Chapter 7
Spatiotemporal Variability of Urban Greenspace and Surface Temperature in Dhaka City: A Public Health Aspect

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Abstract Urban greenspaces can affect the physical and mental health of city residents and they can also contribute to improving urban environmental quality in ways that can benefit human health. Dhaka, a megacity with over 22.4 million residents, has progressively lost its greenspace over the past decade as the city has grown and urbanised. This study evaluates the availability and accessibility of greenspace considering its population and residential areas, as well as assessing the changes to greenspace in the last 30 years throughout the city. We utilized secondary data from the 2011 Census and areal imagery to perform the analysis for city wards, the smallest administrative unit, using ArcGIS software. We generated geospatial maps of greenspace distribution and accessibility as well as vegetation, land surface temperature and humidity in different years. Accessibility to greenspace was measured with 100-meter and 300-meter buffer zones, and a total of 56.5 square kilometers area of 77.47 square kilometers of residential area fell under these territories. Changes in vegetation were obtained using Normalized Difference Vegetation Index (NDVI) for the years 1990, 2000, 2010, and 2020, and a high level of loss in vegetation was observed. Land Surface Temperature (LST) and Normalized Difference Moisture Index (NDMI) were used to assess the temperature and humidity for the same years. We measured that Dhaka has 2.24% greenspace coverage and only 2 wards out of 110 have greater than 20% greenspace coverage. A highest estimate of 0.003207 square meter per capita greenspace was found at ward-46, which does not even meet the minimum health standard. Increased temperature and decreased humidity were observed in Dhaka city from 1990 to

This work is supported by Drexel University.

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N. Biloria et al. (eds.), *The Empathic City*, S.M.A.R.T. Environments,
https://doi.org/10.1007/978-3-031-32840-4_7

2020, in a level that may adversely impact on the city population's public health. We found a high correlation between NDVI with LST and NDMI. In 49% of wards, vegetation and humidity decreased, whereas temperature increased. This study provides noteworthy information on the lack of greenspace throughout Dhaka city. The spatial distribution of greenspace provided in the study has the potential to be useful in taking measures for improving sustainable greenery management in the city area and the health of Dhaka's growing population.

Keywords Greenspace change · Urban public health · Spatial analysis · Availability · Dhaka city

7.1 Introduction

Urbanization is a highly dynamic process, while greenspace is a key to maintaining urban sustainability. Green or open space(s) generally can be defined as forests, gardens, parks, or grasslands (Zhang et al., 2017), which are either public or private. Open spaces covered with greenery or croplands used for agriculture can also be considered as greenspace within the urban territory (Helbich, 2019). Generally, urban nature exists in the form of public parks, reserved forests, playgrounds, or other open spaces that offer various services and activities for people living nearby. The accessibility to these green and open spaces offers city dwellers an opportunity to get in touch with nature which ultimately may assist them to maintain and improve their physical and mental health (Huang et al., 2017; Shoari et al., 2020). Greenspaces have therefore been, considered by many researchers as beneficial to the city's public health and for wider benefits (Liu et al., 2021).

There are diverse health benefits derived from greenspace usage by people of and at different ages. These are the sources of mental satisfaction for the people living in residential areas (Tsai et al., 2018), engaging in workplace, or studying in educational institutions. The opportunity to spend time and play in the open space and greenery helps to strengthen the physical development and cognitive growth of the children (McCormick, 2017; Vanaken & Danckaerts, 2018). Additionally, it brings tangible benefits inpreventing diseases and conditions like obesity (Huang et al., 2017), depression (Helbich et al., 2018a, b), adverse birth outcomes (Ebisu et al., 2016), diabetes, suicidal tendencies (Helbich et al., 2018a, b), mortality (Mitchell & Popham, 2008), respiratory diseases, etc. Numerous contributions of open space have been identified as beneficial for elderly people to help maintain emotional wellness as well as a well-balanced physical health despite of their age (Kardan et al., 2015; Gong et al., 2016).

Major importance has been given to the contributions of greenspace in controlling heat and the humidity balance of the air that are linked with transporting harmful microorganisms playing an important role in disease emergence, dissemnination and, also, creating a pandemic like the present time. Furthermore, greenspace or open areas provide a wide door to the sense of freedom and recreation in stressful urban environments (Zhang et al., 2017; Walawalkar, 2020). It supports different social gatherings and activities, festivity celebrations, holiday amusements, and recreation for all classes of people. As a result, it becomes a key mean of socialization (De Vries et al., 2013; Rahman & Zhang, 2018), broadens people's social networks, and strengthens unity within the community (Chiesura, 2004). Open spaces also support the practice of sports, cultural activities, hobbies, and creative learning that help in the skills development of people engaged in different professions. This is why it is very necessary to maintain a specific and quantifiable proportion of greenspace for all the residents of the city that is within reach.

Greenspaces have various roles in securing a healthy environment for the city too. They can make a contribution in improving soil quality and reducing soil erosion (Meo et al., 2021). Green vegetation helps maintain the surface temperature(s) by controlling the heating of the atmosphere (Marković et al., 2021); thus, fighting against climate change, and slowing or stopping cities from turning into urban heat islands (Wan et al., 2004; Liu et al., 2021). In addition, it refines the air quality, helping to protect the urban region and its population from exposure to air pollution (Yang et al., 2015; Kothencz et al., 2017; Gill et al., 2007; Bowler et al., 2010). It contributes to reducing noise pollution from the nearby areas (Cohen & Sherman, 2014) and associates with humidification, asepsis, which is beneficiary for human, animal, and plant health.

Additionally, there is a huge contribution of greenspace towards biodiversity (Schuch et al., 2017) that works as the domicile for the living beings and supports the food chain as well as the ecosystem which is very necessary for the sustainable future of the city landscape. For such contributions, promoting greenspace in urban areas has become a concern globally. In fact, United Nations extended its agenda for urban areas to ensure a sustainable environment for their human settlements as a part of the sustainable development goals (SDG 11) (Rahman & Zhang, 2018). It shows the necessity of preserving green nature in the developing world for the wellbeing of the urban people. Overall, greenspaces in the urban area contribute to creating a healthy biological community and to improving the prosperity of the city's people (Landers & Nahlik, 2013). The proper and appropriate distribution of greenspace is thus not only an example of urban area management, but also a need and right for all the people of the city.

In city areas, greenspace offers multiple benefits where the most significant contribution is in offering a sustainable urban health environment to its dwellers. Yet, there has been a failure in Dhaka city to provide access to green areas at different residential locations. This city is the home of many millions of people, alongside whom continuous urban development activities are carried out throughout the city many of which are polluting the environment and hampering the ecology and ecosystem. In such a situation, it is crucial to provide enough greenspace for the people of the city to help them practice healthy activities that enhance their physical and mental wellbeing (Shoari et al., 2020). This is especially so in the scenario of the recent pandemic and outbreak of airborne diseases, where it is important to look at the current status of the city and undertake adequate actions for the betterment if and as needed. To address the existing situation, this study was carried out to assess the availability of greenspace in Dhaka city in respect to its geographic size and population, as well as accessibility from residential areas, and discussed the outcomes while keeping public health aspects in mind. This study also analyzed the changes in vegetation and eco-environmental components namely, temperature and humidity from 1990 to 2020 that have significant impacts on the sustainable health outcomes of the city dwellers. This kind of analysis is about creating relationships between vegetation and temperature and represents a new concept for Dhaka city. Previous studies conducted in this area only focused on the portion of greenspace available or changes in vegetation. However, the availability of greenspaces based on population density in the small administrative area and proximity according to health standards are missing from the existing studies. Moreover, the impact of vegetation changes on the eco-environment has been overlooked until now. Therefore, this study will be valuable for the policy makers and urban planners to take location- specific initiatives for the betterment of the current situation within the city. It will also be useful to identify important existing gaps in the urban greenspace management of Dhaka city.

7.2 Study Area

Dhaka is the capital city of Bangladesh and is characterized by a dense population, many high-rise buildings, and a pattern of continuous urban development activities. It lies in the central part of the country between 23° 42′ N to 23° 54′ N latitude and 90° 20′ E to 90° 28′ E longitude (Byomkesh et al., 2012). The city corporation is divided into Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC), and governs 110 wards as the city's smallest administrative units (BBS, 2011) (Fig. 7.1). There are approximately 22.4 million people in an area of 306.4 square kilometers (https://worldpopulationreview.com/world-cities/dhaka-population). The city is situated on the eastern bank of the Buriganga river and is surrounded by Buriganga, Turag, Tongi, and Balu rivers (Byomkesh et al., 2012). The drainage network of the city was outstanding long ago. In the last few decades, drainage area and open space have been lost enormously due to rapid development activities. The economy of the city is based on industry and a large service sector which attracts rural migrants into the city for their livelihoods. The population increased rapidly with a growth rate of 3.39% in 2022 (United Nations – World Population Prospects, https://population.un.org/wpp/). Such a scenario provokes activities to accommodate all these people within the city's boundary which in their turn are influencing temperature increases (Ahmed et al., 2013). Some of the notable parks and greenspaces in Dhaka are Ramna Park, Suhrawardy Udyan, Chandrima Udyan, Gulshan Park, the national Botanical Garden, and Shishu Park (Rahman & Zhang, 2018), but many other green areas are getting occupied every year, posing a major threat to the sustainable environment of the city.

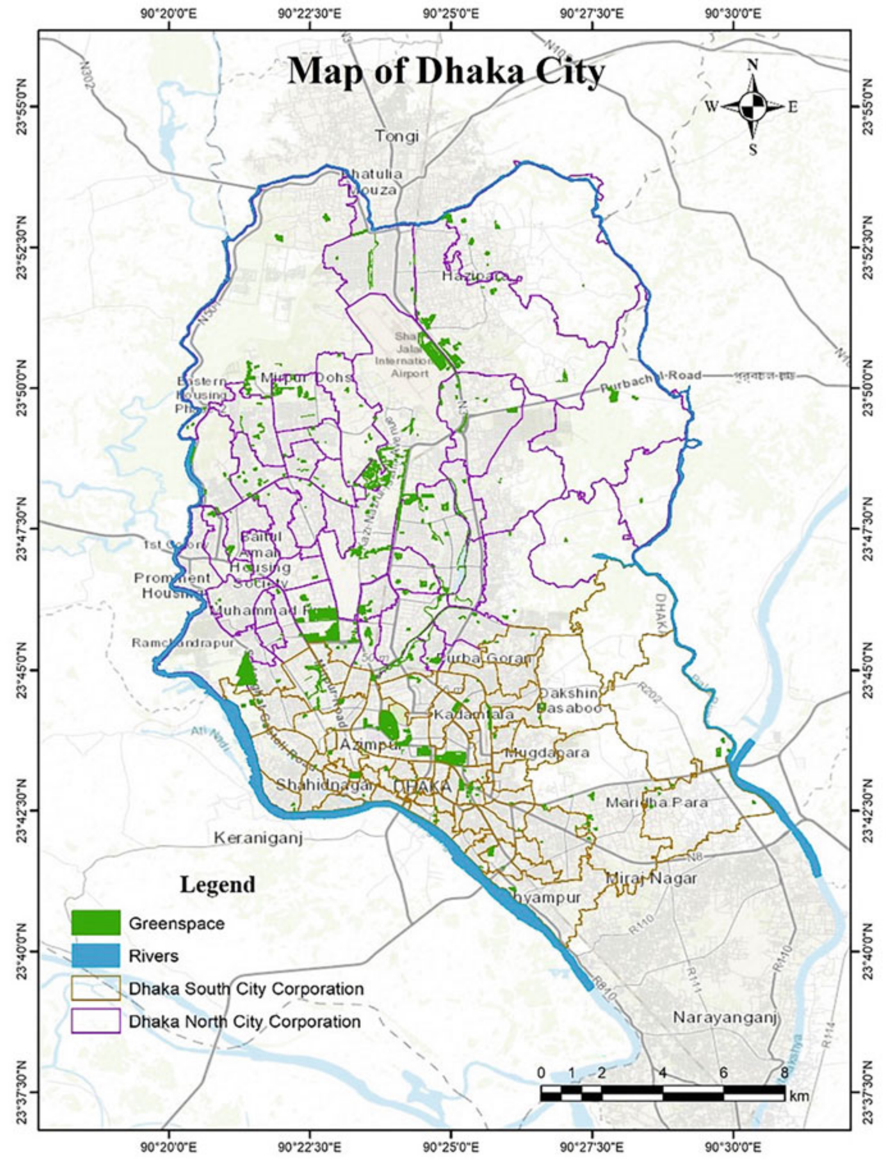

Fig. 7.1 Map of Dhaka City. (Data Source: Survey of Bangladesh)

7.3 Methodology

7.3.1 Data Sources

Geospatial data provided by the World Bank (2018) were used to acquire land use shapefiles for greenspace and residential areas in Dhaka city (https://databank.worldbank.org/). Shapefiles of greenspace was extracted from the land use map and analyzed to calculate ward-wise availability and proximity. Per capita availability of greenspace was calculated using available population data of Dhaka city for the year 2014 (https://databank.worldbank.org/). To detect differences in vegetation, surface temperature, and humidity from 1990 to 2020, open-source remote sensing images were downloaded from United States Geological Survey (USGS) earth explorer (https://earthexplorer.usgs.gov/). Landsat images for Dhaka city are available at a 30 meter resolution from worldwide reference system (WRS) 137 path and 44 row (Nawar et al., 2022), and these images are usable due to their continuous monitoring records for many years (Liu et al., 2021). During winter, these images provide good visualization and least cloud cover, and are useful for analysis after minor image corrections. To detect the changes over 30 years, images were collected for four years at 10 years interval. Based on availability, Landsat-5 images for the year of 1990, 2000, and 2010, and Landsat-8 images for 2020 were collected. Information on these images is given in Table 7.1. For image correction, Top of Atmosphere (TOA) reflectance was applied (Nawar et al., 2022) for further analysis. All the images were projected into Universal Transverse Mercator (UTM) zone 46 north along with the datum of World Geodetic System (WGS) 1984. Landsat 4–5 Thematic Mapper (TM) images contain 7 bands, and Landsat-8 Operational Land Imager (OLI) images contain 11 bands. From these images; red, infrared, and thermal bands were used to calculate normalized difference vegetation index (NDVI), normalized difference moisture index (NDMI), and land surface temperature (LST). In several steps of the analysis, different values for the maps were obtained from the zonal statistics and attribute tables of the maps after exporting them into excel outputs in the GIS environment.

Table 7.1 Description of the Landsat images used for NDVI, LST and NDMI analysis

Satellite	Date of image	Bands used for NDVI, LST, and NDMI	Wavelength (μm)	Spatial Resolution (m)
Landsat 4–5 TM	07-01-1990 19-01-2000 30-11-2010	Band-3	0.63–0.69	30
		Band-4	0.76–0.90	30
		Band-5	1.55–1.75	30
		Band-6	10.40–12.50	120
Landsat 8 OLI_TIRS	20-11-2020	Band-4	0.64–0.67	30
		Band-5	0.85–0.88	30
		Band-6	1.57–1.65	30
		Band-10	10.60–11.19	100
		Band-11	11.50–12.51	100

7.3.2 Methods

7.3.2.1 Availability and Accessibility of Greenspace

Greenspace availability was calculated at the ward level for Dhaka city. Firstly, greenspace shapefile was extracted from World Bank's land use map of 2018 for the ward boundaries of the city. Formerly, the available greenspace at each ward was divided by the total area at each ward to calculate the percentage of available greenspace for the small administrative boundary unit (Eq. 7.1) (WHO, 2016). Subsequently, per capita availability was calculated at the ward level where the area of greenspace in square meters in every ward was divided by the total population in that ward in 2014 (Eq. 7.2). All these calculations were done in MS Excel 2019 using the following equations:

$$\textit{Percentage of Available Greenspace} = \frac{\textit{Total area of greenspace in Ward}}{\text{Total area of the Ward}} * 100 \tag{7.1}$$

$$\textit{Per capita availability of Greenspace} = \frac{\textit{Total area of greenspace in Ward}}{\text{Total no.of population in that Ward}} \tag{7.2}$$

Accessibility to greenspace was represented in respect to the main residential areas of the city. Residential areas are usually those portions of the city where houses are dominant. Shapefiles for the residential area was extracted from World Bank's land use map for the year 2018. The buffer tool from the Geoprocessing toolbox was used to create 100 meter and 300 meter buffer zones around greenspaces in ArcGIS, as previously identified to visualise the availability of green area within this distance for the wellbeing of people (Barbosa et al., 2007; Houlden et al., 2019; Fuertes et al., 2020). After that, the intersect tool was used to identify the greenspace 300 meters buffer zones that fall within the residential areas. Finally, the total residential area of the city and the total residential area falling within 300 meters greenspace buffer zone were measured to detect what percentage of the residential units have access to green spaces.

7.3.2.2 NDVI, LST and NDMI Calculation

NDVI maps for vegetation, LST maps for surface temperature and NDMI maps for surface wetness were prepared in ArcGIS with the Landsat images for all the considered years (see above) as a part of the change detection process. To detect healthy vegetation through remote sensing, NDVI is one of the most useful methods (Helbich, 2019; Marković et al., 2021; Nawar et al., 2022). In this process, vegetation was identified by the reflectance from the visible red (wavelength 0.6 μm) and near-infrared (NIR) (wavelength 0.9 μm) bands. The difference between the two reflectance was divided by their total reflectance to calculate NDVI as the following equation-

$$NDVI = \frac{NIR - RED}{\mathrm{NIR} + \mathrm{RED}}$$

In Landsat-5, band 3 represents red and band 4 represents near-infrared. For Landsat-8, band 4 and band 5 represents red and NIR, respectively. The range of NDVI lies between −1 to +1. The more the value is close to +1 the greater number of healthy vegetation it indicates. The negative values close to −1 generally symbolizes presence of waterbody in the region (Marković et al., 2021).

For the LST calculation different techniques have been adopted by the researchers. Hence, the Landsat images contain the detailed information of the reflectance of the bands; it is easy to obtain LST by doing some step-by-step calculations in ArcGIS. In this study, the mono-window technique to calculate LST from Landsat-5 and split-window technique to calculate LST from Landsat-8 was adopted (Chowdhury & Islam, 2021). The digital numbers (DNs) of the thermal band (band 6 for Landsat-5, and band 10 and 11 for Landsat-8) were utilized to calculate LST with Eqs. 7.3, 7.4 and 7.5. At first, the DNs were converted into radiance, and then into brightness temperature (T_B) in Kelvin. Finally, the temperature value was converted into degree Celsius for this study. For Landsat-5, Eq. 7.3 was followed to get the radiance-

$$L_\lambda = \left(\frac{\mathrm{LMAX}_\lambda - \mathrm{LMIN}_\lambda}{Q_{calmax} - Q_{calmin}} \right) (Q_{cal} - Q_{calmin}) + \mathrm{LMIN}_\lambda \tag{7.3}$$

Here; L_λ is the spectral radiance; $LMAX_\lambda$ is the spectral at sensor radiance which is scaled a Q_{calmax}; $LMIN_\lambda$ is the spectral at sensor radiance which is scaled a Q_{calmin}; Q_{cal} is the quantized calibrated pixel value in DNs; Q_{calmax} is the maximum quantized calibrated pixel value (corresponding to $LMAX_\lambda$) in DNs; Q_{calmin} is the minimum quantized calibrated pixel value (corresponding to $LMIN_\lambda$) in DNs (Chowdhury & Islam, 2021). L_λ is obtained in W/m^2 sr μm unit.

For both thermal bands of Landsat-8, the following equation was used to calculate the radiance-.

$$L_\lambda = M_L Q_{cal} + A_L \tag{7.4}$$

Here; L_λ is the spectral radiance for the sensor's aperture in W/m^2 sr μm unit; M_L and A_L are the band specific multiplicative rescaling factor and band specific additive rescaling factor respectively from the metadata; Q_{cal} is the quantized and calibrated standard product pixel values in DNs.

The obtained radiances from both Landsat images were converted into brightness temperature (T_B) with Eq. 7.5-

$$T_B = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \tag{7.5}$$

Here; K_1 is the thermal conversion constant in W/m^2 sr μm unit; K_2 is the thermal conversion constant in Kelvin unit (K) (Chowdhury & Islam, 2021). After that, land surface emissivity (LSE) and proportion of vegetation (P_v) were calculated with Eqs. 7.6 and 7.7 for calculating LST from Landsat-5-

$$LSE\ (\varepsilon) = 0.004 * P_v + 0.986 \tag{7.6}$$

$$P_v = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 \tag{7.7}$$

Using the LSE value, temperature was finally estimated in Kelvin for Landsat-5 with the following equation-

$$LST = \frac{T_B}{\left\{1 + \left(\frac{\lambda T_B}{\rho}\right) lnLSE\right\}} \tag{7.8}$$

Here; wavelength of emitted radiance (λ) = 1.5μm and ρ = h*c/σ where c is the velocity of light; h and σ are constants with known values (Roy et al., 2015). Subtracting 273.15 from the gained LST, temperature was converted into degree Celsius in the maps.

For Landsat-8 LST was calculated with the following formula from the split window algorithm-.

$$\begin{aligned} T_s = {} & T_{10} + C_1\ (T_{10} – T_{11}) + C_2\ (T_{10} – T_{11})^2 + C_o + (C_3 + C_4\ w)\ (1 - \varepsilon) \\ & + (C_5 + C_6\ w)\ \Delta\varepsilon \end{aligned} \tag{7.9}$$

Here; T_{10} and T_{11} are at-sensor brightness temperatures of band 10 and band 11, respectively (obtained from Eq. 7.5); C_0-C_6 are coefficients; ε is the mean surface emissivity and Δε is the emissivity difference; and w is the atmospheric water vapor content (Chowdhury & Islam, 2021). From this equation temperature was found in Kelvin which was converted into degree Celsius following the same procedure for Landsat-5.

For retrieving surface wetness, there are several equations such as Normalized Difference Water Index (NDWI), Normalized Difference Moisture Index (NDMI), Modified Normalized Difference Water Index (MNDWI) etc. Among these NDMI has been proved to have strong association with humidity (Liu et al., 2021) and hence; it was used as an indicator of humidity in this study. NDMI uses near-infrared band (ρ_{NIR}) and middle infrared band (ρ_{MIR}) for humidity estimation.

$$NDMI = \frac{\rho_{NIR} - \rho_{MIR}}{\rho_{NIR} + \rho_{MIR}}$$

Band-4,5 for Landsat-5, and band-5,6 for Landsat-8 were used to calculate humidity with this equation.

7.3.2.3 Cross-Section and Correlation Graphs

For the comparison of changes in NDVI, LST, and NDMI in different years, three polylines (AB, CD and EF) were drawn arbitrarily (Fig. 7.2) on the map of Dhaka city in ArcGIS. The values of NDVI, LST and NDMI for these polylines were then exported into excel files and plotted in graphs to provide a comparative analysis among the chosen years.

Correlation graphs were prepared by extracting multi values to point through the creation of fishnet in ArcGIS. The values of NDVI, LST, and NDMI for all the years were extracted from these points and exported into excel files. Then, scatter plots were generated in MS Excel 2019 where the correlation between NDVI-LST and NDVI-NDMI for each year was shown.

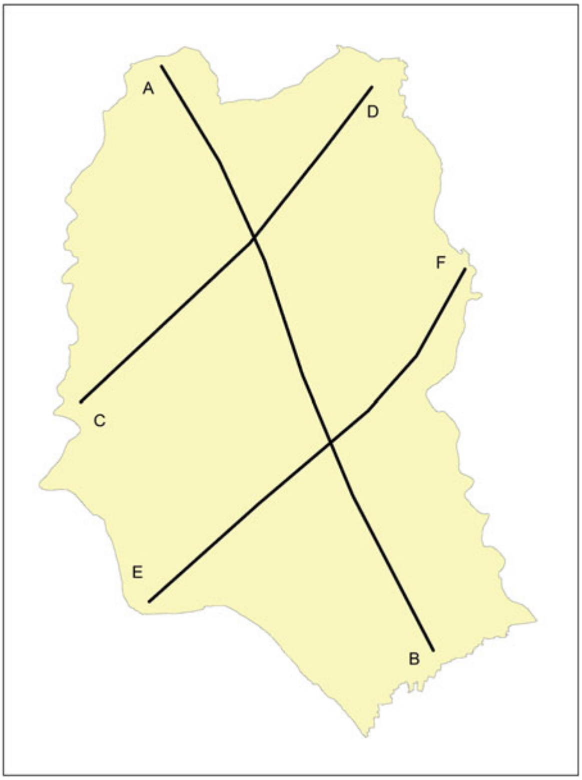

Fig. 7.2 Polylines for cross-section graphs

7.4 Results and Discussion

7.4.1 Availability of Greenspace

Dhaka city had only 2.24% greenery within its area in 2018. Greenspace in 2018 was distributed at the ward boundary to estimate the percentage of greenspace according to the total area. The outcomes showed a nonuniform distribution of green areas throughout the city. Only two wards had greenspace of more than 20%; ward-32 in DSCC, including Arambagh, Fakirapool, etc. areas, had the highest coverage (23.84%) (Fig. 7.3) and ward-40 covering Bhatara in DNCC had 22% of greenspace (Fig. 7.3). Only two other wards had green features more than 10% (W-47 from DNCC, and W-61 from DSCC with 17.4% and 19.51% coverage, respectively). Whereas the rest from 110 wards did not have any mentionable green and open space. Perhaps surprisingly, 26 wards had *no* coverage of greenspace at all, among which 22 wards were from DSCC (Fig. 7.3). Nonetheless, the total coverage of greenspace is less in DNCC compared to DSCC.

Therefore, the availability of greenspace considering the total population of each ward has been calculated based on the data of 2014. This per capita availability estimation showed a very concerning situation condition throughout the whole city. Ward-46 in DNCC, covering Baburpara, Munda, Barbagh, Rajabari, etc. areas, had the highest per capita greenspace (0.003207 m^2) availability (Fig. 7.4). Ward-61 and Ward-31, covering parts of Puran Dhaka, Gopibag, Kamlapur, Motijheel, etc. had the second (0.002093 m^2) and third (0.001581 m^2) highest per capita green area, respectively. Another 17 words fell within the range of 0.000289296–0.000804998 m^2 per capita greenspace availability, while the rest of the wards had less than that (Fig. 7.4).

7.4.2 Accessibility of Greenspace

From the analysis it was observed that $<$25% area of the city fell under 300 meters buffer zone of green and open spaces (Fig. 7.5). The accessibility was then calculated in respect to the residential zones of the city identified by World Bank in 2018. Intersecting the 300 meters buffer zone with the residential areas it was found that only 56.5 square kilometers residential areas had greenspace coverage, whereas the total residential area was 77.47 square kilometers. Greenspace availability considering the total residential area was only 8.86% where the suburban areas were not considered (Fig. 7.5).

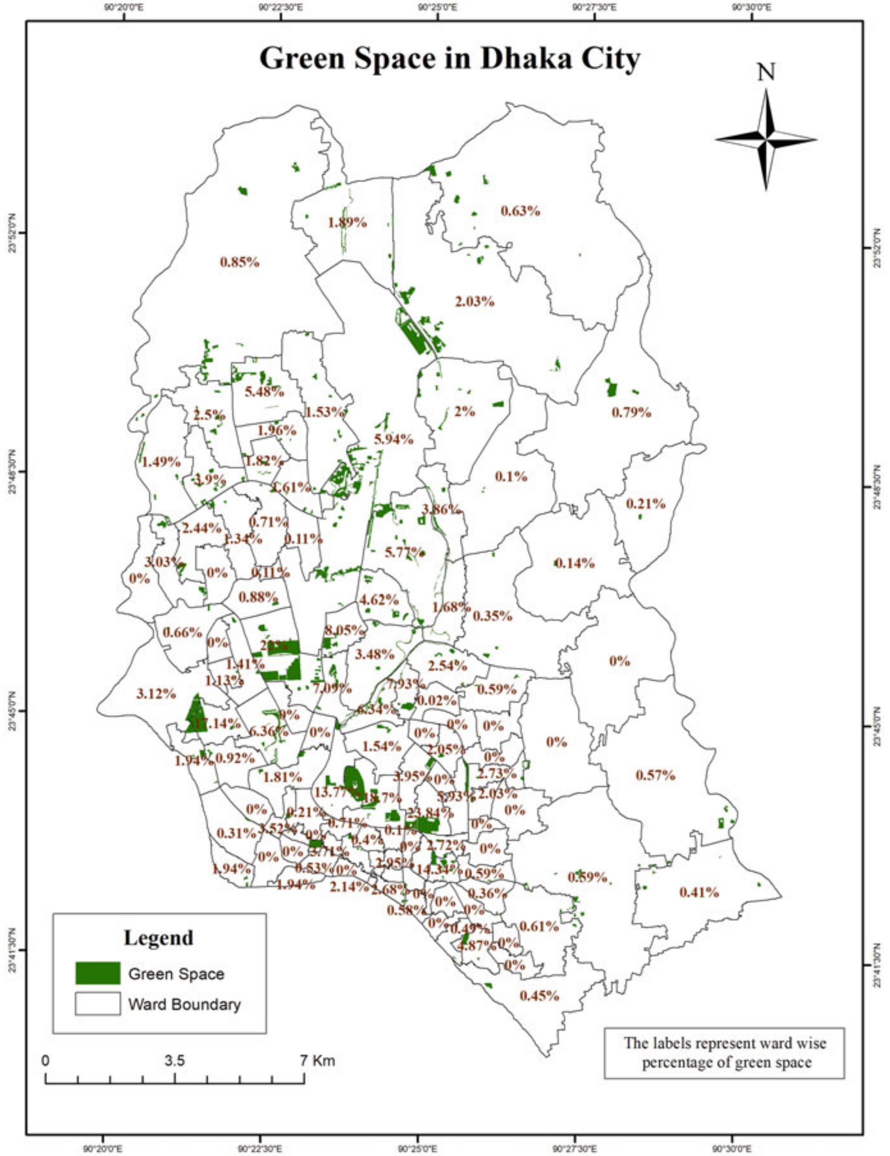

Fig. 7.3 Percentages of greenspace at ward level in Dhaka city, 2018. (Data source: World Bank, 2018)

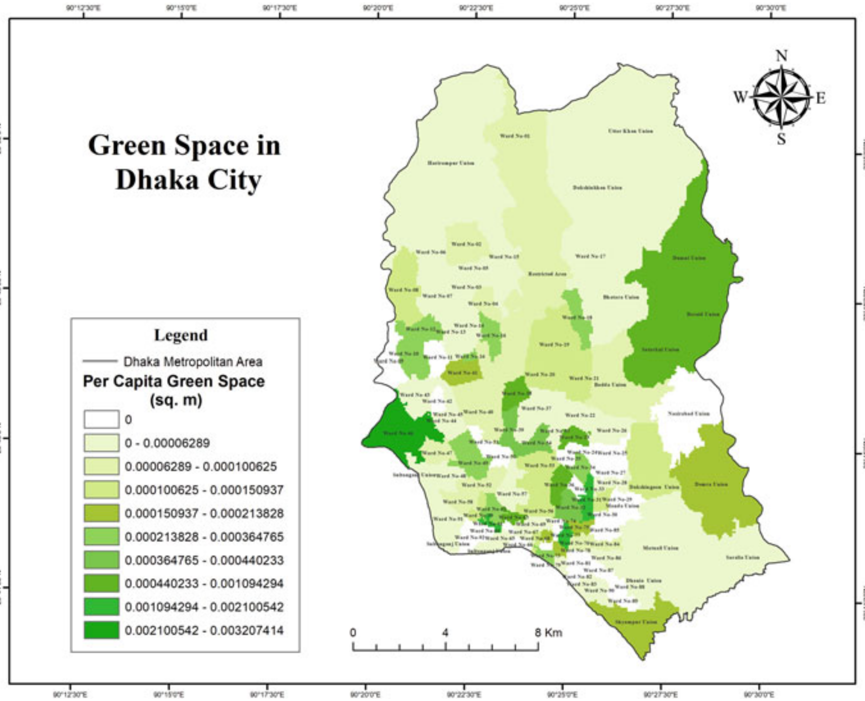

Fig. 7.4 Per capita greenspace availability at the ward level, Dhaka, 2014. (Data Source: World Bank, 2014)

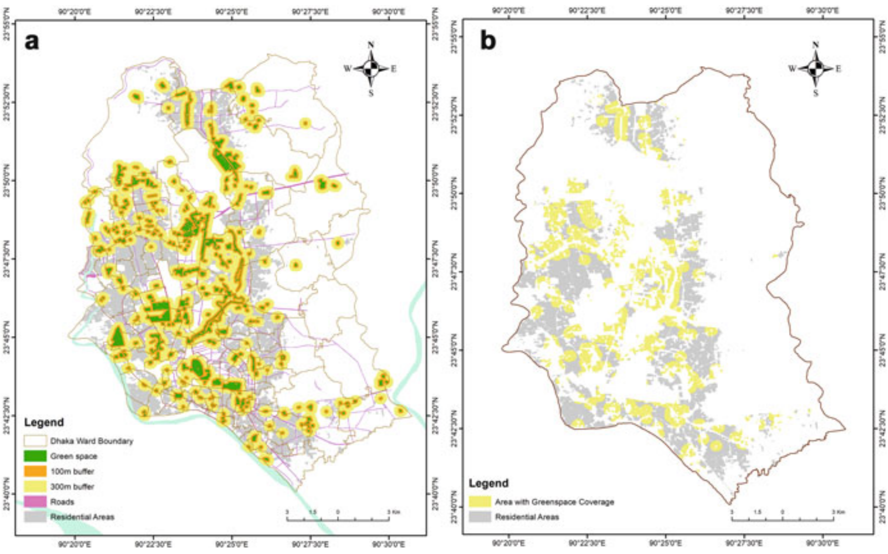

Fig. 7.5 Accessibility to greenspace (**a**) for the entire city, (**b**) for residential areas in Dhaka city, 2018. (Data Source: World Bank, 2018)

7.4.3 Changes in Vegetation over the Years and their Impact on Temperature and Humidity

Changes in vegetation coverage across 30 years were assessed through NDVI analysis. From 1990 to 2020, significant changes in the amount of vegetation were observed (Fig. 7.6). The range of NDVI has slightly increased from 1990 to 2020. From the zonal statistics of the maps, it was observed that 55 wards among 110 had undergone a drop to the maximum level of NDVI in 30 years. The mean value of

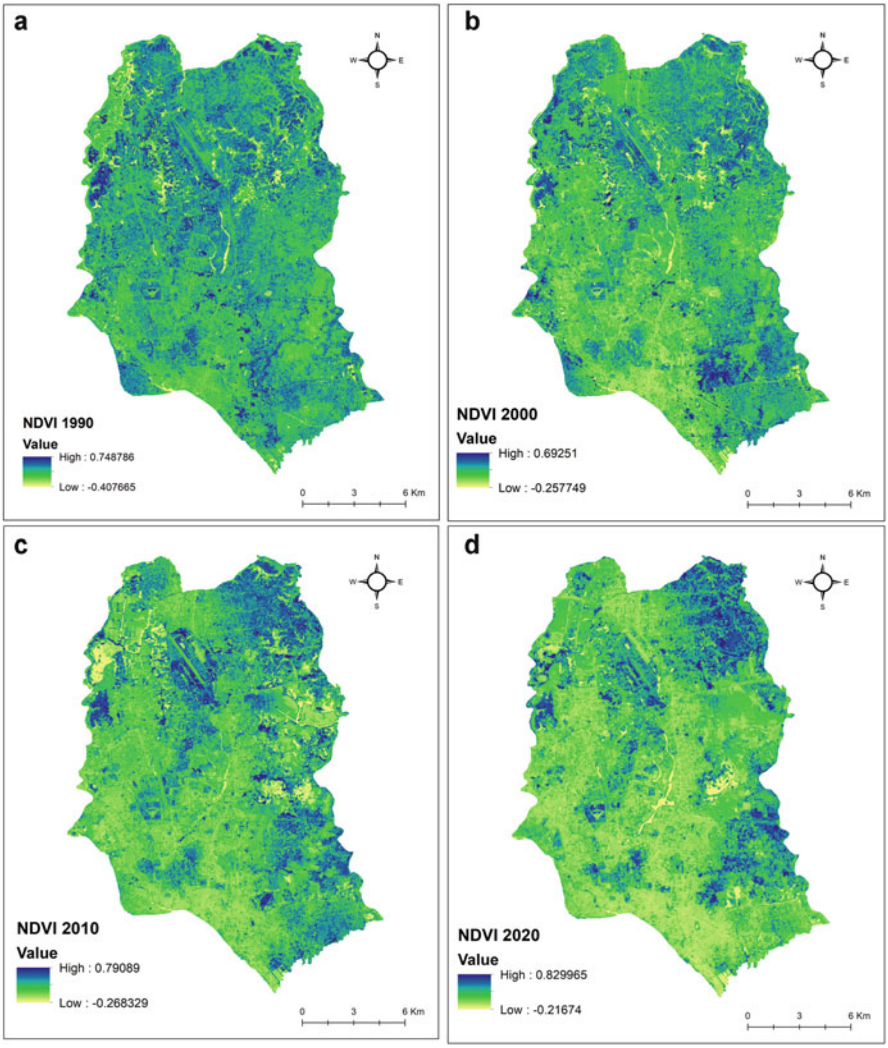

Fig. 7.6 NDVI maps of Dhaka city for the years of (**a**) 1990, (**b**) 2000, (**c**) 2010 & (**d**) 2020

NDVI reduced from about 59% area in 2000 from 1990, 42% area in 2010 from 2000 and 60% area in 2020 from 2010 of the total area of the city. Overall, this reduction of mean NDVI value was in 54% area from 1990 to 2020. Ward-1, 29, 38, 45, 48, 51, 52, 54, had a major change in the maximum range of vegetation (a 20–35% decrease) in the mentioned period. However, from the vegetation classification, it can be seen that dense vegetation or forest can be found within 0.66–1 range of NDVI, (Buyadi et al., 2013). No ward of Dhaka city has the value within 0.66–1 which shows that there is no dense vegetation or forest situated inside the city.

From the cross-section graphs of NDVI the changes of vegetation in different locations can also be observed. The x axis of the graphs represents distance in meters and the y axis represents the maximum value of NDVI. In all the cases vegetation was observed to be the least in 2020 (Fig. 7.7).

Dramatic changes in land surface temperature (LST) were observed across the last 30 years. The highest value of temperature increased from 25 °C to 31.5 °C in Dhaka city from 1990 to 2020 (Fig. 7.8). The lowest value of temperature increased from 10.82 °C to 18.78 °C in the mentioned period. The highest temperature slightly dropped in 2000 (24.59 °C) compared to 1990 (25.1 °C), but after that, a huge rise happened across the last 20 years. Consequently, the highly temperate region is increased with the intensity of temperature in 2020 (Fig. 7.8). The zonal statistics showed that both the maximum and minimum value of temperature increased in 99.7% area of the city in 2020 compared to1990. Ward-1, 7, 12, 13, 20, 22, 23, 29, 34, 35, 52, 54 faced a temperature rise ranging from 5-8 °C in 30 years. Similar increases in temperature were observed in all the wards where maximum range of vegetation had decreased.

Moreover, the cross-sectional graphs of the LST give us a clear picture of huge rise of temperature in different areas between? 2010 and 2020 (Fig. 7.9). This rise was considerable and progressive with the highest temperatures being observed in 2020.

Significant changes in the maximum and minimum level of NDMI were observed along with an area reduction of the highest humidity locations. From the zonal statistics of 110 wards, the highest value of NDMI reduced from 0.991215 in 1990 to 0.674787 in 2020 from 77 wards, indicating a reduction in humidity. The lowest NDMI value slightly increased to −0.45009 in 2020 from −0.537397 in 1990. Ward-1, 7, 34, 36, 45, 46, 47, 48, 51, 52, 54, 55, and 56 went through mentionable change where the maximum level dropped to 0.15–0.28 (almost 25–40%). About 4.7% highly humid area has turned into lowly humid zone in the northwestern part of the city (Fig. 7.10) through extensive changes (50–90% decrease from the year 1990 value). Similarity was observed where vegetation and humidity both had been changed. A total of 54 wards were identified that had decreases in NDVI, increases in LST and decreases in NDMI values.

From the cross-sectional graphs the same thing was observed where NDMI is very low in 2010 and 2020 (Fig. 7.11). Overall, NDMI is lowest in 2020 in all the three scenarios and 54% area of the city had a decreased NDMI in 30 years.

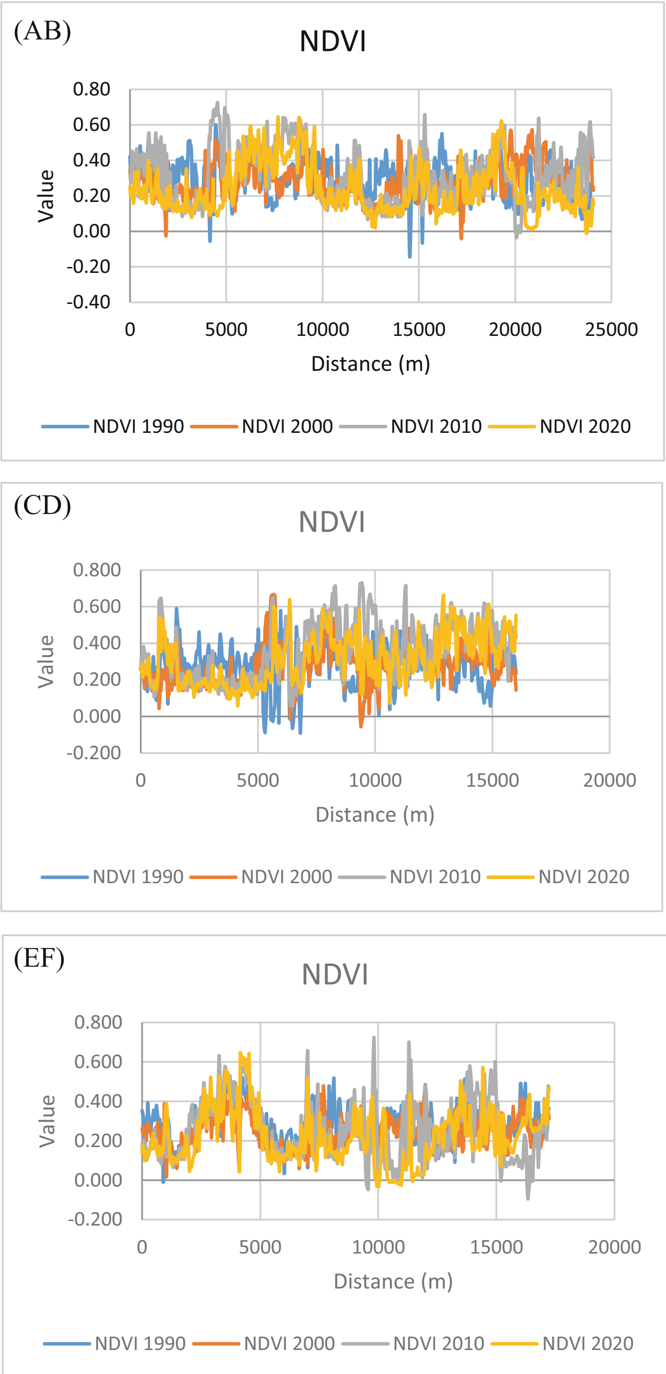

Fig. 7.7 Cross sectional graph of NDVI

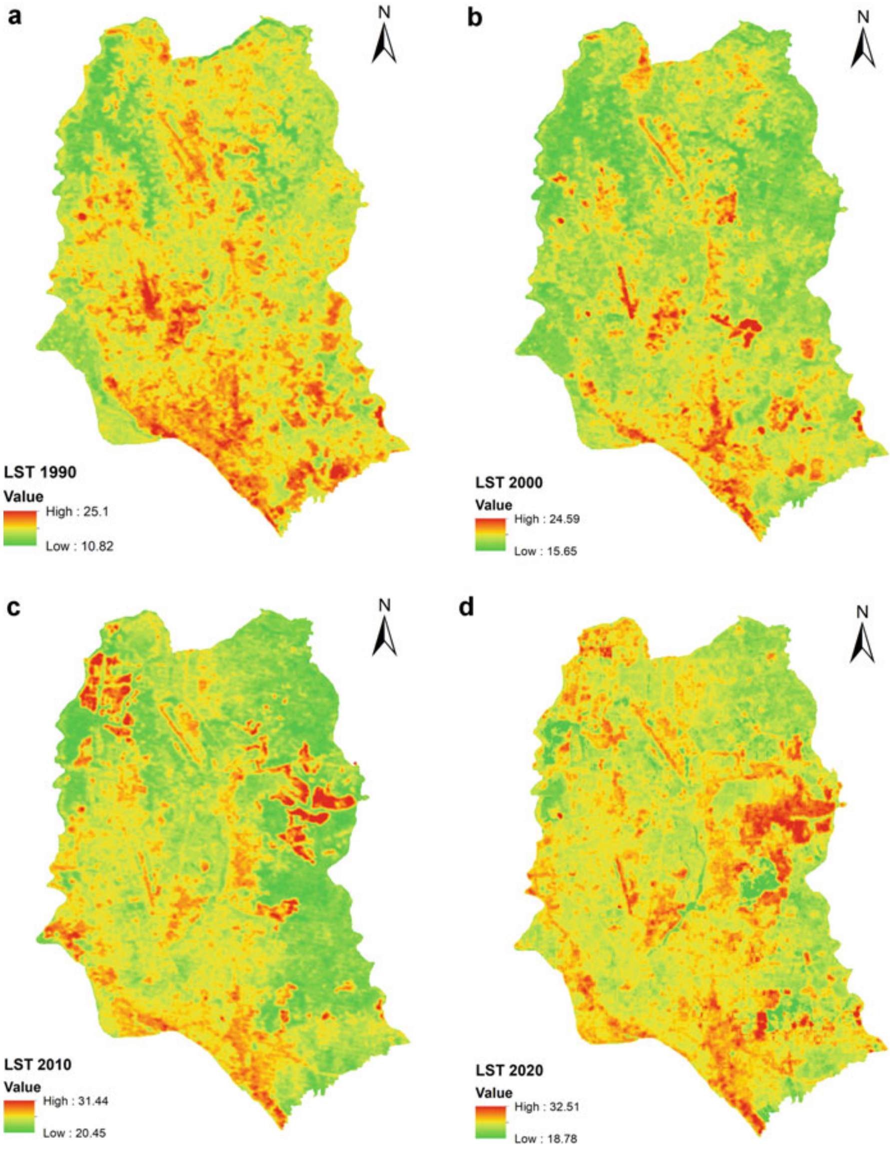

Fig. 7.8 LST maps of Dhaka city for the years of (**a**) 1990, (**b**) 2000, (**c**) 2010 & (**d**) 2020

The impact of vegetation on surface temperature and humidity was observed through correlation analysis between NDVI, LST, and NDVI, NDMI. In four different years, the changes in temperature with respect to vegetation were detected, and a negative trendline was generated in all the cases, indicating the temperature increases when the vegetation coverage decreases. In 30 years, vegetation throughout the city decreased considerably whereas land surface temperature increased

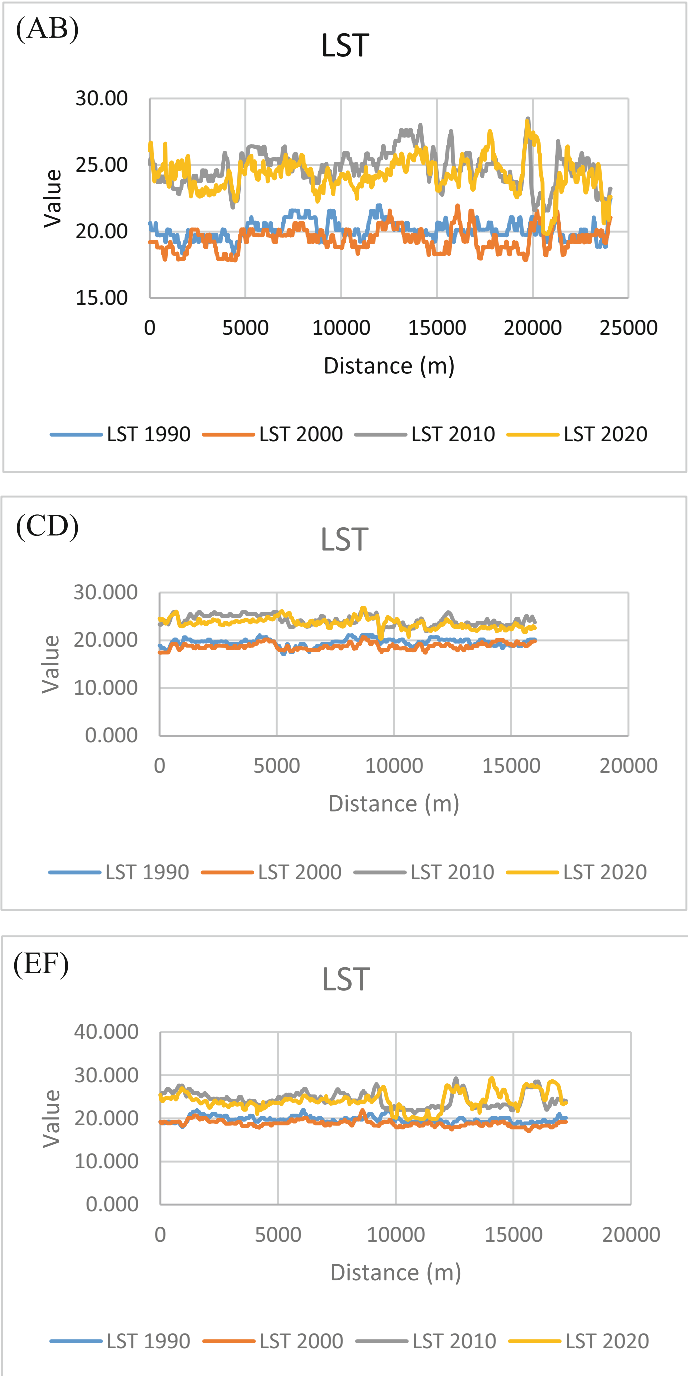

Fig. 7.9 Cross section graph of LST

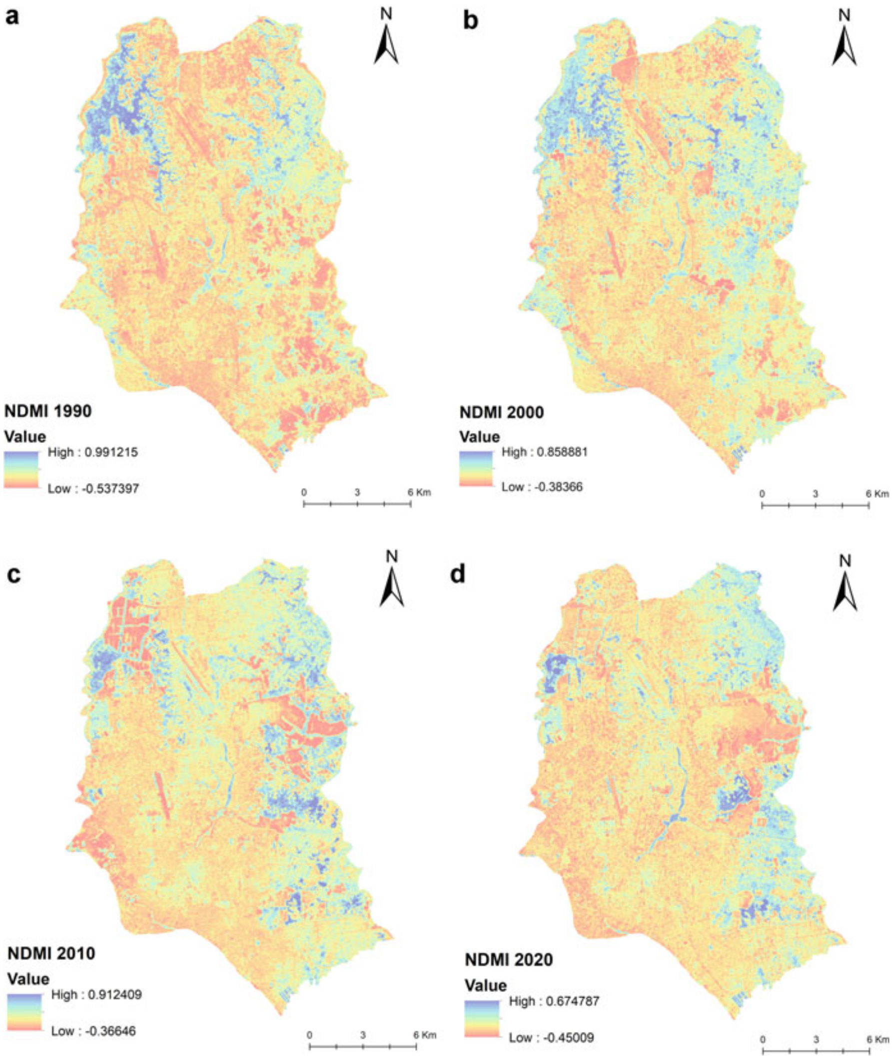

Fig. 7.10 NDMI maps of Dhaka city for the years of (**a**) 1990, (**b**) 2000, (**c**) 2010 & (**d**) 2020

simultaneously. Moreover, the slope of the trend line is quite similar in each year which implies that there is a visible correlation between reduced vegetation and increased temperature (Fig. 7.12).

In the same manner, changes in surface humidity with respect to vegetation were analyzed, where a significant impact was also established. In this case, the correlation showed a positive trend line implying that enhancement of vegetation resulted in the increase of humidity in the atmosphere. Such a relationship showed the same trend for all the years (Fig. 7.13). The slope of the trend line in the graphs established

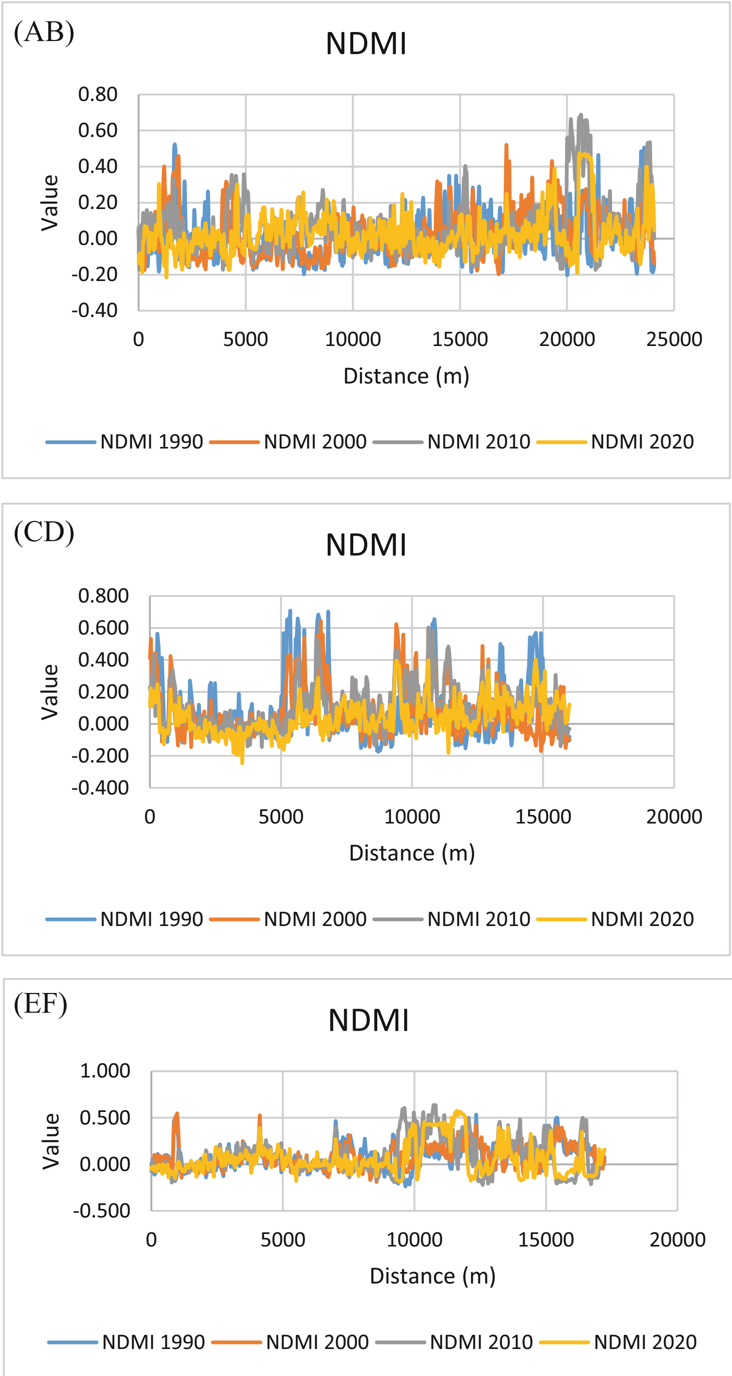

Fig. 7.11 Cross section graph of NDMI

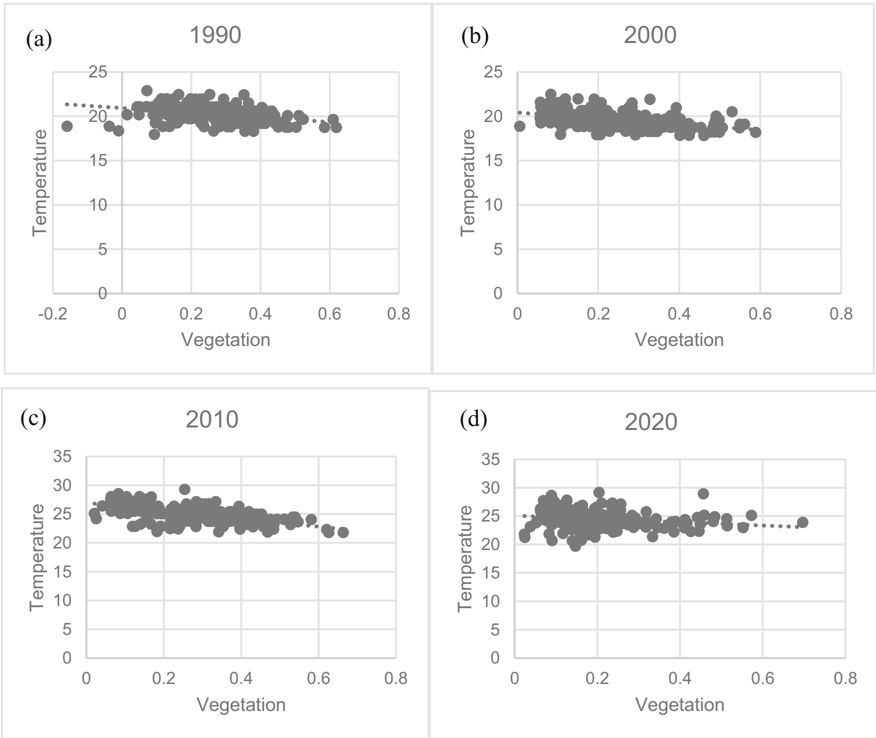

Fig. 7.12 Correlation of NDVI and LST for the years of (**a**) 1990, (**b**) 2000, (**c**) 2010 & (**d**) 2020

this positive relationship more resolutely, and the dependence of these two variables was quite clear.

From the correlation analysis, it can be interpreted that Dhaka city had a significant reduction in vegetation cover that contributed to the rise of surface temperatures and a reduction in humidity over the last three decades. Both temperature and humidity are two important elements of our atmosphere that play many direct and indirect impacts on human health, discussed below.

7.5 Discussion and Conclusion

According to United Nations Environment Program (UNEP), a *minimum* of 25% open space coverage is needed to maintain a sustainable city where it may or may not include a water body along with a plantation (Rehnuma et al., 2017). When it is about greenspace only maintenance that amount has to be a minimum of 20% of the total area of the urban territory (Rahman & Zhang, 2018). Considering these targets, only two wards (Ward-32, 40) of Dhaka city can meet the standard crossing 20%

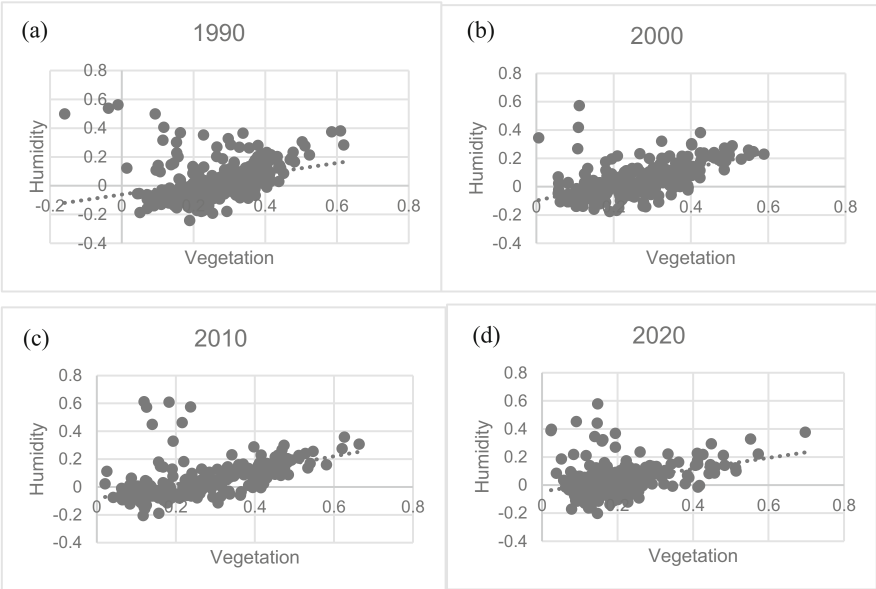

Fig. 7.13 Correlation of NDVI and NDMI for the years of (**a**) 1990, (**b**) 2000, (**c**) 2010 & (**d**) 2020

coverage among 110 wards. In total, 26 wards have no greenspace coverage and 96% wards have less than 10% coverage; it shows the poor management of available green spaces within the city.

The coverage of greenspace is not evenly distributed within different wards or residential areas. Other similar studies in Dhaka city found the same result at different times and the situation continues to worsen. Dhaka city's greenspace is reducing day by day because of the lack of policy, proper maintenance, and poor management (Byomkesh et al., 2012). Rehnuma et al. (2017) also identified the deficiency in the DNCC with a strong recommendation towards the need of reclaiming the green area. Razia (2018) found dissatisfaction among the residentials of the city about access to greenspace. In another study, Rahman and Zhang (2018) discovered only 8.5% greenspace coverage within the city. Despite the social, cultural, and economic benefits of greenspace, Dhaka city stands in a very poor position according to its current green area possession. Moreover, the per capita availability of greenspace is far from the satisfactory levels identified for urban areas. The World Health Organization (WHO) recommends a minimum of five square meters of greenspace availability per person in the city area (Beiranvand et al., 2013; Badiu et al., 2016; Lin et al., 2019). But even then, the *highest* availability of greenery per person is only 0.003207 square meters which implies that the health and wellbeing of the people of Dhaka city are at stake. The fact is, increasing migration to the city continues to increase population density and pressure. So, the amount of greenery needed to maintain a healthy environment in other cities of the world is not enough for Dhaka's current and growing population, even if the total area of greenspace is considerable relative to the size of the city. This present study found 2.24% green and open space in Dhaka, and 8.86% coverage in the residential area which is too little to provide a healthy environment for 21.7 million people.

The analysis of changes in green vegetation in the last 30 years revealed only negative outcomes in terms of reduction of area coverage. From the NDVI analysis, the high range of vegetation was reduced in half of the wards. Another study in Dhaka city conducted for an almost similar time period showed 56% green area loss in 31 years from 1989 to 2020 based on NDVI analysis (Nawar et al., 2022). This huge amount of green space loss occurred as the city had to accommodate a rapidly increasing population in this short span of time (Nithila et al., 2021). From the year of 1995 to 2010, the rate of urbanization increased from 54.42% to 77.36%, and per capita CO_2 emission increased from 0.2 to 0.4 metric tons which can be the probable cause of the rapid temperature rise in 2010 (BBS, 2012; World Bank, 2013). The city grew in terms of structural and economic development without consideration for sustaining a healthy environment for the next generation. As a result, the average temperature increased drastically from 25 °C to 32.5 °C in the winter season from 1990 to 2020 whereas humidity became much less in a area making the city one of the most uninhabitable in the world. Such an increase of temperature within 1995 to 2011 has been observed in another study conducted in Dhaka city (Mohiuddin et al., 2014).

A significant correlation between vegetation reduction and temperature increment was established in this analysis. An elevated temperature can be a reason for heat stress in people and bring with it serious health exposures (McGregor & Vanos, 2018). Vescovi et al. (2005) also depicted the potential health risks associated with temperature rise, whereby the public health of Bangladesh is at risk for the same reason with a number of direct and indirect impacts (Shahid, 2010). In high and rising temperatures, the transmission of harmful microorganisms can happen in both indoor and outdoor environments causing various diseases. The findings of this study indicate that the presence of more vegetation in Dhaka city could have controlled the temperature rise, thus reducing such health exposures. Humidity is another factor closely related to public health risks? from various potential threats. Low humidity in a higher temperature environment is considered to be quite helpful for the comfort of the population. However, the humidity decrease beyond a certain level can have adverse effects for people and such conditions were observed in many regions of Dhaka city during the winter season. A negative range of surface wetness was observed from this analysis which is harmful for both plants and animals. Such levels can cause extreme dryness in a human body with transepidermal water loss, skin roughness, decreased elasticity, and eczema at indoor environment (Goad & Gawkrodger, 2016). Moreover, in the recent pandemic, studies show low humidity might have a relationship with increases in Covid affected cases (Wu et al., 2020; Babuna et al., 2021).

There is a balance that needs to be maintained in terms of both temperature and humidity that can be favorable in maintaining good health for the population of any place. To balance these atmospheric components, the contribution of plants is known to all, and this is why it is very much needed for the urban areas to sustain a permissible portion of greenspace. This study finds that, the existing greenspace management condition is very much negative for Dhaka city, putting its population at risk from various factors. The situation is already beyond control in our estimation. If adequate remediation measures are not taken soon, and if proper city management cannot be ensured, Dhaka risks becoming an uninhabitable city for the present and future generations.

Acknowledgments The authors would like to express their gratitude towards Md. Uzzal Chowdhury for providing useful insights in the manuscript.

Conflict of Interests The authors declare that they have no conflict of interest.

Author Contributions ZQ initiated the preliminary concept of the study and reviewed the manuscript. HHS contributed to idea generation and provided feedback on data analysis. KTKN performed analysis, conducted the literature review and wrote the manuscript. KRB reviewed and edited the manuscript. JB reviewed and edited the manuscript.

Funding This work is supported by the Pathways to Equitable Healthy Cities grant from the Wellcome Trust [209376/Z/17/Z]. For the purpose of Open Access, the author has applied a CC BY public copyright licence to any Author Accepted Manuscript version arising from this submission.

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