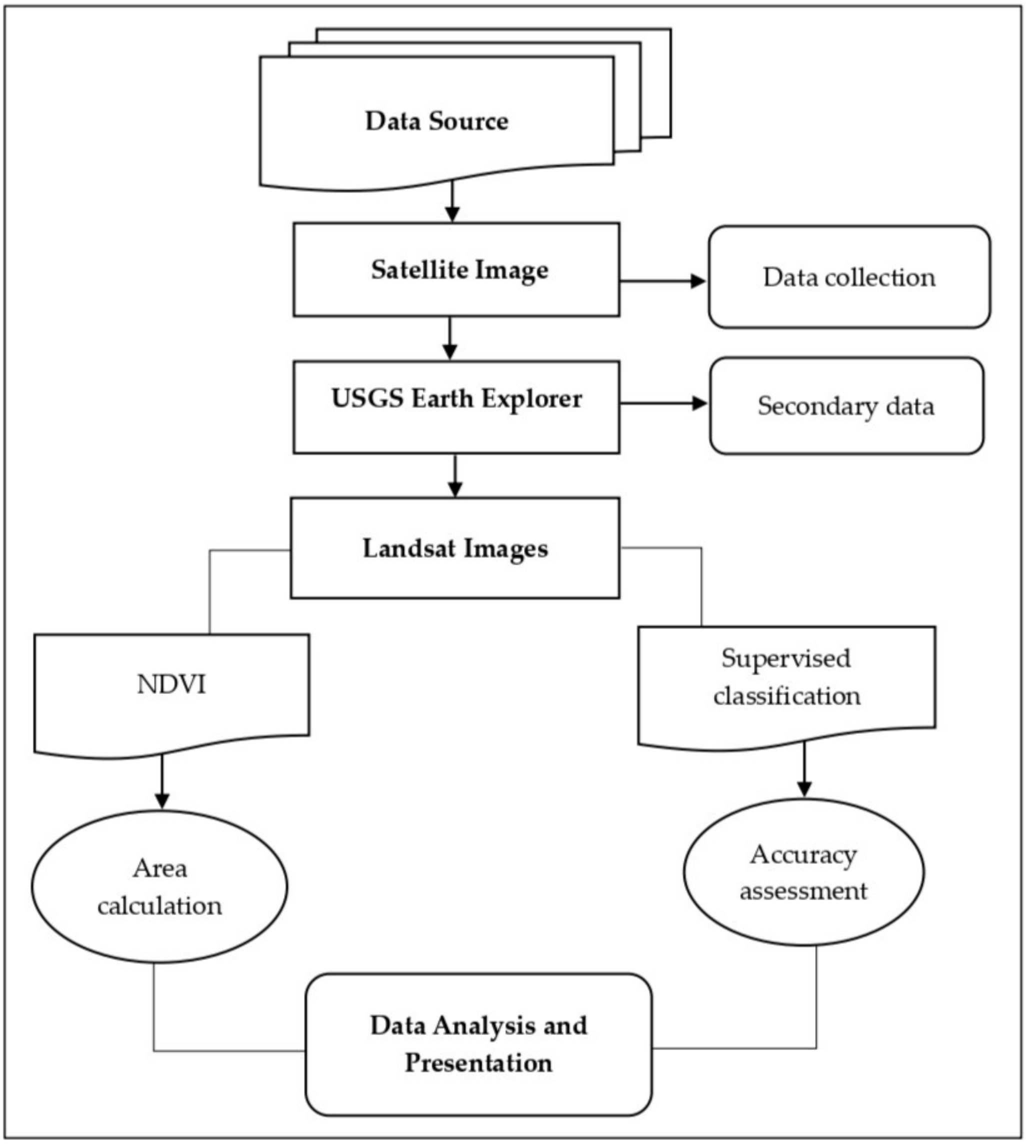

Figure 2. A schematic diagram showing the methodological workflow followed during the study.

2.3. Data Sources

The USGS Earth Explorer provided the Landsat data used in this study, which were from Landsat Collection 1 level 1. Since they provide data beyond what can be obtained through traditional methods, Landsat images are widely used in studies including remote sensing. Landsat 4–5 TM images for the years 1991, 2001, and 2011 and Landsat 8 images for 2021 were used. The worldwide reference system (WRS) provides path and row numbers for Landsat data worldwide, where Landsat 4–5 and 8 use WRS-2 data. The images available in 1991, 2001, 2011, and 2021 were collected with less than 10% cloud cover (see Table 1).

Table 1. Satellite images used in the study and their sources.

Satellite Images	Date of Acquisition	Band Name	Wavelength (m)	Day/Night Indicator
Landsat 5 TM	25 March 1991	Red (B3)	(0.63–0.69)	Day
	21 March 2001	Near Infrared (B4)	(0.76–0.90)	Day
	6 April 2011			Day
Landsat 8 OLI_TIRS	23 March 2021	Red (B4)	(0.64–0.76)	Day
		Near Infrared (B5)	(0.85–0.88)	

2.4. Data Correction, Mapping and Accuracy Assessment

2.4.1. Image Pre-Processing

Landsat datasets were downloaded from the USGS Earth Explorer (USGS-http://www.usgs.gov, accessed on 5 June 2022). Landsat 5 Thematic Mapper (TM) data were available for satellite images from 1991, 2001, and 2011 while Landsat 8 Operational Land Imager (OLI) data were used for 2021 to extract the urban green space in DSCC. The Landsat images have a spatial resolution of 30 m. The map was created using these data sources. The digital number (DN) values were converted using the Top of Atmosphere (TOA) reflectance in accordance with USGS (2018) standard methods [37]; no further geometric adjustments were performed in this inquiry as USGS had finished geometric corrections on Level 1 T products. Haze can significantly affect the spectral reflectance characteristics of land cover data [6]. To address this, the 2001 satellite image was enhanced and visual haze was reduced using the ERDAS Imagine haze reduction tool. After georectification, all satellite images were projected to GCS WGS 1984 UTM Zone 46 N (datum) to ensure consistency.

A field visit was carried out in 2022 for ground truthing. In total, 24 randomly selected sites were selected to determine the accuracy of green space from Google Earth images and through field validation (see Figure 3).

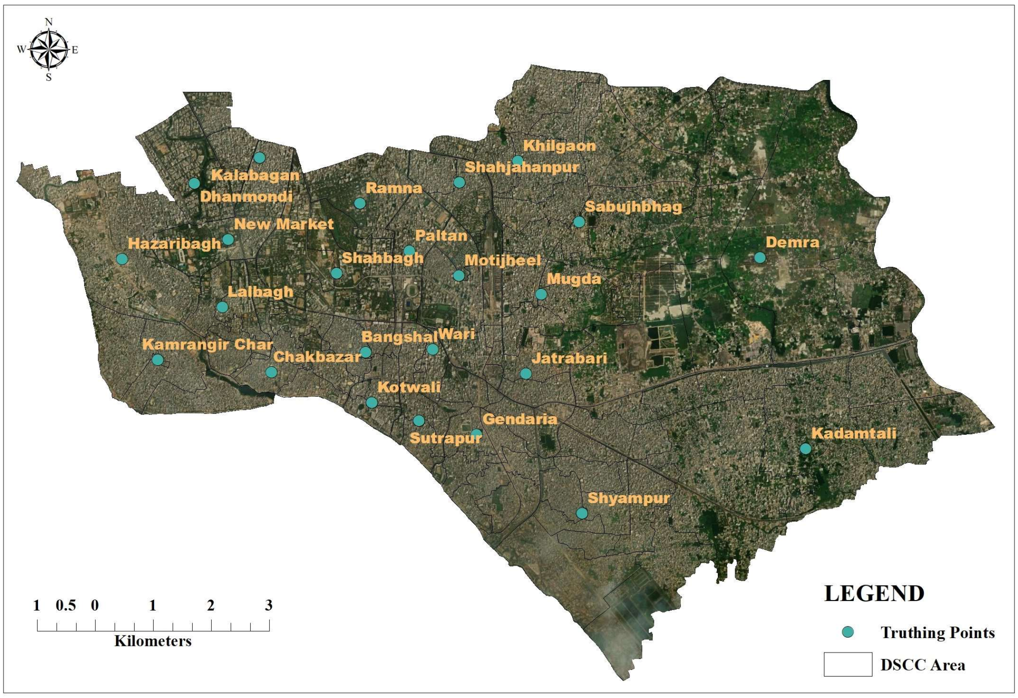

Figure 3. Points of ground-truthing in the DSCC area that were used in the present study.

2.4.2. Image Classification

This study used the Maximum Likelihood supervised classification technique, which was found to be suitable for mapping tree coverage [38,39]. With the use of Arc GIS 10.8, the

LULC maps for both years were created by supervised categorization with the Maximum Likelihood approach. Class histogram plots were then used to assess the training samples. For the Landsat 5 TM images, Bands 1–4 and 7 were used for classification, while Band 6 was excluded due to its thermal properties. Conversely, the software's image analyzer tool has been used to stack Bands 1–7 of the Landsat 8 OLI TIRS for this purpose. The training sample manager tool was then used to mark pixel signatures, with approximately 200 sample points randomly selected from the total images. The urban class represented any infrastructure not entirely composed of green spaces.

The DSCC's boundary was obtained by using the mask tool in the Arc Toolbox. Google Earth Pro was used to prepare the shape file for the DSCC. The study employed the WGS 1984 UTM Zone 46 projection system. The terms "urban" and "other classifications" were used in this study to refer to built-up areas, water, bare land, and any other infrastructure that is not vegetation. For a single class, a few studies employed 50–100 training samples [40].

The number of bands in the images was counted to determine the training samples. The training pixel locations were dynamic and varied according to the images. After that, the raster was converted into a polygon, and each class's single cohesive polygon was made using the dissolve tool. Consequently, two separate classes that were prepared for calculation were contained in a single file. We added a field to the attribute table and measured the area in square kilometers for each class area evaluation using the "calculate geometry" function.

2.5. NDVI Analysis

NDVI was selected for this study due to its widespread use in detecting healthy vegetation [41,42], as its values are generated from the reflectance of healthy vegetation. The NDVI values were derived from the red and near-infrared bands of Landsat-5 TM (1991, 2001, and 2011) and Landsat OLI TIRS (2021) satellite images. Positive values indicate vegetation cover, while high vegetation density is indicated by values around 1. NDVI values are generally calculated using the following equation.

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \tag{1}$$

where

NIR = pixel values from the near-infrared band

and

RED = pixel values from the red band

The decimal values in this formula were obtained by using the float command. Landsat sensors detect solar radiation reflected from the Earth's surface. Specifically, red reflectance is captured by bands 3 and 4, while near-infrared reflectance is captured by bands 4 and 5 of Landsat 8.

We used the following equation to calculate the NDVI:

$$\text{NDVI} = \text{Float}\ (\text{NIR} - \text{R})/\text{Float}\ (\text{NIR} + \text{R}) \tag{2}$$

NDVI values range from -1 to +1, where a value closer to -1 indicates the absence of vegetation and a value closer to +1 indicates healthy vegetation. Four NDVI classes were identified (Table 2) in this experiment. NDVI thresholds were found in the literature with related studies [6]. In this study, we have shown NDVI analysis using a single range of values. Values below zero signify areas without vegetation, which may include water bodies, buildings, and road networks. Values between 0 and 0.33 reflect sparse vegetation, typically consisting of unhealthy or minimal vegetation. There is no significant vegetation in this area, with a value between 0.33 and 0.66, which indicates grasslands or cultivated lands or moderately dense plants in parks, gardens, etc. This range is classified as 'moderate vegetation' in this study. Values ranging from 0.66 to 1 indicate dense vegetation, including thick plant growth, large trees, and urban forests, and are classified as 'healthy vegetation'.

Table 2. NDVI classes according to the Earth Observation System used in the study.

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

2.6. Accuracy Assessment

A confusion matrix, also known as error matrix, has been used to evaluate the accuracy of results acquired from categorized images [43]. Reference data were obtained from Google Earth Pro and field surveys [44]. Several formulas were used to evaluate the accuracy of the classified satellite images. In this study, approximately 100–150 random points were selected from each class of green space in the classified satellite images using ArcMap. The number of randomly selected points varied for each year (1991/2001/2011/2021). Using Google Earth Pro, the points were compared to each reference point. The analysis of 1991/2001 data were compared with Google Earth reference maps (2001/2004). By contrasting it with the real-world producer points, the selected user point's accuracy was determined [45]. In addition, some random points were also selected for ground-testing. These points included Motijheel, Khilgaon, Ramna, Malibagh, Shahbagh, Bangshal, Dhanmondi, Mugda, Wari, and Jatrabari. These locations were selected at random and compared with the data being analyzed to ensure accuracy. Finally, we assessed the overall user and producer accuracy and the Kappa coefficient using the equations below.

$$\text{Overall accuracy} = \frac{\text{Total number of correctly classified pixel (Diagonal)}}{\text{Total number of reference pixel } \times \text{ } 100} \tag{3}$$

$$\text{Producer's accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of reference pixel in that category (column total } \times \text{ } 100)} \tag{4}$$

$$\text{User accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of reference pixel in that category (column total } \times \text{ } 100)} \tag{5}$$

$$\text{Kappa Coefficient (T)} = \frac{(\text{TS} \times \text{TCS}) - \sum(\text{Column Total} \times \text{Row Total})}{\text{TS}^2 - \sum(\text{Column Total} \times \text{Row Total})} \times 100 \tag{6}$$

where

TS = Total number of samples taken;
TCS = Total number of correct samples;
Column total = Total sample in each column;
Row total = Total sample in each row.

3. Results

3.1. Green Space in DSCC

Our study used geospatial techniques to evaluate the spatiotemporal variations in green spaces in DSCC. Over recent years, green spaces have decreased due to increasing urban development. Areas previously densely vegetated in DSCC have been converted to built-up areas due to increasing demands for residential, commercial, and other services. The findings of our study show that since 1991, there have been fewer green places. The area analysis by year shows that 2021 had the least amount of green space, while 1991 had the highest (Table 3). Most changes in the total green spaces occurred between 2011 and 2021. The presence of built-up areas and other areas has risen since 1991. In 1991, the healthy green spaces covered an area of 20 km^2. Table 3 shows the temporal changes in green space in DSCC between 1991 and 2021.

Table 3. Temporal changes in green space and urban built-up and other areas in DSCC.

Classification	**1991**		**2001**		**2011**		**2021**	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
Green space	20	46	10.25	21.3	9.27	19.7	5.26	9.5
Urban and others	25.25	54.9	35	78.7	35.8	80.3	39.1	90.5

As the population grows, the demand for homes and infrastructure also rises, making it essential to monitor green spaces carefully Analyzing the relationship between Dhaka's population, the number of houses, and the total green space reveals that the city had more green space in the past, when both population and housing were lower (Figure 4). The northeastern area of Dhaka's south city corporation shows more green areas, whereas the western part shows less green space. Ramna, Demra, and Khilgaon areas had more green space than other wards. DSCC had 21.3% green space (10.25 km^2), while other areas accounted for 78.7% (35.8 km^2). In 2011, the green space in DSCC increased by 19.7 percent (9.27 km^2).

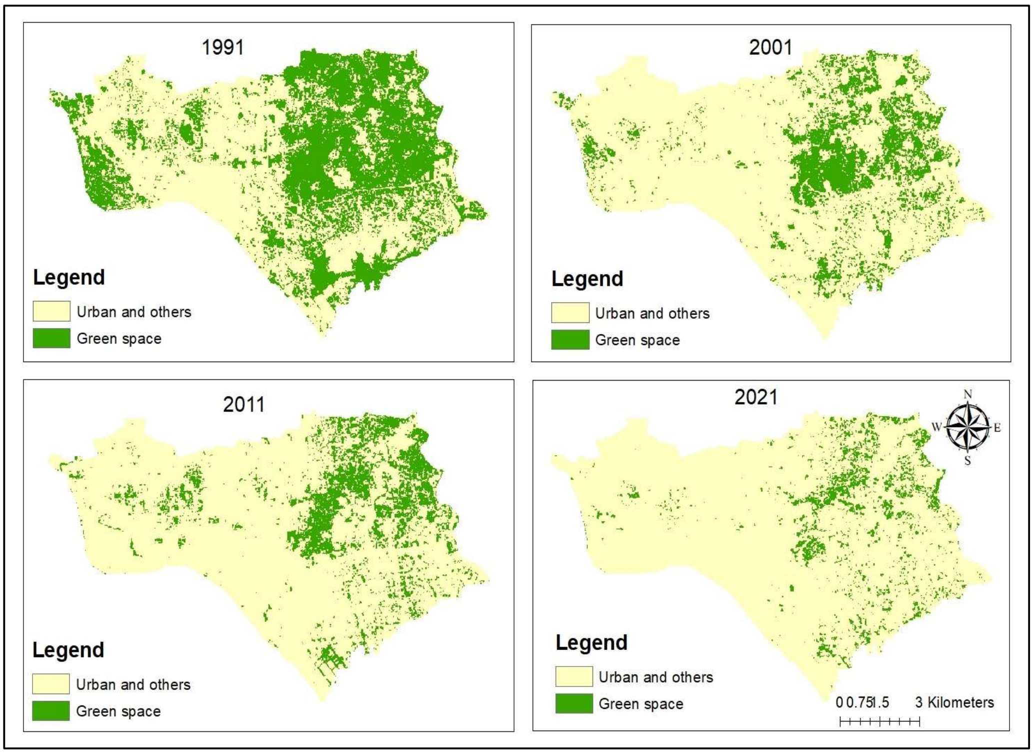

Figure 4. Spatial distribution of urban green spaces in DSCC in the years 1991, 2001, 2011, and 2021.

Over the past decade, there have been no significant alterations in the Dhaka City area. Following the city's division into North and South in 2011, most of the designated green parks and playgrounds were transferred to Dhaka North City Corporation (DNCC), Bangladesh. In DSCC, only the north-eastern zone has a significant presence of vegetation and green spaces, while the rest of the district needs more green space. Ramna Park displays the highest amount of vegetation in the area compared to other city corporation wards.

In 2001, only 21.3% (10.25 km^2) of DSCC was covered with green space, while nearly 78.7% (35 km^2) of the area was covered with settlements, water bodies, and other land cover classes (Figure 4). The extent of green areas in DSCC in 2001 was notably lower than in 1991 (Table 3). Our result shows that only 19.5% of the area of DSCC was covered with green space. Thus, the changes in green areas in DSCC were comparatively higher in 2011 than in 1991 and 2001. By 2021, only 9.5% of DSCC was covered with green space, with almost 90.5% of the region covered by settlements, water bodies, and other land uses. The drastic reduction in green space by 2021 was significantly greater compared to previous decades, largely driven by the development of essential infrastructure and the city's role as part of Bangladesh's capital.

Green spaces are associated with urban built-up areas and other classes, as evident from a decreasing trend of green spaces over time and a growing trend of urban infrastructure (Figure 5). Our study reveals a net decrease of 36.5% in green spaces within the DSCC area between 1991 and 2021.

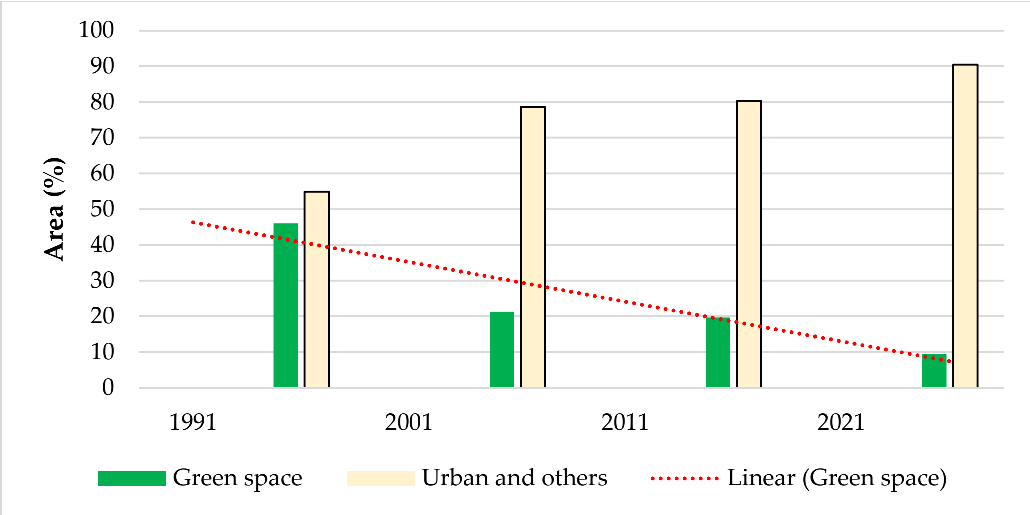

Figure 5. Association of green space with development of urban built-up and other areas.

3.2. Changes in Green Space in DSCC

Following the NDVI classification methodology, Figure 6 illustrates our vegetation classification analysis. The results indicate that vegetation in the area is predominantly sparse, with only a few open fields visible in the satellite imagery. In 1991, healthy or dense green spaces covered 13.6% of the total area. From 1991 to 2021, there was a 36.5% decrease in the amount of healthy green space. Dense green spaces decreased by 8.37 km^2 (0.3%) over this period, while urban and other areas expanded. Even a slight variation in NDVI values can significantly impact the assessment of healthy vegetation percentages.

Between 2001 and 2011, the largest percentage change in healthy vegetation occurred. Conversely, the period from 2011 to 2021 saw the most significant decrease in moderate to sparse vegetation. A clear correlation between healthy green space and urban development is evident when comparing the growing trend of urban infrastructure with the declining trend of green areas over time. The result shows that, in 1991, almost 20.7% of the area had sparse vegetation within a 10 km^2 area, whereas 11.8% and 13.6% of the area was covered with moderate and dense vegetation, respectively. An almost 7 km^2 area was covered with dense vegetation, which is 13.6%. Some areas, such as Mugdapara, Mirjannagar, Kadamtala, Bamboo, Purba Goran, Demra, Ramna Park, Shahabag, and Shahrawardi Uddan, had more green space than others. In 1991, DSCC had healthier green space compared to 2001, 2011, and 2021. In 2001, almost 13.2% of the area had sparse vegetation, with a 5.5 km^2 area. An estimated 5.8% of the area was covered with moderate vegetation, while only 2.3% had dense vegetation, totaling nearly 7 km^2 of dense green space—a very low figure. That year, areas like Mugda, Bashabo, Goran, Shahbagh, and Kamalapur experienced significant losses in green space. In 2001, DSCC had more moderate green space compared to 1991, 2011, and 2021 (Table 4). By 2011, 13.8% of the area had sparse vegetation, with moderate vegetation covering 5.1%, and only 0.9% of the area had dense vegetation. Only an area of 8.3 km^2 was covered with dense vegetation, which is very low. Urban and other areas represented 80% in 2011. Ramna Park, Mintu Road, Shahbagh, Baldha Garden, Shahrawardi Uddan, and Demra areas had the majority of moderate to dense vegetation. By 2021, sparse vegetation covered approximately 7.3% of the 67.5 km^2 area. Accordingly, 1.08% and only 0.3% of the total area were covered with moderate and dense vegetation, respectively (Table 4), which shows that very little healthy and visible green space is present in the DSCC area. Thus, only a 2.7 km^2 area was covered with dense vegetation. Urban and other areas in 2021 were 90.5%, with 39.1 km^2. After all, all lands are covered with urbanized areas, water bodies, and other areas By 2021, DSCC had a much smaller portion of green space compared to 1991, 2001, and 2011 (Figure 7). However, some green spaces with moderate to sparse vegetation still existed in regions like Shahbagh, Ramna Park, Green Model Town in Mugda, and Baldha Garden.

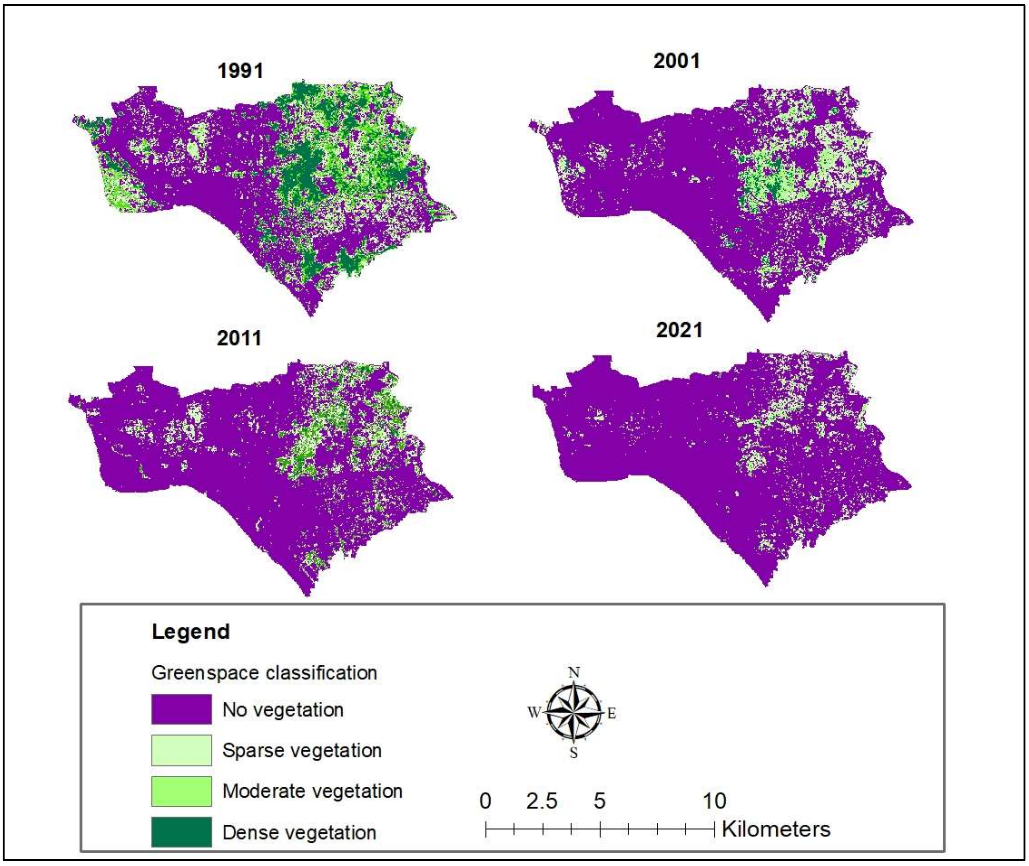

Figure 6. Vegetation quality in DSCC in the years 1991, 2001, 2011, and 2021.

Table 4. Temporal changes in green space vegetation quality on 1991, 2001, 2011, and 2021 in DSCC.

Classification	**1991**		**2001**		**2011**		**2021**	
	Area (km^2)	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**
No vegetation	25.25	54	35	78.7	35.8	80.2	39.1	90.5
Sparse vegetation	10	20.7	5	13.3	5.5	13.8	3	7.3
Moderate vegetation	3	11.8	3	5.8	2.7	5.1	2	1
Dense vegetation	7	13.6	2	2.3	1.8	0.9	1	0.3

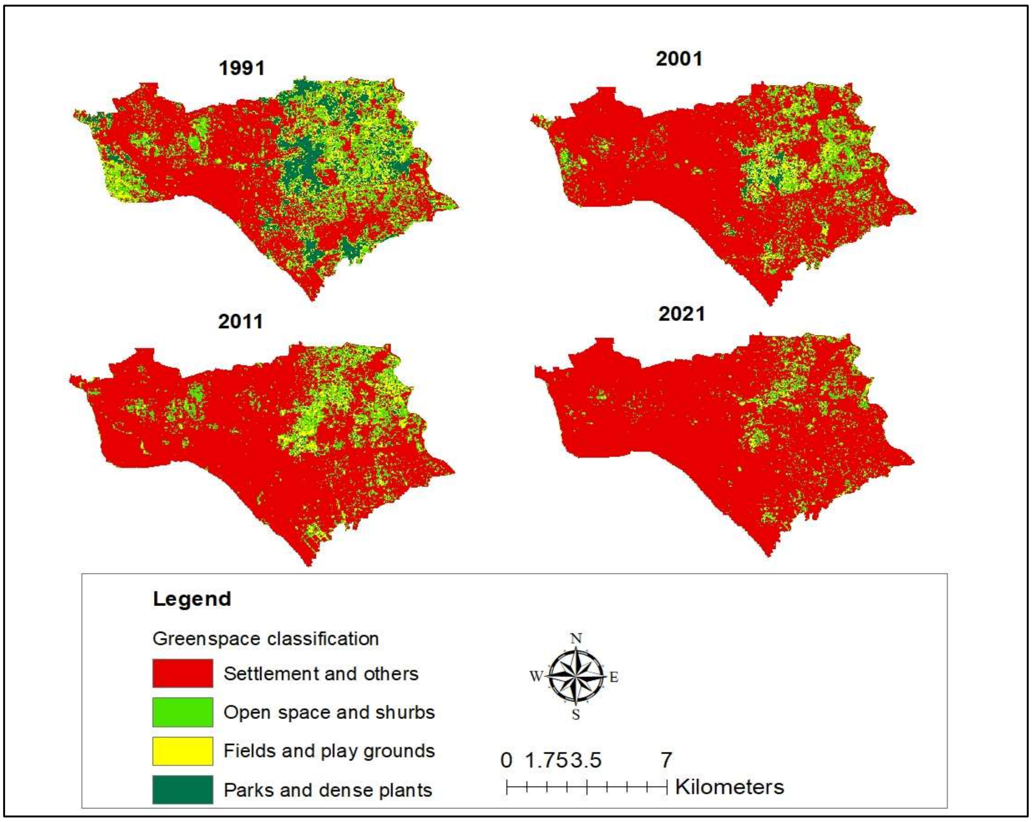

Figure 7. Different types of green and open spaces in DSCC on the year 1991, 2001, 2011, and 2021.

3.3. Green Space Classification and Preserved Spaces in DSCC

Over the last 30 years, extensive areas of green space have been lost because of urbanization and settlements. Figure 7 shows how the urban green and open spaces in DSCC are categorized. Most of the regions on this map are settlement water bodies and other open space, while the black line represents the municipal corporation's ward boundaries. According to our study, open space and bush coverage in the area accounted for 45%, 36%, 25%, and 15% in 1991, 2001, 2011, and 2021, respectively. North, south, and eastern zones have greater open land. Khilgaon, Mugda, Ramna, and Jatrabari areas are relatively open and include parks and dense trees. Green fields and playgrounds comprised nearly 8%, 6%, 4%, and 2% of the DSCC area, respectively, in the years 1991, 2001, 2011, and 2021 (Figure 8). Khilgaon, Mugda, Ramna, and Jatrabari areas had more open space with parks and dense trees. In 2001, while most of the urban green spaces still included parks and open fields, their extent was noticeably reduced compared to 1991.

Figure 8 shows some preserved space and parks in different DSCC wards. The Bangshal, Jatrabari, and Wari areas feature small parks and the Baldha Garden, a notable botanical garden. Shahabag, Dhaka University, and Shahrawardi Uddan areas are covered with various dense trees and parks. Demra area also has open green space with parks. Motijheel, Mugda, Khilgaon, and Sabujbag areas have relatively more open fields, parks, shrubs, and densely vegetated areas in DSCC.

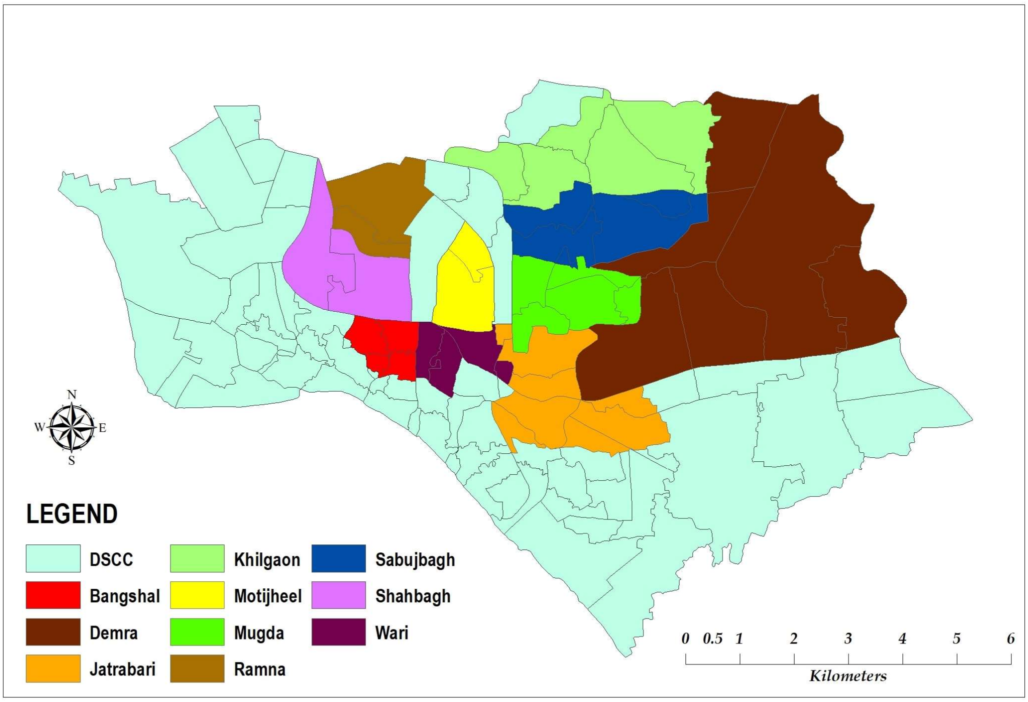

Figure 8. Major green space preserving areas in DSCC.

3.4. Validation of Image Classification

To evaluate the accuracy of green space maps generated from Landsat data, 100 stratified random pixels were selected for each classified map for the years 1991 and 2001, while 120 points were used for 2011 and 150 points for 2021. An accuracy assessment using a confusion matrix was carried out using field data, the geographical feature accessible on green space classified maps, and Google Earth-based high-resolution images. Since the nonparametric kappa test considers all of the confusion matrix's parts rather than just the diagonal ones, it was also utilized to quantify the classification accuracy. Ground-truthing points were also collected from 24 randomly selected points by field visit to the study area.

Referenced point data obtained from various sources were used to evaluate the categorization accuracy of the maps created using satellite data. The accuracy of the categorization was evaluated using error matrices, which are compiled for all four years in Table 5, with the kappa statistics, the producer's accuracy, and the user's accuracy for each land-use class. For the 1991 classified image, while producer accuracy was 84% on average, user accuracy was 87% on average. For the 2001 image, users and producers were, on average, 80% and 74% accurate, whereas for the 2011 image, they were 80% and 82% accurate. For the image from 2021, the average user and producer accuracy were 73% and 84%, respectively. Overall accuracy was 80.25% on average. For 1991, a kappa value of 0.71 was calculated. The kappa values for 2001, 2011, and 2021 were 0.57, 0.62, and 0.59, respectively (Table 5), where value ranges above 0.6 are regarded as acceptable and desirable. The results of the calculation of overall accuracy were 86%, 79%, 81%, and 79%, which are considered as good results. The accuracy of the analysis varied from moderate to high.

We physically measured the data at ground level after visiting the designated sites (Figure 3). This allowed us to establish the ground truth. The ground truthing location was chosen for the 2021 classification of images process. The 2021 image's overall accuracy was 77%. After visiting these locations, green spaces were discovered there, with only a few exceptions.

Table 5. Overall calculation of accuracy * and Kappa coefficient.

Type	1991				2001				2011				2021			
	PA	UA	Overall	Kappa	PA	UA	Overall	Kappa	PA	UA	Overall	Kappa	PA	UA	Overall	Kappa
Green space	84	87	85%	0.71	74	80	78%	0.57	82	80	81%	0.62	84	73	77%	0.59
Urban and others	82	83			76	77			80	82			82	78		

* Where "PA" and "UA" stands for "Producer's Accuracy" and "User's Accuracy", respectively.

4. Discussion

Our study, using NDVI and satellite image classification, reveals a declining trend in urban green spaces within the Dhaka South City Corporation (DSCC) area. Post-classification change analysis clearly illustrates the disappearance of green spaces and the expansion of urban sprawl in DSCC. We employed a comprehensive and robust methodological framework to detect the dynamics of green space in DSCC, and our findings align with those of Nawar et al. [6], Khan et al. [31], Byomkesh et al. [32], and Sorker et al. [46].

The trends observed in DSCC are not unique and mirror patterns seen in other rapidly urbanizing cities globally. For instance, similar reductions in green spaces have been documented in cities like Delhi, India, and Lagos, Nigeria, where urban sprawl has outpaced the development of green infrastructure [2,47,48]. This global comparison suggests that the challenges DSCC faces in maintaining adequate green spaces are part of a broader pattern associated with unplanned urbanization. However, the situation in DSCC is particularly severe due to the city's high population density and the limited land available for expansion. Following Bangladesh's independence, Dhaka began to rapidly urbanize, with the most significant population growth occurring between 1981 and 1991, leading to the expansion of municipal boundaries [49]. This process was further accelerated by the construction of bridges over the Buriganga River [50]. As a result, DSCC's population, which was 8.9 million in 2011, has grown to approximately 10.2 million as of 2022 [20].

Green spaces in urban environments are vital for enhancing well-being by providing social and environmental benefits that significantly improve overall quality of life [51]. However, the reduction in vegetation cover observed in this study may lead to higher pollutant concentrations, exacerbating respiratory diseases and other health issues among the city's residents [52,53]. Our findings indicate a drastic decline in green spaces as urban development progresses. After cross-verifying the analyzed sequences with an accuracy evaluation, the overall accuracy of the images was 80.5%.

Despite this level of accuracy, the declining trend in green space raises serious concerns about the sustainability of urban development in Dhaka South City Corporation (DSCC). Specifically, 36.5% of the total green space, including healthy vegetation, has been lost. The northeastern region of DSCC, including areas such as Ramna Park, Shahbagh, and Baldha Garden, retains a relatively higher amount of vegetation compared to other parts of the city.

The dynamics of green spaces are crucial for assessing a city's environmental health. To maintain a healthy environment, a balance between urban development and green spaces is essential [54]. However, urban expansion and population growth are the primary drivers behind the decline in green spaces [55]. Migration, particularly to the capital, significantly contributes to this urban population growth [56]. Despite the city's limited capacity to meet the demands of urban life, people continue to migrate to Dhaka. The informal livelihood sector has made DSCC a major destination for migrants transitioning from rural to urban areas. Since independence, open spaces in Dhaka have increasingly been converted into built-up areas due to migrant settlements on previously unoccupied land [6,55]. The city's limited capacity to support its growing population has placed considerable pressure on these open areas [56]. This study can serve as a baseline for developing future policies on the distribution and accessibility of urban green spaces.

For Dhaka and other cities facing similar challenges worldwide, it is crucial to set realistic and attainable goals for urban green space preservation to guide the development of effective plans and policies [57]. Two key factors are essential for the planning, development, and preservation of urban green spaces: the availability of land and an adequate water supply [47]. Integrating rooftop gardening and green building initiatives into strategic city planning is vital for preserving and expanding urban green spaces, preventing their disappearance [6].

The findings of our study highlighted the urgent need for stakeholders, decision-makers, and the public to prioritize sustainable development goals. By doing so, they can work towards creating a more resilient, greener, and cleaner Dhaka, serving as a model for other cities globally [12,53]. This holistic approach is essential to ensure that urban areas remain livable and environmentally sustainable amid rapid urbanization [58]. Future research could explore the effectiveness of these interventions in other urban contexts and assess their potential application in DSCC. Additionally, further studies could investigate the socio-economic factors driving the encroachment of green spaces and explore community-based approaches to urban greening.

The distribution of green space was determined in the study using imagery from Landsat series satellites with a resolution of 30 m. More green places may have been found if higher-resolution satellite images had been used. The satellite images used in the study were collected in April and May of 1991, 2001, 2011, and 2021. Due to the excessive cloud presence in satellite images, some maps do not show a hundred percent accuracy. The images' accuracy was evaluated using Google Earth Pro (version 7.3); images from 1991 and 2001 that had been analyzed were cross-checked with maps from 2001 to 2004 obtained from Google Earth. The collection of more ground-truthing points from field visits can improve the accuracy of the assessment process [45]. Future studies can incorporate these drawbacks to find a more accurate scenario for green space changes in DSCC.

5. Conclusions

Our study clearly finds that the extent of green spaces is inadequate and alarmingly low in DSCC. There has also been a rapid decline in urban green space in the area, from 46% in 1991 to only 9.5% in 2021. This decline can be attributed to inadequate policy, poor planning and management, and, most critically, insufficient political will. The absence of green areas has made DSCC and Dhaka a gloomily dull city. Regretfully, Bangladesh lacks national and local policies that may be an effective means of resolving this issue. Setting attainable and realistic goals is vital for DSCC rather than creating rushed plans. It is also crucial to safeguard the current green spaces in DSCC to make Dhaka city more livable.

The findings of our study resonate with global urbanization trends, where rapid urban growth often leads to the degradation of green infrastructure. The situation in DSCC is particularly acute due to its high population density and limited land availability, which exacerbate the challenges of maintaining adequate green spaces. This decline has profound implications for the city's livability, environmental sustainability, and the well-being of its residents, highlighting the urgent need for effective policy interventions.

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