Index-Based Change Detection, Spatial Zoning and Environmental Criticality of Urban Land Cover: A Spatiotemporal Study on Gazipur Sadar Upazila of Bangladesh

ABSTRACT

Urbanization has become a comprehensive phenomenon worldwide as well as in Bangladesh. This study has tried to analyze the urban land cover change pattern of Gazipur Sadar Upazila between 2001 and 2021. This study also has made an investigation to classify the urban land cover of Gazipur Sadar based on categorical spatial zoning and analyze how urbanization affects nearby green spaces to monitor environmental criticality. Multispectral Landsat satellite imageries, population census data, air quality index, and open-ended questionnaire data were used as the operational data. Spectral indices such as NDVI, and IBI, were performed from remotely sensed satellite data. NDVI was used to extract green cover and IBI was used to extract the built-up area. Spatial zoning was done based on existing literature, expert interviews, and RS analysis. Environmental criticality was analyzed by correlating population density and air quality data with the extracted green cover. Between 2001 and 2021, the built-up area expanded by around 77.7 km^2 and green cover by about 74.79 km^2. Although the green cover flourished, it decreased in Tongi and Konabari. Besides, the south-western region of Gazipur experiences rapid growth in built-up areas. Three classified zones e.g., industrial and manufacturing zone, forested, zone, and neutral zone were extracted from criteria-based spatial zoning. The results of green space per capita analysis showed that from 2001 to 2021, green space in the study area decreased by 10-713 m^2. Environmental criticality analysis illustrated that in 2001, two regions (Tongi and Konabari) were classified as highly critical, and by 2021, this number had escalated to five (Tongi, Konabari, Kasimpur, Basan, Gachha). Furthermore, the study uncovered that the criticality in urbanized areas is growing rapidly.

Keywords: Urbanization; indices; built-up; green space; spatial zoning; environmental criticality.

1. INTRODUCTION

Historically, humans have altered land to acquire basic survival needs, but the increasing pace of exploitation has led to significant alterations in ecological systems and environmental functions at all levels, from local to global [1]. Land transformation and development are usually referred to as processes of urbanization that are associated with demographic change, economic growth, and aerial expansion [2, 3]. Urbanization in conjunction with technological advancements and population pressure has led to an alteration in urban land use and land cover (LULC) patterns [4]. Rapid urbanization is the most common characteristic in all emerging countries, and it is a continuing dynamic process that significantly affects the landscape with some negative consequences [5]. A significant proportion of agricultural land and forest area has been converted to urban settings as a result of urbanization, which can unambiguously and directly lead to land use land cover change (LULCC) [6]. United States Population Fund estimated that, by 2030, approximately

80 percent of urban people will be concentrated in emerging nations [7]. The unanticipated implications of urbanization in the urban periphery can affect the sustainability of the urban landscape [5]. Urban landscape indicators include leaf hue, ambient temperature, water, vegetation (which corresponds to urban green space), ecology, and other indicators that describe the natural setting of an urban area [8]. Urban areas benefit immensely from green space because of its environmental, social, economic, and artistic contributions to human well-being [7]. From an environmental aspect, green space enhances the environment by absorbing atmospheric emissions, sequestering carbon, generating oxygen, detoxifying air and water, regulating climate, preserving soil moisture, conserving biodiversity, and boosting urban health [7, 9]. For healthy well-being WHO recommends 9.5 m^2 of green space per capita [10]. In developing countries, the urban periphery's environment is inferior to that of affluent countries, as developing countries do not usually prioritize greenery in urban development plans [7]. Bangladesh is a developing nation with an overwhelming population that has increased substantially in recent decades facing a considerable shift of natural land cover because of urban growth and the patterns of such growth are complicated and harmful to the urban environment [11, 12]. Rapid urbanization reduces vegetation in urban areas, which harms the environment and human living standards [13]. Agricultural land in Bangladesh decreased by 56,537 ha between 2000 and 2010 as a result of urbanization [14]. In addition, urban growth directly or indirectly affects the temperature in urban regions of Bangladesh [15]. Being an important urban hub, besides Dhaka and Chittagong, Gazipur has seen considerable urban growth in recent decades. The proximity to the capital city, availability of arable land, and the presence of industrial activities are the primary reasons influencing its urban expansion. Rapid land cover change mostly impacts agricultural land in the Gazipur district; from 1990 to 2020, roughly 87 km^2 of the built-up area converted from 53 km^2 of agricultural land and 28 km^2 of forested vegetation cover as well as agricultural land contributed around 398 km^2 to the increase vegetation [5]. GIS and RS technologies emerged as valuable tools for assessing environmental quality and evaluating spatiotemporal changes in urban land cover [13]. Bangladesh, as a developing country, pays little attention to how growing urbanization, industry, and other human activities degrade the country's metropolitan landscape. Several studies have been conducted using GIS-RS on urban land cover change and its impact on temperature, groundwater, and natural landscape e.g., Arifeen et al. [5] investigated the changes in LULC in the Gazipur district between 1990 and 2020. Shapla et al. [16] conducted a study to assess how agricultural land in the Gazipur District has changed over time. Uddin et al. [17] evaluate the transformation of Gazipur City Corporation's land cover and estimate the future trend of LULC change. Abdullah et al. [18] investigated the causes and trends of deforestation in Gazipur. Roy et al. [19] investigate the shift in urban expansion and land surface temperature from 2006 to 2020. However, there are few studies on Gazipur analyzing the multidimensional effects of urbanization on environmental quality and urban sustainability. Furthermore, Gazipur is heterogeneous in nature, but no spatial zoning has ever been carried out. A comprehensive analysis with remote sensing, demographic, and environmental data can help to assess environmental criticality and identify highly critical areas of urban land cover. Spatial zoning can be a useful tool for both environmental preservation and development activities [20] in a heterogeneous landscape like Gazipur. The primary objective of this research is to examine the pattern of urban land cover change in Gazipur Sadar Upazila between 2001 and 2021 based on RS indices. This study also tries to classify the urban land cover of Gazipur Sadar based on categorical spatial zoning as well as demonstrate how urbanization impacts neighboring green spaces in order to measure environmental criticality.

2. METHODOLOGY

2.1 Study Area

Gazipur Sadar is an Upazila (sub-district) of the Gazipur District in Bangladesh, which is a constituent of the Dhaka Division and situated between 23°53' and 24°11' north latitude and 90°15' to 90°30' east longitude (Fig. 1). The landmass of Gazipur Sadar is approximately 446.38 square kilometers. It is made up of 8 unions: Mirzapur, Basan, Pubail, Baria, Kayaltia, Kasimpur, Konabari, Gachha, and two metropolitan areas: Tongi and Gazipur Sadar [21].

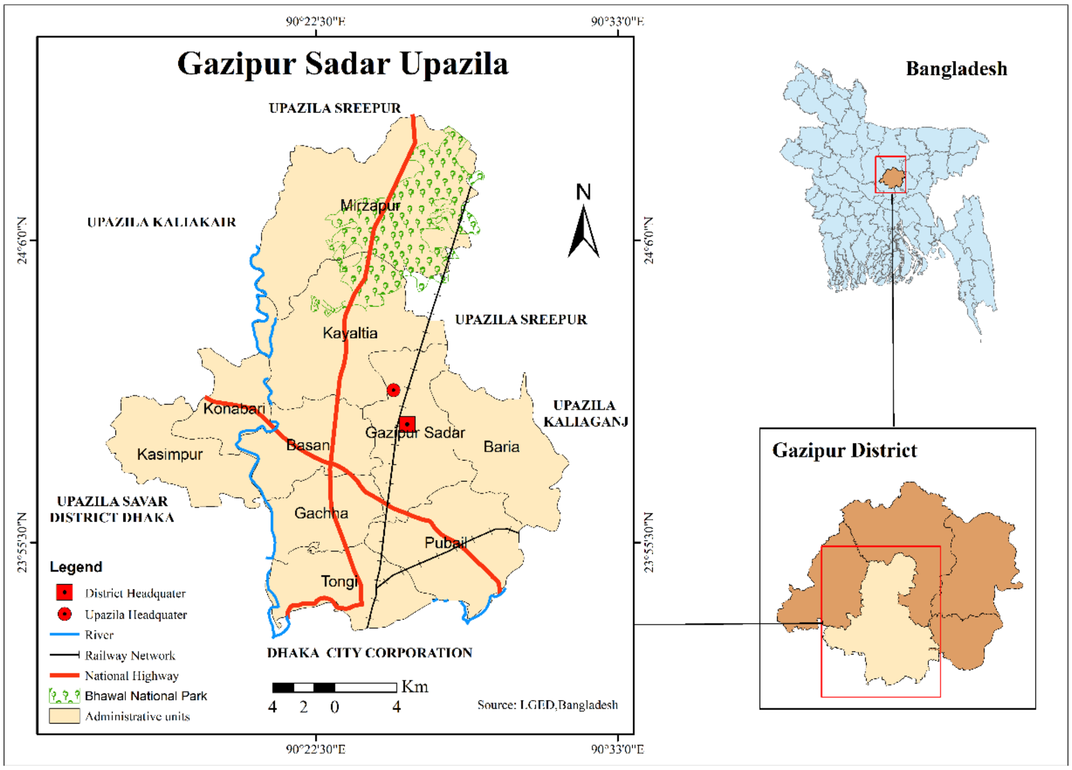

Fig. 1. Study area map

2.2 Sources of Data

This study employs both spatial and non-spatial data from primary and secondary sources, which include remotely sensed data, population data, air quality data, and expert opinions. The following table (Table 1) demonstrates the overall description of the secondary data.

Table 1. Description of the collected data

Data Type	Year of data	Data source
Landsat imagery	2001, 2011, 2021	USGS (https://earthexplorer.usgs.gov/)

Population Data	2001, 2011	Bangladesh Bureau of Statics (BBS)
Air Quality Data	2014 to 2021	Department of Environment (DoE), GoB

2.3 Satellite Image Selection and Pre-processing

Landsat satellite images are regarded as an effective tool for detecting and assessing environmental changes owing to their intermediate spatial resolution and accessibility to long-term data. Landsat 5 (TM) and Landsat 8 (OLI) satellite imagery with 30 m resolution (except band 6 of Landsat 5 as well as bands 10 and 11 of Landsat 8) were obtained from the USGS (United States Geological Survey) website for 2001, 2011, and 2021 in accordance with predetermined paths and rows for the study area. To obtain cloud-free images, dry seasons were designated. The obtained imagery was in GeoTIFF format with a minimum amount of cloud cover (less than 10%) and projected to Universal Transverse System UTM Zone 46 of WGS 1984 (World Geodetic System). To obtain the bottom-of-atmosphere reflectance, the top-of-atmosphere (TOA) reflectance values of the imagery were transformed by atmospheric modification using ENVI (Environment for Visualizing Images) software [22].

2.4 Spectral Indices

In remote sensing, various indices are used to perform change detection. Two remote sensing-based indices were used in this analysis: NDVI and IBI. These indices generate values ranging from -1 to +1. This combination makes use of different spectral responses of built-up areas as well as different types of land cover [23]. NDVI is a widely used index in remote sensing [24]. A positive NDVI value represents high vegetation, whereas water and built-up areas represent negative and near-zero values [23]. According to [25], NDVI is given as:

$$\text{NDVI} = \frac{\text{NIR-Red}}{\text{NIR+Red}} \qquad (1)$$

An index-based built-up index was constructed by merging the NDBI, NDVI, and MNDWI indices to improve built-up extraction from other structural features. A larger positive IBI value represents built-up areas, whereas negative and zero values represent undeveloped areas [26]. According to [27], IBI is given as:

$$\text{IBI} = \frac{[\text{NDBI-(NDVI+MNDWI)}/2]}{[\text{NDBI+(NDVI+MNDWI)}/2]} \qquad (2)$$

A user-defined approach was used to analyze the NDVI and IBI values for extracting vegetation cover and built-up area. The extracted land cover was used to estimate the green space and built-up in each area in Gazipur Sadar Upazila (Fig. 3b and Fig. 4) using a field calculation tool in ArcGIS software.

2.4.1 Accuracy Assessment

The integrity of a defined land cover is determined by its accuracy. To accomplish this assessment, approximately 100 random sample points were selected from classified images of NDVI and IBI of the respective years. Those sample points were validated through Google Earth Pro as a reference map for assessing the ground truth. To condense the results, a confusion matrix was created, which was then utilized to build the following assessments: user accuracy, producer accuracy, overall accuracy, and Kappa coefficient [15]. A Kappa value greater than 0.75 indicates intense classification accuracy, whereas a kappa value less than 0.40 signifies subordinate accuracy [15].

$$\text{User Accuracy}=\frac{\text{Number of correctly classified pixels in a category}}{\text{Total number of classified pixels of that category driven from reference data}}\times 100 \quad (3)$$

$$\text{Producer Accuracy}=\frac{\text{Number of correctly classified pixels in a category}}{\text{Total number of classified pixels of that category driven from reference data}}\times 100 \quad (4)$$

$$\text{Overall Accuracy}=\frac{\text{Total number of corrected pixel}}{\text{Total number of reference pixel}}\times 100 \quad (5)$$

$$\text{Kappa}=\frac{(\text{Total sample}\times\text{Total Corrected pixel})-\sum(\text{Ref. pixel total}\times\text{Classified Pixel total})}{(\text{Total sample}^2)-\sum(\text{Ref. Pixel total}\times\text{Classified Pixel Total})} \quad (6)$$

2.5 Analysis of Population Data and Air Quality Data

The quality of an area's urban environment can be ascertained by its population density, air quality, and abundance of vegetation [28]. The air quality index (AQI) is a method for assessing daily air quality in any city or continent [29]. It reveals whether the air is clean or contaminated, as well as the potential health implications for the general public. In Bangladesh, AQI comprises five particulate pollutants: ozone, NO_2, CO, SO_2, and particulate matter ($PM_{2.5}$ and PM_{10}) [30]. To conduct this study, population and air quality data were used to determine temporal fluctuations in environmental quality. A time series of AQI data from 2014-2021 was acquired from the Clean Air and Sustainable Environment project by the Department of Environment, GoB, and population census data for 2001 and 2011 were collected from the Bangladesh Bureau of Statistics census report [21, 31]. For temporal change detection, population data of 2021 and air quality data of 2001 and 2011 were predicted through the linear regression method for this research.

$$Y = a + bx \quad (7)$$

Here, x indicates the time series for both types of data, and y indicates the population for the prediction of population data. For air quality data prediction, y is used to represent air quality data. B represents the slope of the linear regression line, and a represents the y-intercept of the regression line [32, 33].

$$\text{The slope of the regression line, } b = r\frac{S_Y}{S_X} \quad (8)$$

The intercept of the regression line, $a = \bar{Y} - b\bar{X}$ (9)

$$\text{Coefficient Correlation, } r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2 \sum(Y-\bar{Y})^2}} \quad (10)$$

$$\text{Standard Deviation of x, } S_X = \sqrt{\frac{\sum(X-\bar{X})^2}{n-1}} \quad (11)$$

$$\text{Standard Deviation of y, } S_Y = \sqrt{\frac{\sum(Y-\bar{Y})^2}{n-1}} \quad (12)$$

2.6 Techniques of Spatial Zoning

Spatial zoning is a process of segmentation of a heterogeneous area based on homogeneous characteristics [34]. This approach ensures that each designated area has a uniform character, facilitating more organized and effective planning and development [35]. Spatial zoning was done based on certain criteria or variables listed in Table 2 from RS analysis, and existing literature. The criteria were validated by expert opinion.

Table 2. Approach of spatial zoning

	Consideration	Source
Literature Review	Major Industry	[36]
	Forested Area	[37], [18]
	Urban Growth	[5], [17], [19]
	Change in Agricultural Land	[16], [38]
Primary Data	Expert Opinion	Interviews
Analytical Data	Population Growth	Author
	Change in Green Space	
	Change in Built-up Area	

2.7 Environmentally Critical Areas Identification

Since vegetation is a reliable indicator of environmental quality, it promotes the living standards of the respondents living in a territory [7]. The estimated dimensions of green space per capita were determined by dividing the amount of vegetation by the population of each area. Statistical analysis was carried out to determine environmental criticality with regard to the quality of the environment in Gazipur Sadar Upazila. For the assessment, index-based maps were developed for the respective years through the amount of vegetation, air quality index data, vegetation per capita, and population density [39]. Two EQI indices are listed in equations 13 and 14. Areas that contain low densities of vegetation and poor air quality, as determined by these EQI index 1 (equation 13), will obtain lower values and therefore can be designated as extremely critical areas. Consequently, in EQI index 2, (equation 14) places that have dense populations and lower per capita green space will have lower values, and therefore may be regarded as critical areas. According to this method, lower index values imply a high level of criticality with low quality of the environment that is inapt for human habitation; conversely, a higher index value indicates lower criticality with compatible environmental quality that is appropriate for the habitation of humans [7].

$$\text{EQI Index 1} = \frac{\text{Amount of Vegetation}}{\text{Air Quality Index Value}} \tag{13}$$

$$\text{EQI Index 2} = \frac{\text{Green Space Per Capita}}{\text{Population Density}} \tag{14}$$

The whole study was conducted under the following methodological framework (Fig. 2):

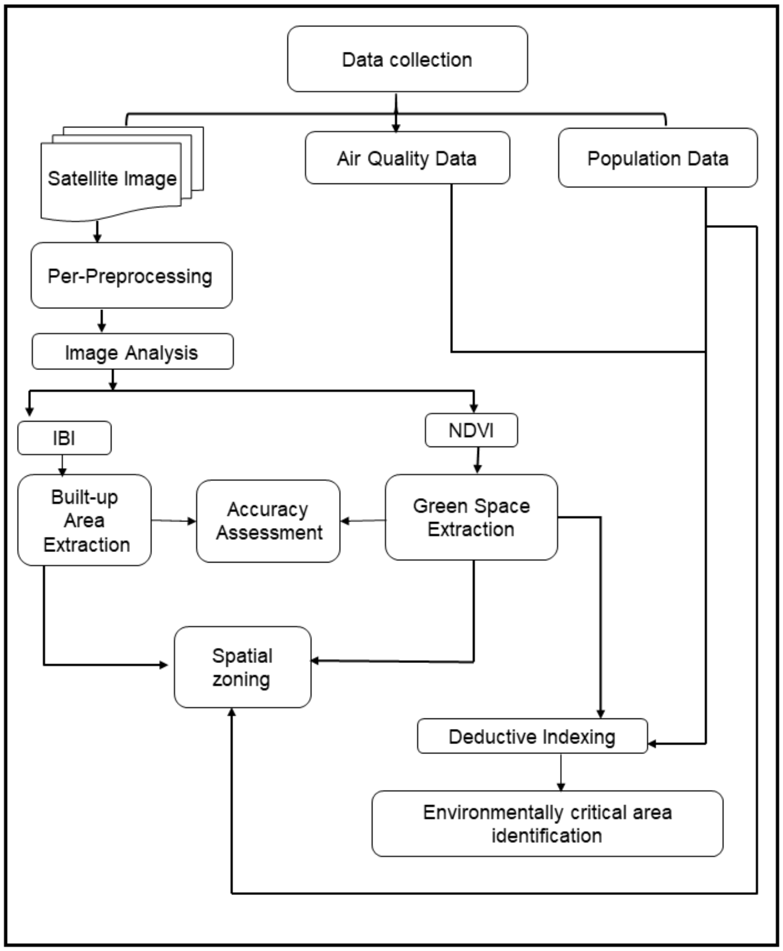

Fig. 2. Methodological framework

3. RESULTS AND DISCUSSION

3.1 Change in Green Cover

The extracted green cover map from NDVI, demonstrated satisfactory accuracy assessment results as shown in Table 3.

Table 3. Accuracy assessment of the green space map driven by NDVI

Year	Classification	User Accuracy	Producer Accuracy	Overall Accuracy	Kappa Coefficient
	Green Space	91.83%	95.74%	94%	

2001	**Other land cover**	96.07%	92.45%		0.87
	Green Space	88.46%	100%		
2011	**Other land cover**	100%	88.88%	94%	0.88
	Green Space	88%	88%		
2021	**Other land cover**	88%	88%	88%	0.76

The subsequent figure and table (Fig. 3a and 3b and Table 4) illustrate the change in green space that was assessed for each area in Gazipur Sadar Upazila. The following figure (Fig. 3a) shows that the highest NDVI value (0.88) was found in 2021 compared to 2001 (0.82) and 2011 (0.83) which indicates a slow increase in green cover. From 2001 to 2021, vegetation in the entire area has increased by around 42 percent. The Bhawal National Park in Gazipur, the largest natural reserve forest of Bangladesh [40] impacted the proportion of vegetation cover in the area. Due to the existence of a natural reserve forest, Mirzapur has a higher percentage of greenery than other areas.

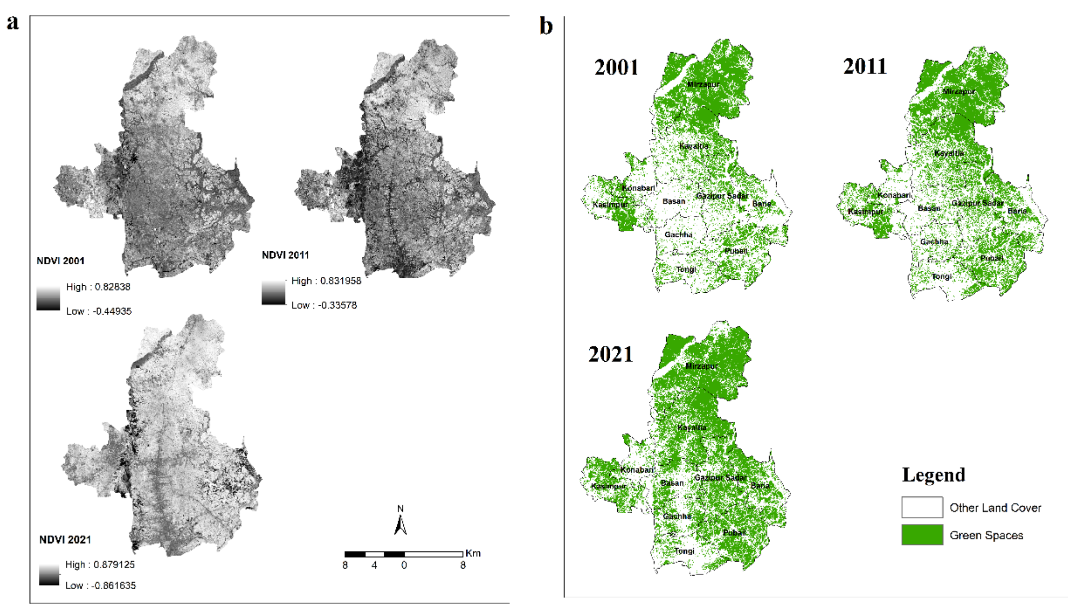

Fig. 3. Distribution of green space (a) NDVI maps of Gazipur Sadar Upazila (b) Extracted Green space from NDVI.

The temporal analysis shows (Table 4) a fluctuation in green space over the last two decades. During the study period, the green space increased significantly by more than 15%

in Kayaltia, Pubail, and Gazipur Sadar and nearly 10 percent of green space flourished in Baria, Basan, and Gaccha Union. Furthermore, Mirzapur and Kasimpur Union show a modest increase in vegetation more than 5 percent. Although green space has flourished in most areas Tongi and Konabari Union lost their green space by 0.5 and 0.3 percent.

Table 4. Amount of green space in Gazipur Sadar Upazila

Area	Vegetation area (Km^2)			Change (Km^2)		
	2001	2011	2021	2001-2011	2011-2021	2001-2021
Tongi	7.81	7.06	7.47	-0.75	0.41	-0.34
Gazipur Sadar	13.80	18.40	25.31	4.59	6.91	11.50
Mirzapur	69.43	68.92	72.53	-0.50	3.61	3.10
Kayaltia	27.06	34.33	45.84	7.27	11.51	18.78
Konabari	5.69	5.07	5.46	-0.62	0.39	-0.23
Basan	3.24	5.57	12.13	2.32	6.56	8.88
Gaccha	2.57	5.43	9.83	2.86	4.39	7.25
Baria	12.6	17.06	23.34	4.46	6.28	10.75
Pubail	17.31	24.59	30.41	7.28	5.82	13.09
Kasimpur	14.89	15.32	16.91	0.43	1.58	2.01

Another significant cause behind the increase in overall vegetation cover of the area is the accelerated growth of agricultural land [5, 17]. In addition, homestead vegetation (grows for economic activities related to population growth) common phenomenon in Bangladesh, contributes to the vegetation growth in this area besides natural or forested vegetation [5].

3.2 Change in Built-Up Area

The built-up area map created from IBI demonstrated a permissible result of accuracy assessment, represented in Table 5**.**

Table 5. Accuracy assessment of built-up area map driven by IBI

Year	Classification	User	Producer	Overall	Kappa

		Accuracy	Accuracy	Accuracy	Coefficient
	Built-up	86.93%	97.56%		
2001	Non-built-up	98.14%	89.83	93%	0.85
	Built-up	80%	88.88%		
2011	Non-built-up	90%	81.81%	85%	0.70
	Built-up	75.47%	95.83%		
2021	Non-built-up	5.74%	81.81%	91%	0.80

According to the built-up map (Fig. 4 and Fig.5), urban areas are expanding rapidly in the south and north-western regions. The central portion of Gazipur Sadar Upazila experiences the most prominent growth of urban land cover. Due proximity to Dhaka city, results in the growth of urban sprawl in the southern part than the northern part.

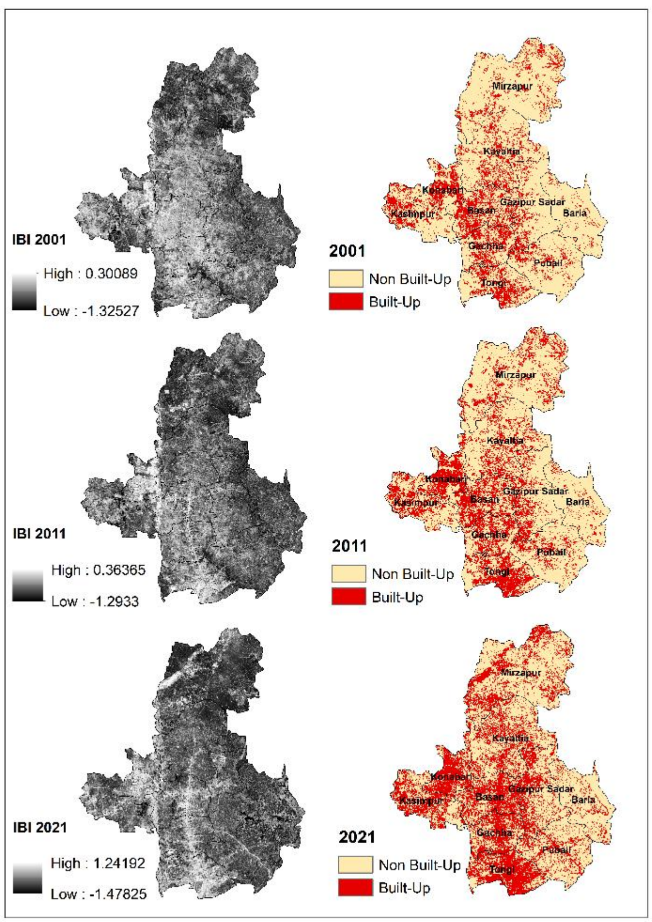

Fig. 4. Extracted built-up area using IBI

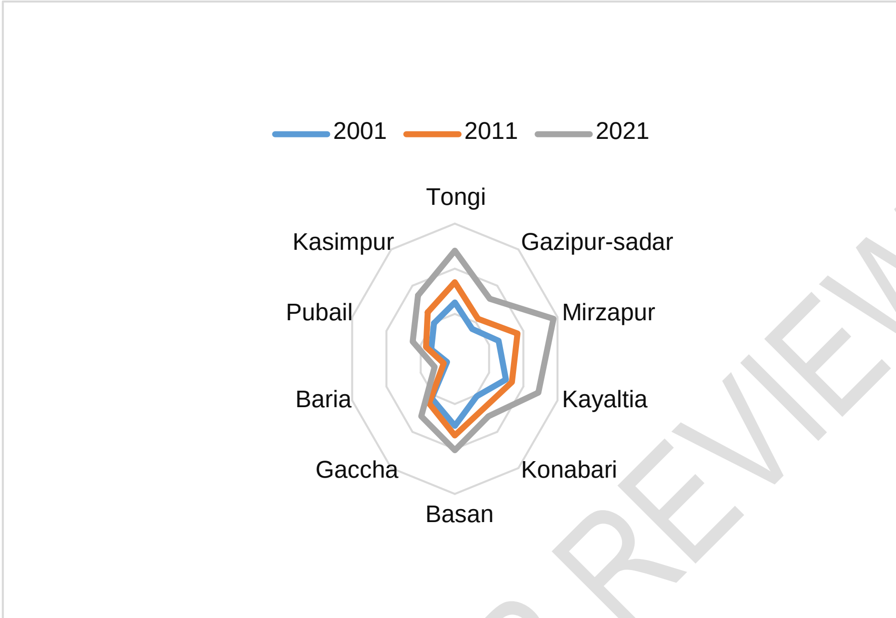

Fig. 5. Urban growth direction

The following table (Table 6) shows that the built-up area gradually increased at a double rate from 2001 to 2021. Approximately 77.7 km^2 of the built-up area has increased over the last two decades. During the time period, the built-up area increased significantly by more than 5% in Baria, Basan, Gaccha, and Pubail Union. Meanwhile, the urban growth rate is higher than 7% in Konabari and Kasimpur Union. Furthermore, nearly 10% of the built-up area increased in Tongi, Gazipur-Sadar, and Mirzapur Union. The increase in the built-up area affects agricultural land in this area [5, 16, 41]. Population growth and industrialization are the primary stimuli to increase impervious land cover in an area [38]. The proliferation of industrial activities over time emerges as new employment opportunities; for this reason, people migrate to these regions for their livelihood and in pursuit of a better way of life, which contributes to enhancing settlement in these areas [18]. In addition to this, better environmental quality, educational facilities, and health services also influence migration to this area which contributes to urban growth [5, 19].

Table 6. Built-up area change

Area	Built-up area (Km^2)			Change (Km^2)		
	2001	**2011**	**2021**	**2001-2011**	**2011-2021**	**2001-2021**
Tongi	12.5	17	24	4.5	7	11.5

Gazipur Sadar	8.2	11	16.5	2.8	5.5	8.3
Mirzapur	12.8	18.3	28.8	5.5	10.5	16
Kayaltia	14.9	16.7	24.4	1.8	7.7	9.5
Konabari	10.3	13.6	15.8	3.3	2.2	5.5
Basan	14.9	17	20.3	2.1	3.3	5.4
Gaccha	10.9	12.2	15.8	1.3	3.6	4.9
Baria	2.3	3.2	5.9	0.9	2.7	3.6
Pubail	6.9	8.4	12.3	1.5	3.9	5.4
Kasimpur	9.8	12.8	17.4	3	4.6	7.6

3.3 Spatial Zoning

After evaluating various elements including industrial presence, forest cover, agricultural status, urban growth, and geographical features the study area was classified into three zones. Zone 1 is referred to as an industrial and manufacturing zone, Zone 2 is referred to as a forested zone, and Zone 3 is referred to as a neutral zone (Table 7 and Fig. 6).

Table 7. Zone-specific factors

Spatial Zone	Factors
Zone 1: Industrial and manufacturing zone	Major industries
	Urban growth
	Extent of vegetation
	Population density
	River
	Road network
Zone 2: Forested zone	Madhupur Bhawal
	Population density
Zone 3: Neutral zone	Low industrial activities
	Urban growth

	Agricultural activities
	Vegetation percentage

Zone 1 (the industrial and manufacturing zone) is situated along the Turag River. This zone includes Tongi, Konabari, Basan, Gaccha, and Kasimpur Union. The areas in Zone 1 have high population density, a high urban growth rate, and a low amount of green space. This zone serves as the main hub for businesses, industries, and employment. Industrial and manufacturing activities in this zone are influenced by its physical location, proximity to Dhaka City, and location of the Turag River. On both banks of the Turag River and in the western and southern sites, many brick kilns were established [42]. There are around 1,500 garment factories situated in the Gazipur Sadr Upazila, and the majority of them are in Zone 1 [43]. In addition to the garment industry, Gazipur also has other industries, including industries like textile, aluminum, leather, pharmaceuticals, food processing, building materials, and so on [42]. Tongi, Konabari, and Kasimpur are the primary industrial hubs in this zone [36, 44, 45].

Zone 2 (Forested zone), consisting of Mirzapur Union, is located in the north of Gazipur Sadar Upazila. This northern site is a part of Madhupur Bhawal Garh, formerly known as Bhawal National Park in Gazipur [40]. Due to the existence of Bhawal National Park, the magnitude of green cover in this zone is higher compared to other zones.

Zone 3 (neutral zone), which includes Gazipur Sadar, Pubail, Baria, and Kayaltia Union, is situated in the southeast. Compared to the areas of Zone 1, this zone has less industrial activity, a lower population density, and a greater amount of green space. Most of the agricultural activity is concentrated in Zone 3 [16, 38]. Additionally, green space gradually increases with population growth in this zone.

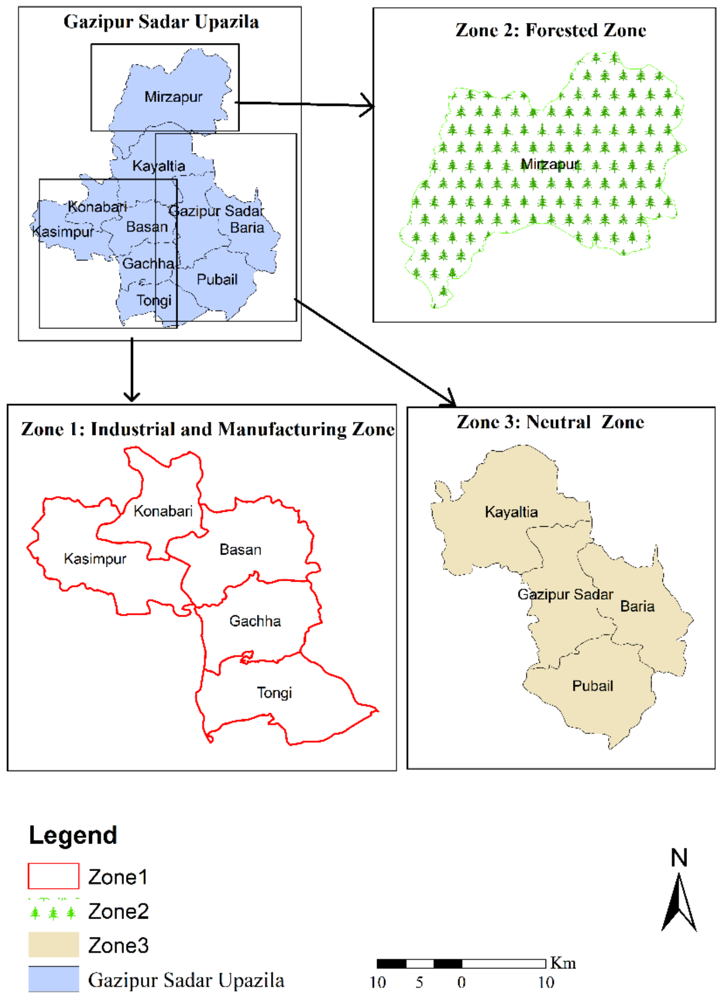

Fig.6. Spatial zoning of Gazipur Sadar Upazila

3.4 Environmental Criticality Analysis

Environmental criticality is a measure of the quality of the environment [39]. It was analyzed through population, green space distribution, and air quality index data. According to the temporal projection of the demographic data (Table 8) of Gazipur Sadar Upazila, the population is growing rapidly over time. A higher population density is found in Tongi, Gaccha, and Konabari Union. Since these areas are commercial hubs of Gazipur, people reside in these areas, which leads to an increase in slums, residential dwellings, and infrastructure. The green space per capita map (Fig. 7 and Table 9) shows that per capita vegetation has declined since 2001. During 2001, the per capita green space range was approximately 30-958 m^2, but this diminished to 14-506 m^2 in 2011 and 10-713 m^2 in 2021 as the population grew with time. Regarding other Asian cities, such as Colombo, which has a per-person green space ranging between 3-70 m^2 [7], the study area has an elevated amount of green space.

Table 8. Existing and predicted population density of Gazipur Sadar Upazila

Area	Population density (km^2)			Change in percentage
	2001	2011	2021	2001-2021
Tongi	8011	14854	21278	23.55
Gazipur Sadar	2519	3673	4827	4.09
Mirzapur	834	1848	2861	3.59
Kayaltia	904	1654	2404	2.66
Konabari	2838	9195	15553	22.57
Basan	2004	5200	8398	11.35
Gaccha	2366	8858	15353	23.05
Baria	857	832	807	-0.08
Pubail	1131	1676	2220	1.93
Kasimpur	1142	3194	5247	7.29

Table 9. Green space per capita of Gazipur Sadar Upazila

	Green Space Per Capita (m^2)		
Area	2001	2011	2021
Tongi	30	14	10
Gazipur Sadar	112	102	107
Mirzapur	958	429	291
Kayaltia	429	297	273
Konabari	90	24	15
Basan	56	37	50
Gaccha	38	21	22

Baria	362	506	713
Pubail	317	304	284
Kasimpur	308	113	76

The analysis also revealed that, comparatively (Table 10) among the three zones, zone 1 experienced a significant decrease in per capita green space. Among the areas of Zone 1 in Tongi and Konabari Union, it decreased significantly which is almost the range of minimum green space per capita by WHO. Compared to 2001, Tongi's vegetation per capita decreased from 30 m^2 to 14 $m^{2,}$ and Konabari's decreased from 90 m^2 to 24 m^2 in 2011. In Tongi and Konabari, the project green space per capita in 2021 was 10 m^2 and 15 m^2, respectively, if population growth and vegetation loss continue at their current rates (Table 9).

Table 10. Zone-specific green space per capita

	Green space per capita (m^2)		
Zone	**2001**	**2011**	**2021**
Zone 1: Industrial and manufacturing zone	69	31	26
Zone 2: Forested zone	958	429	291
Zone 3: Neutral zone	257	230	230

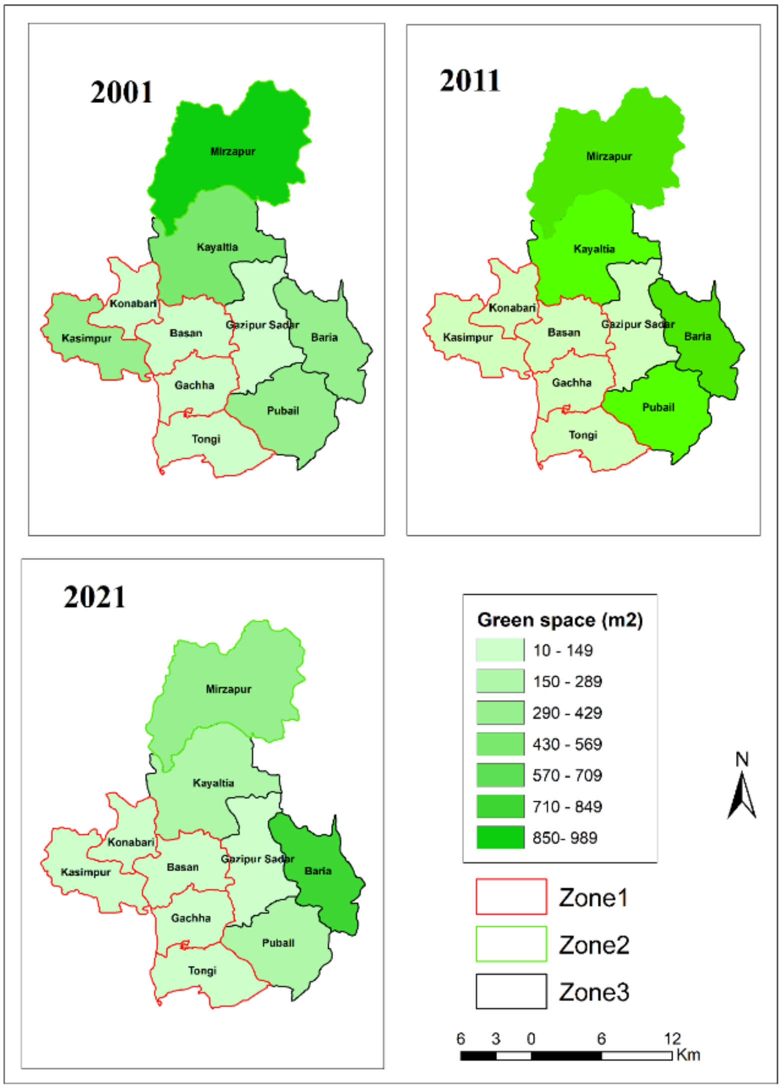

Fig. 7. Green space per capita map of Gazipur Sadar Upazila

Urban green space enhances the sustainability of the environment by removing greenhouse gases from the atmosphere as well as improving air quality by purifying pollutants [7]. Urban regions exhibit greater concentrations of gaseous pollutants because of industrial activities, vehicle exhaust, and domestic activities. Due to the concentration of various industries, the quality of the air in Gazipur is deteriorating. Due to being a business district a number of industrial activities have grown up nearby in Gazipur, and the use of both public and private transportation worsens the air quality by releasing harmful substances such as CO_2, NO_2, PM_{10}, $PM_{2.5}$, SO_X, and others into the environment [46]. The quality of the urban environment deteriorates with increasing population and pollution levels. Map of the scale of environmental criticality based on air quality, green cover, and population density were created using the derived EQI index 1 and 2 (equations 13 and 14). The map (Fig. 8) based on air quality and vegetation demonstrated that the criticality increases over time. Additionally, the following figure (Fig. 8) indicated that Tongi and Konabari Union, which are regarded as industrial and manufacturing zones (zone 1), had a lower index value in 2021. The lower index values of Tongi and Konabari indicate a high rate of criticality with low quality of the environment. Similarly, the environmental criticality map (Fig. 9) based on per capita green space and population density determined that index value decreases over all the areas. In addition, it is assessed that compared to other zones low index value is found in Zone 1 which indicates the low quality of the environment.

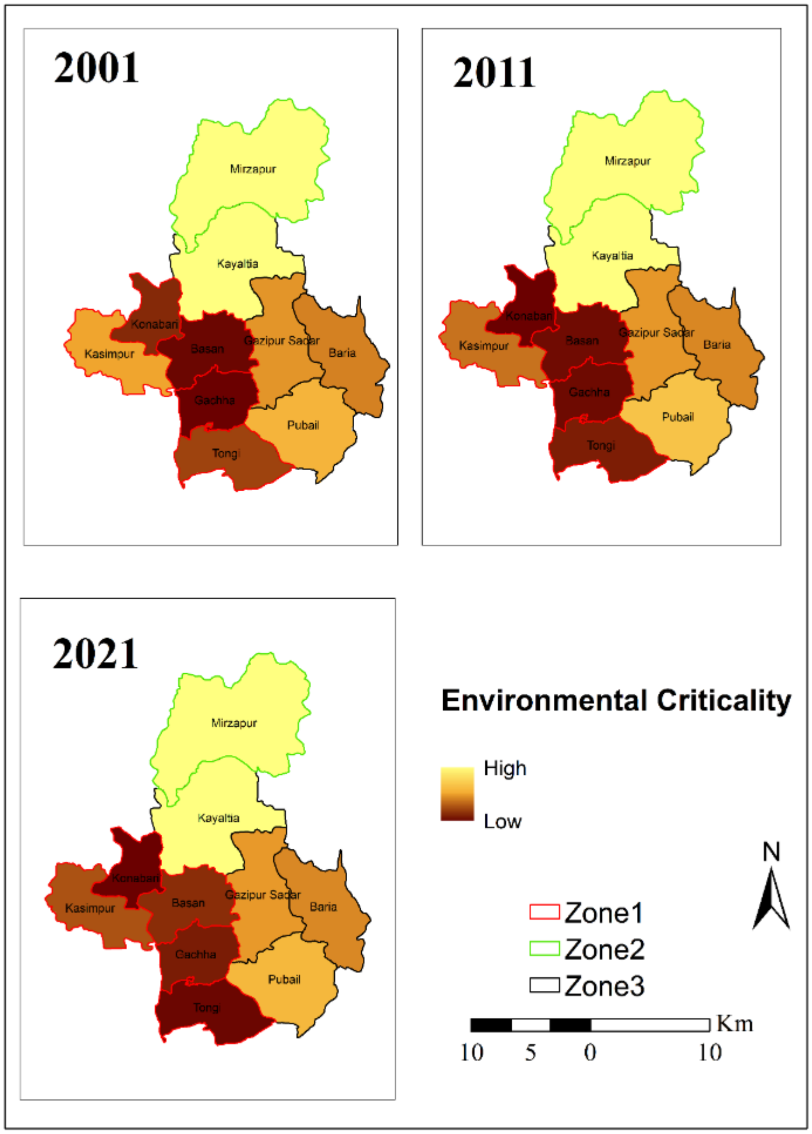

Fig. 8. Scale of environmental criticality based on vegetation and air quality

From 2001 to 2011, environmental criticality increased from 2 to 4 areas in Zone 1, and critical areas will increase to 5 areas if population density grows, and natural space deteriorates over time.

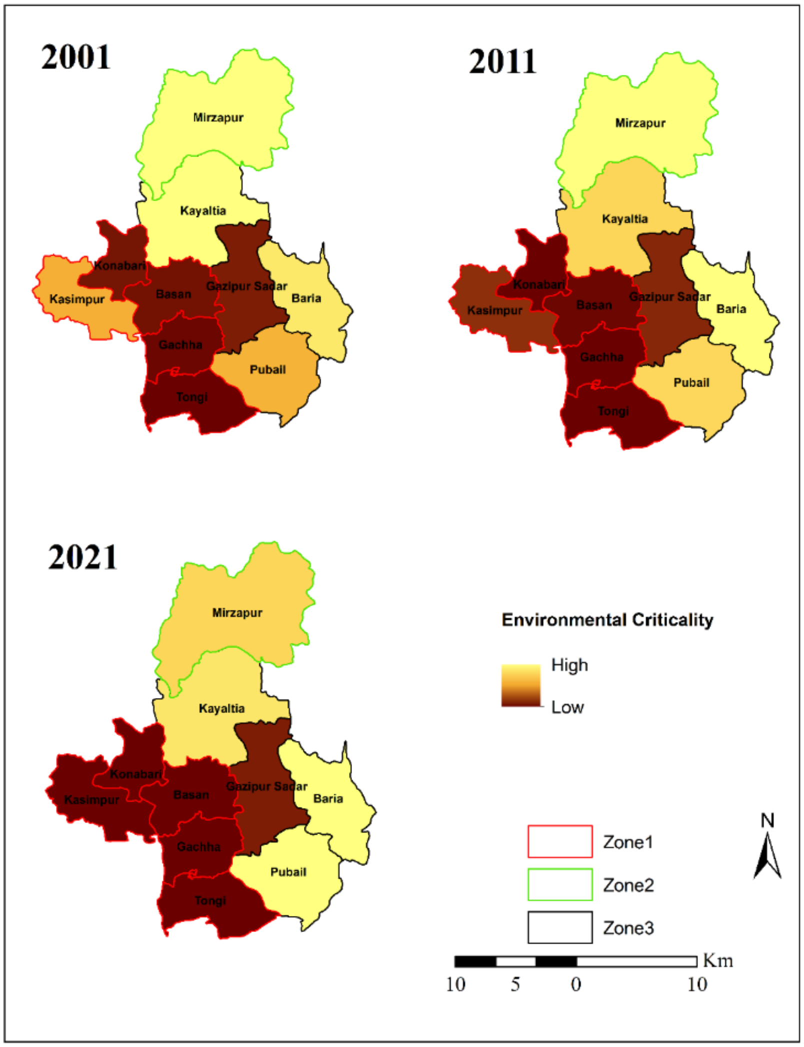

Fig. 9. Scale of environmental criticality based on vegetation and population density

According to the overall assessment, among the areas of Zone 1 Tongi and Konabari witnessed the highest rates of urban expansion and population growth, reducing the concentration of green space. The reduction in green space lowers air quality and, in general, environmental quality. Consequently, these two areas are regarded as highly environmentally critical areas. In conclusion, urbanization is associated with unstructured settlements that decrease the quantity of green cover. In high-risk areas, decisive action is required to eliminate risks and ensure citizens' standard of living, and effective urban planning is required for any ongoing development initiatives to preserve the environment's quality.

4. CONCLUSION

It is apparent that the urbanization of Gazipur has accelerated over time. Throughout this study, a spatiotemporal dataset was utilized to assess urban land and green cover in

Gazipur Sadar Upazila between 2001 and 2021, which assisted in the zoning of the area and analyzing environmental criticality. In this study, index-based analysis demonstrates growth in both built-up areas and vegetation cover. During the study period, green space has increased by approximately 74.79 $km^{2,}$ and built-up has increased by around 77.7 km^2. The study area has been divided into three zones based on criteria-based spatial zoning approach. Zone 1 is considered an industrial and manufacturing zone as most of the industries are situated in this zone. Population density and urban growth rate are comparatively higher in this zone with relatively decreasing greenery. Due to the substantial amount of green space and the presence of Bhawal National Park, Zone 2 is considered as a forested area with no industrial activity. This space is characterized by a very low population and vegetation growth. Zone 3 is regarded as a neutral zone due to the little to neutral increase in urbanization and population density, and comparatively lower industrial activity. Additionally, Zone 3 experienced an increase in green space. With the growth of the population, the minimum green space per capita diminished from 30 m^2 to 10 m^2 from 2001 to 2021. Per capita green space has decreased comparatively in Zone 1. This study reveals increases in environmental criticality and identifies highly critical areas over time. According to the analysis, among the 3 zones lower index values have been found in Zone 1 which indicates high criticality with low environmental quality. This study manifested that the areas with dense vegetation cover and low population density possessed a better quality of environment than the areas with sparse vegetation cover and high population density. Pursuant to the overall assessment, two areas of Zone 1 are considered to be critical areas since they have witnessed rapid urban growth and a decline in green cover, which have deteriorated the environmental standards in these areas. This study focuses the attention of urban planners and policymakers on prospective zonal planning of the area considering the environmental issues that affect the sustainability of this area. Lacks of updated demographic and AQI data influence the result of the study to some extent. An integrated study with higher resolution satellite data, continuous demographic and environmental quality indicative data, and an in-depth field study would have opened new insights into such kind of study.

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