Spatiotemporal dynamics of urban green and blue spaces using geospatial techniques in Chandannagar city, India

Pritha Ghosh · Kiran Kumari Singh

Abstract Green and blue spaces are important landscape elements in a city and there is strong literary evidence available regarding the ecological, social, cultural and recreational benefits of these spaces to people and urban sustainability. Comprehensive quantitative assessment of these spaces is gaining scientific recognition for their utility in sustainable urban planning and drafting greening policies. This study analyzed the spatiotemporal change in urban green and blue spaces in Chandannagar city, India through quantitative assessment for the years 1991, 2001, 2011, and 2020 using Landsat data of 30 m spatial resolution. Normalized Difference Vegetation Index and Normalised Difference Water Index was applied to extract information on urban green and blue spaces. The classified maps were validated through field observations and Google earth images. Spatio-temporal analysis was carried out at ward level to analyze the distribution of urban green spaces (UGS) at the micro level. The result indicated that there was a reduction in green and blue spaces in the central and eastern parts of the city while there was a good amount of UGS in the western part of the city.

The findings of this study shed light on important policy implications for the UGS planning in the city.

Keywords Urban green space (UGS) · Urban blue space · Urban sustainability · Chandannagar · India

Introduction

Recently, the Ministry of Housing and Urban Affairs of India released Ease of Living Index (EoLI) for the year 2020. One of the four pillars of the Ease of Living Index is sustainability, which is measured in terms of the quality of natural resources such as air and water, availability of green spaces, and others in a city (MoHUA, 2020). Urban green and blue spaces in a city are being recognized as important components of urban resilience in India. These spaces are becoming increasingly significant due to the rapid pace of urbanization. The urban population of India in the year 2011 was 377 million and it is expected that there will be an addition of 416 million urban dwellers by 2050 (United Nations, Department of Economic and Social Affairs, 2018). Increasing population, rapid urbanization, concentration of various economic and social activities in cities and rapid land cover changes due to developmental activities are posing significant sustainability challenges in terms of infrastructure, services and natural resources. Cities are highly

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dependent on their internal and external natural resources to function and to strengthen their capacity and thus the urban expansion causes ecological problems such as destruction of vegetation, changes in biodiversity, and modification in the thermal environment in and around the region (Grimm et al., 2008; Ramachandra et al., 2012). The ecological footprint, particularly in urban areas, is very high (Herold et al., 2003). The increasing global urban footprint is making it a frontier of science for sustainability (Elmqvist et al., 2021). However, many cities of the world are not prepared for the multi-dimensional challenges associated with urbanization and urban change (UN-Habitat, 2016).

The incremental loss of Urban green spaces (UGS) has been reported to be one of the challenges which will lead to loss of ecosystem services in an urban environment and pose threat to urban sustainability (Colding et al, 2020). The process of urban densification (spatial and/or population) is causing a threat to the UGS in the cities (Colding et al, 2020). Similarly, the sprawling process has impacted the natural ecosystem in a city. The Green Surge project has defined Urban Green Spaces (UGS) as any vegetated surface such as park, forests, lawns, residential gardens, street trees and blue spaces such as lake and wetland that support growth of vegetation (Cvejic et al., 2015) and urban farmlands, open undeveloped/non-bare land within the cities (Breuste et al., 2013). Interconnected network of UGS is a component of the Urban Green Infrastructure (UGI) and provides a wide range of ecosystem services. UGI is an urban planning approach that aims to create a network of multifunctional UGS to maintain sustainability of the urban environment (Gee et al., 2009). The Sustainable Development Goal (SDGs) in its 11th goal has targeted to provide universal access to safe, inclusive and accessible green and public spaces by 2020 (United Nations, 2015).

Studies suggest that successful integration of UGS in urban planning requires information about the extent, composition, distribution, and functional characteristics of UGS (Niemela, 1999). According to Gupta et al., (2012), the lack of information on the quantity and quality of UGS causes hindrance to the management and development of the UGS in a city. Remote Sensing techniques have become important in the study of UGS and natural resource management in the last few decades. The most widely used method is the Normalized Difference Vegetation Index (NDVI) derived from remote sensing images. Various scholars have used NDVI to distinguish between vegetated and non-vegetated areas ((Hur et al., 2010; Kaur et al., 2021; Nero, 2017; Sathyakumar et al., 2019; Singh, 2018). The goal of this article is to provide insights on the Spatio-temporal dynamics of UGS in Chandannagar city, India using remote-sensing techniques. The study assesses and analyses the UGS and blue space change over time and space and traces the distribution of UGS types at the ward level.

Literature review

Numerous studies have found that the nature in a city such as green and blue spaces are vital for urban sustainability and resiliency (Singh, 2018; Singh et al., 2021), sustainable urban planning and sustainable development policy making (Barik & Pattanayak, 2019; Bush, 2020; Mell, 2018; Roy et al., 2012) and health and well-being of urban dwellers (Mitchell & Popham, 2008; Wolch et al., 2014). The loss of natural landscape and a couple of green space due to fast urbanization is going on and may be harmful to human health and quality of life (Budruk et al., 2009). Despite a greater recognition of green spaces for urban sustainability this theme particularly the urban park is little researched in South Asia (Nagendra & Gopal, 2010). However, the academic scholars have been extensively working on the nature-based solution (based on green and blue infrastructure) to mitigate the impact of air pollution and heat island effects (Chaturvedi et al., 2012; Jansson, 2014; Kumar & Pandey, 2018; Madhumathi et al., 2016; McDonald, et al., 2016; Muthulingam & Thangavel, 2012; Rahaman et al., 2021; Sannigrahi et al., 2017; Shah et al., 2021; Sharma et al., 2021). UGS also reinforces the method of carbon sequestration, and mitigate the results of temperature change (Nowak and Crane, 2000; Escobedo et al., 2010; Sahana et al., 2019). Urban green landscapes act as ''soft engineering'' strategy for climate adaptation and disaster risk reduction (Gill et al., 2007; Govindrajulu, 2014; Munang et al., 2013). Urban green and blue infrastructure have been considered critical for climate adaptation of cities (IUCN, 2019). Studies have also reported that these spaces in the form of in-home gardens can complement livelihood sustainability

(Balooni et al., 2013; Staatsen et al., 2017) and urban nature can contribute to the daily food requirements of urban dwellers, particularly the poor community (Kaoma & Shackleton, 2014). The global policies such as United Nations Sustainable development goal (SDG) 2030 and the New Urban Agenda have also been very significant in endorsing the public and green spaces for their role in the promotion of cities' sustainability and citizens' well-being (UN-Habitat, 2017; United Nations, 2015).

In urban planning, the terms blue spaces denote visible water features such as river, pond, canal, or fountain and these spaces function similarly to green spaces (Tang, 2017). Blue spaces integrate aesthetic, cultural, and ecological characteristics into the urban environment (Karmanov & Hamel, 2008) and are placed under the same umbrella of green spaces (Wolch, et al., 2014). The literature on urban blue spaces is scant and there is a need for in-depth study on the negative and positive aspects of these aspects. If they can perform ecological functions and lead to a positive aesthetic experience, they can also be perceived as a negative feature if they are not monitored or poorly managed (Haeffner et al., 2017).

There are strong literary evidences on the benefits of urban nature for human well-being, health and health-equity (Bratman et al., 2019; Lai et al., 2019; WHO, 2016). UGSs are found to be positively associated with mood and physical activities and negatively associated with mortality, heart rate, and violence (Kondo et al., 2018). Regardless of the benefits that the green, open and blue spaces offer, they are vulnerable to major land-use changes and are frequently compromised. The reduction of urban green cover can affect the quality of human life in a city and increase the risk of disasters. In order to achieve the goal of urban sustainability, the nature-based solution can prove to be an effective tool. The World Health Organization (WHO) has specified a minimum standard of 9 m^2 green space/city with an ideal UGS value of 50 m2 per capita (WHO, 2012). It is well articulated that a city should have green spaces and a detailed inventory of UGS on their quantity and quality is required (Singh, 2019).

As stated earlier, the present study is an attempt to analyze the spatio-temporal dynamics of urban green and blue spaces in the city of Chandannagar, India. The contributions of this study can provide information about the availability and quantity of these spaces

in a small-sized city. This study quantified the city's urban green and blue space over different time periods. Thereafter, the result is analysed at ward level. This study has sought to fill a gap in knowledge production on urban sustainability, in particular on urban nature. Evidence-based literature has found that there is an over-representation of big cities either from the global north or the south on the issues of urban sustainability and that bias in the selection of cities can undermine the ability to formulate urban nature policy for smaller cities especially from the developing world (Bell & Jayne, 2009). Cities are not homogenized entity and ignorance of small cities in the conceptualization of broad urban agendas can't provide practical solutions (Thrift, 2000). The local processes, the sense of place, cultural and socio-ecological processes, identity, and history play vital roles in shaping the city. A city can be small in size but can be productive in its function and influence (Rondinelli, 1983). Most of the studies conducted on urban nature in big cities depict scaling effects e.g. the UGSs are found to be proportionally less or are declining due to urbanization (Akuraju et al., 2020; Fuller & Gaston, 2009). However, a similar result may not be observed in other cities. The scaling effects of cities should not be considered a law (Chang et al., 2018). The scientific community has been advocating the production of contextualized and local-based knowledge on urban science and policy from the global south because the theory or evidence generated by the global north can't be applied to the cities of the global south (Nagendra et al., 2018). Similarly, the research findings collected from big cities can't be extrapolated to small and medium-sized cities in policymaking particularly in developing countries (Kendal et al., 2020). This study has taken up a small-sized city of India to generate evidence-based results.

Material and methods

Study area

Chandannagar, a former French Colony, is located on the eastern part of India and is about 30 kms (19 miles) north of Kolkata city (Fig. 1). This city is situated in the Kolkata agglomeration region and one of the most historic cities in this region. It is the 6th municipal corporation of West Bengal, India. This town is under
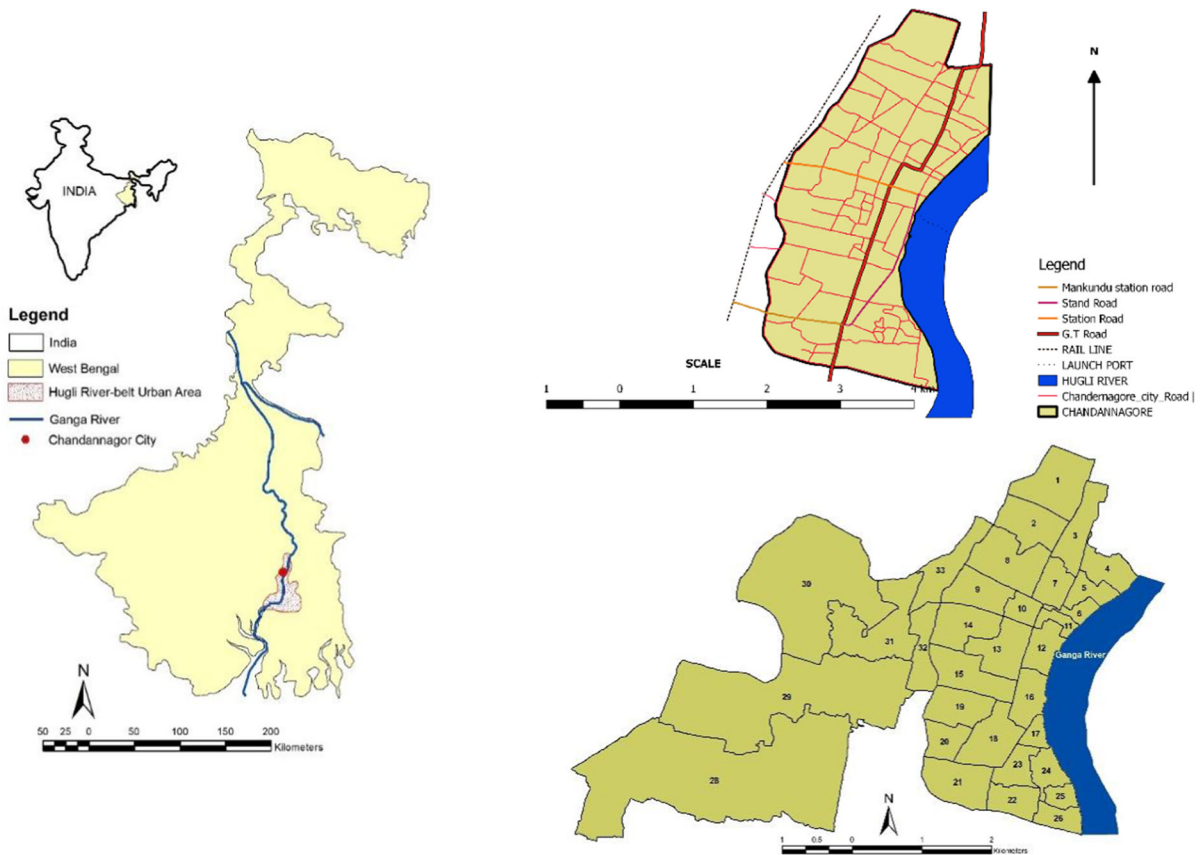
Fig. 1 Location of Chandannagar City and its administrative wards. (The top right image is showing Chandannagar Municipal Corporation (CMC) boundary before 1994 and the bottom right image is showing the CMC boundary after 1994)

control of Chandernagore Municipal Corporation (CMC). The total area of the town was 9.5 km^2 (Ukil, 1996) before 1994 and there were 27 municipal wards. The ward 27 is an isolated ward of CMC since the inception of the city. In 1994, the geographical area of the city (CMC) was increased to 22.03 km^2 (2203 hectare) by including land on the western periphery and the new wards from 28 onwards were created. The eastern boundary of the city is created by river Hoogli, the north western boundary is marked by the river Saraswathi and the south western area of the CMC boundary is marked by a Canal.

According to the District Census handbook, the Chandannagar name is derived from the shape of the bank of river Ganga (Hugli River) which appears half-moon crescent near the city. The old town Chander-nagore was established in 1673 as a French colony. In 1688, it became a permanent French settlement. The French government allowed the Indian Government to

have control over Chandannagar in 1952 and in 1955 this city was integrated into the West Bengal State (Census of India, 2011). Bounties of ponds and waterbodies interspersed in the city provide it a natural and unique image. The city is located on a levees on western side of river Hoogly and its western part is marshy and low lying. The waterbodies are naturally associated with remnants of the former depression. Historically, the city was a place of importance for trade activities, commerce, adminis-tration but suffered demolition and restoration during colonial rules (Mukhopadhyay and Chakraborty, 2003). The impression of colonial legacy is still reflected on its urban design and architecture (resi-dential quarters with lawns in the front and garden at the rear and the waterfront) and gridiron pattern of streets (wide roads with full of the tall mahogany trees on both sides of the street) (Kar et al., 2020; Ukil, 1996). The cultural heritage of the city demonstrates

tourism potential and got momentum recently due to the interest of French Government in revival of the city's glory (Rahkshit & Chaudhuri, 2020).

Total population of the city was 166,867 (0.166 million) with the average population density of 7578 persons/km^2 in 2011 (Census of India, 2011). The population growth was slow from 1901 to 1931, but from 1931 to 1941 the city experienced high population growth due to influx of immigrants towards the city from the surrounding villages (Chakma & Nandi, 2014). In the post-independence time, the city experienced remarkable growth in terms of development of urban settlement till the year 2001 through the waves of migration which resulted in the spatial expansion of the city towards west. Due to its location near to Kolkata city, pleasant environment, scenic beauty and development of transportation and communication system, the city became a residential suburb of Kolkata city. The rapid population growth and built-up surface expansion led to alteration in land use pattern of the city impacting the ponds and the green spaces. The Chandernagore Municipal Corporation, in its draft development plan, prepared land use development and management plan and proposed to provide and maintain parks, playground at each ward for social and environmental benefit to the city. It also proposed to utilise the land for health conservation, education and recreation (Draft Development Plan, 2007–2012). Study has reported that the people of the city are close to nature and they practise gardening for refreshing their mind as their hobbies. However, the urban agricultural practices suffered due to lack of irrigation facilities in the city (Chakrabarti, 2019).

Data

Data related to population was collected from the Census of India website (https://censusindia.gov.in/) for the years 2001 and 2011. The ward level map as shown in Fig. 1 was procured from the Municipal Corporation office. The "shapefile" of the ward level boundary was created on Geographic Information System (GIS) platform for the years 1991 and 2001 separately due to the change in the boundary of the city. The projection parameters were taken from the Landsat image. To extract the UGS in the city for the years 1991, 2001, 2011, and 2020, the satellite images were downloaded from the website of the US Geological Survey (USGS-http:/www.usgs.gov). The

study used Landsat 5, Landsat 7 and, Landsat 8 satellite images. The spatial resolution of the Landsat images is 30 m. Landsat images of four different years are digitally processed to study the temporal dynamics of urban green and blue spaces. The image processing steps were followed by a field visit exercise for ground-truthing conducted in the month of January 2020. Google earth images at different time scales were used for accuracy assessment by taking 35 random points. The details of the satellite data used in the study are shown in Table 1.

Method

Remote sensing (RS) and Geographic Information Science/Systems (GIS) are widely used in green and blue spaces studies, management of natural resources, governance and planning at different scales, and smart city initiatives (Anguluri & Narayanan, 2017; Bhaskar, 2012; Singh, 2018; Zlinszky et al., 2015). Geo spatial techniques can better provide data on spatiotemporal dynamics of urban green and blue spaces, their distribution, quality, and quantity (Sathykumar, et al., 2018; Singh, 2018). The present study has employed remote sensing and GIS in all phases of data processing and analysis to achieve the aim of the study. Image processing was started with pre-processing (atmospheric correction) of all the satellite data to convert digital numbers (DN) to the top of atmosphere spectral reflectance. The urban green and blue spaces were extracted from Normalized Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI) respectively.

Normalised difference vegetation index (NDVI)

Remotely sensed information about vegetation has become very important in vegetation assessment, monitoring, and management processes at the local, regional and global levels. Normalized Difference Vegetation Index (NDVI) is one of the most widely used indices calculated from the red and near infrared bands. The normalisation process yield the result varying from (negative) −1 to (positive) + 1 (Rouse et al., 1974). The positive values indicate vegetation cover and the value close to 1 indicate high density of vegetation. NDVI can be expressed as:

$$NDVI = (NIR\ Band - R\ Band)/(NIR\ Band + R\ Band) \tag{1}$$

This study has employed the NDVI method for the computation of UGS. After the process of manual thresholding, the UGS were extracted from the NDVI.

Normalised difference water index (NDWI)
$$\begin{aligned} NDWI = &(Green\ Band - NIR\ Band)/ \\ &(Green\ Band + NIR\ Band) \end{aligned} \tag{2}$$

NDWI is a widely used method to delineate, and extract open water features. It employs green and near infrared bands and is expressed as the formula given in Eq. 2. The value of NDWI varies from (negative) −1 to (positive) + 1. Values from 0 to (positive) + 1 indicate water body.

Computation of urban green space (UGS) distribution and analysis with respect to demographic data

This study has derived UGS in three different years at ward level. In order to extract ward level information, the ward boundary shapefile of Chandannagar city was overlaid on the green space maps. The percentage of UGS and the UGS area per inhabitant in each ward were derived for the years 2001, 2011 and 2020 to assess the quantity of UGS in the neighbourhood. The year 1991 was avoided due to major change in the city boundary. These two quantitative information are considered important parameters in the study of UGS distribution. The percentage of UGS was computed by using the information on area of UGS (in m²) and the geographical area (in m²) of each ward while per inhabitant UGS was computed by dividing the total area of UGS (in m²) in a ward by the ward population. In the present study the assessment was done for the wards from 1 to 33 excluding ward 27.

Fig. 2 Field photo captured during field visit in January, 2020 ▶ (GPS points are shown)

Results

The result of this study is presented in six sections: the first three sections present the UGS and blue space maps of the city and their accuracies for the years 1991, 2001, 2011, and 2020 which were followed by spatiotemporal analysis of NDVI and NDWI. The fourth section analyses the UGS and blue spaces distribution at the ward level. The fifth section deals with per inhabitant UGS and the sixth section analyses the quantity of UGS with respect to the population of the city.

### UGS and blue space maps and their accuracies

Accuracy assessment was performed to validate the results obtained after image processing. The result generated through NDVI and NDWI were verified with the ground data. The field visit was carried out in the month of January, 2020. The GPS locations and field photos are shown in Fig. 2. The estimated overall accuracies of the UGS maps derived from the NDVI function using Landsat data were 81.11%, 91.2%, 88.6% and, 92.5% for the years 1991, 2001, 2011, and 2020 respectively. The estimated overall accuracies of the blue space maps derived from NDWI function using Landsat data were 85.12%, 90.1%, 89.2% and, 82.1% for the years 1991, 2001, 2011 and 2020.

Spatiotemporal analysis of NDVI

The result indicated that the NDVI value derived from Landsat images ranged between −0.25 to 0.24 in the year 1991, −0.22 to 0.40 in 2001, −0.20 to 0.55 in

Table 1 Details of satellite data sets used in the study

Sl. no.	Satellite/Sensor	Date of acquisition	Spatial resolution
1	Landsat 5 (TM)	20 November 1991	30m
2	Landsat 7 (ETM)	04 November 2001	30m
3	Landsat 5 (TM)	07 November 2011	30m
4	Landsat 8 (OLI/TIRS)	20 January 2020	30m
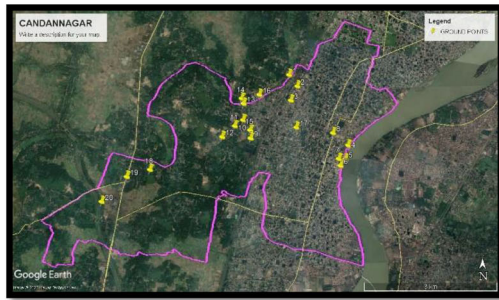
Snapshot of the GPS locations for ground verification (points overlaid on Google Earth image)

Stand road (or bank of river) (GPS Point-6)

Ashram

JT at stand road (GPS Point-5)

Playground in ward no. 10 (GPS Point-7)

KMDA Park and picnic sports (GPS Point-9)

Green area, ward no. 30 (GPS Point-10)

Children park, ward no. 30 (GPS Point-15)

Chandernagore College (GPS Point-6)

Avenue trees (GPS Point-4)

Settlements in ward no.33 (GPS Point-3)

Urban agriculture in ward no. 30 (GPS Point-16)

Settlement near waste site (GPS Point-2)

Orchard in ward no. 28 (GPS Point-12)

Ganga river (GPS Point-4)

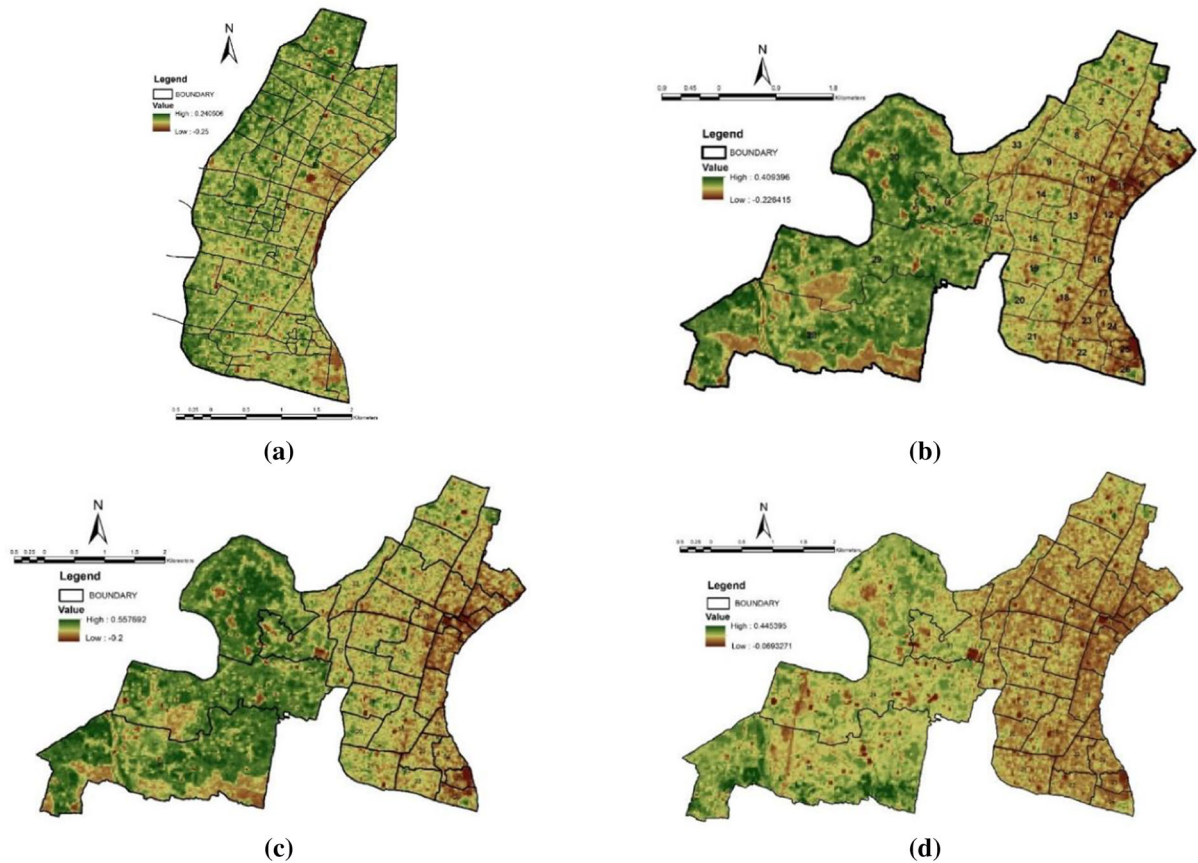Pond in ward no.13 (GPS Point-17)

Saraswathi river (GPS Point-14)

Fig. 3 NDVI derived from Landsat images of the years: (**a**) 1991; (**b**) 2001; (**c**) 2011; (**d**) 2020. Ward boundary of the Municipal Corporation is overlaid on each image

2011, −0.06 to 0.44 in 2020 (Fig. 3). The result indicated that the maximum value of NDVI had increased between the year 1991 to 2020. The higher values in all the years were recorded in the western parts of the city which had a high amount of vegetation cover. The western part of the city has large orchards mainly used for Banana and mango cultivation. The pictures of various UGSs are presented in Fig. 3. The eastern part of the city was mainly dominated by the built-up spaces where the green spaces were found along the roads near Hoogly River, around the roundabouts, in patches as private home gardens, in institutions, and in public buildings. The major green parks in the city are KMDA (Kolkata Municipal Development Authority) park, Chhutti park (Holidays Park), New Digha park and Wonderland park. Table 2 presents the temporal dynamics of the areal coverage of these spaces. A comparison of the four UGS maps (Fig. 4) revealed that between 1991 and 2020 a

notable spatiotemporal change was reported. The reason for the high difference between the years 1991 and 2001 is the change in the boundary of the city. In 1994 the geographical area of the city was increased to 22.03 km^2 (2203 hectare) after the expansion of the municipal boundary. The results presented in Table 2 indicated that the city had 26.31, 31.91, 31.45, and 31.36 percent of the geographical area under urban UGS in 1991, 2001, 2011, and 2020 respectively. The city lost 13.4 hectares of its UGS between 2001 and 2020.

The Urban and Regional Development Plans Formulation & Implementation (URDPFI) Guidelines of Ministry of Urban Development (now as the Ministry of Housing and Urban Affairs) have recommended 12–14% and 14–16% of the land use share for recreational uses for small & medium-sized cities and large & Metropolitan cities respectively. In the case of green cities, the guideline has proposed to

Table 2 Temporal changes in UGS and blue space distribution (Area in hectare)

Sr. no.	Class name	1991		2001		2011		2020		Change between 2001 and 2020 (hectare)
		Area	%	Area	%	Area	%	Area	%	
1	Green spaces	250.38	26.31	703.7	31.91	693.9	31.45	690.3	31.36	−13.4
2	Waterbody	51.48	5.36	209.0	9.50	193.2	8.76	201.0	9.12	−8.0

Percentage is calculated as per the geographical area of the city in different years
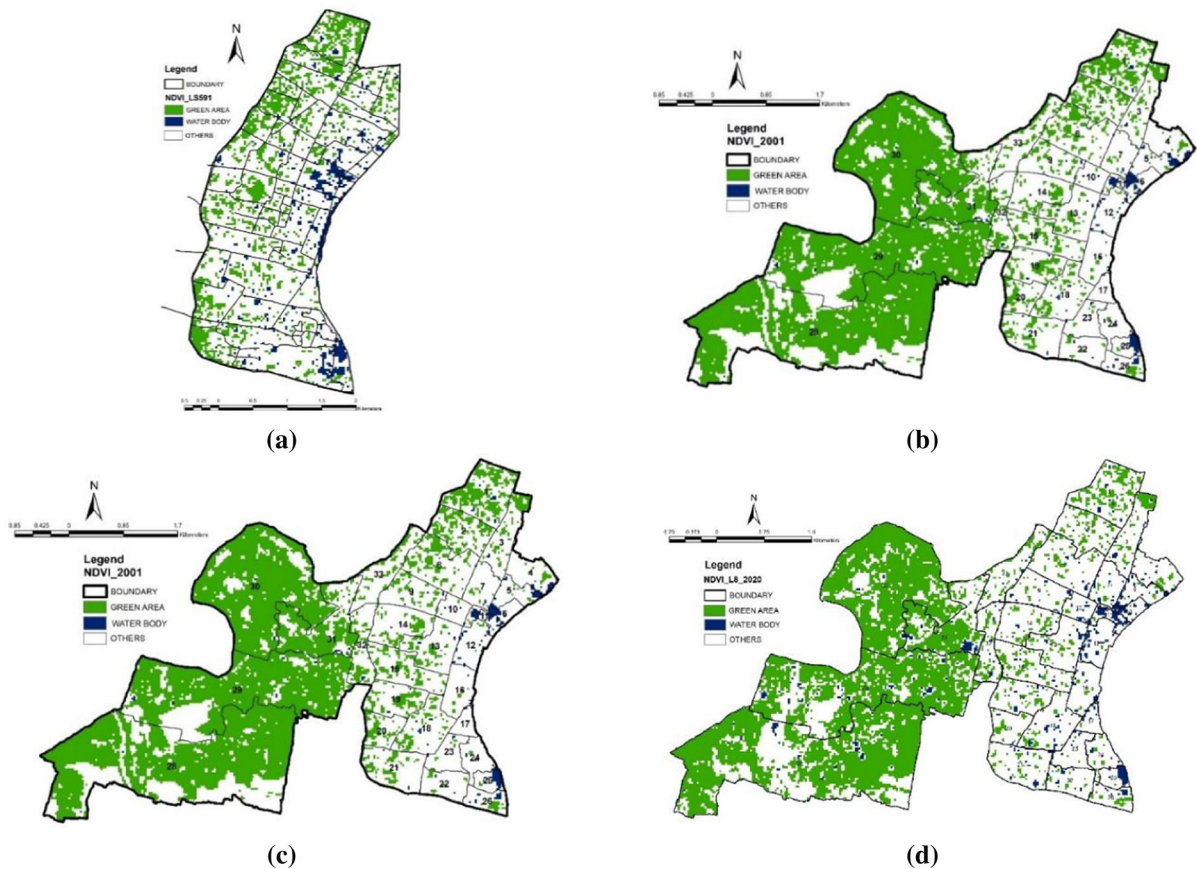

Fig. 4 UGS distribution at ward level in the years: (**a**) 1991; (**b**) 2001; (**c**) 2011 and; (**d**) 2020

earmark about 25–35% of the total area as recreational and open spaces (MoUD, 2014a). The recreational areas in the guidelines include park, playground, garden, open space, water bodies, and other natural features (MoUD, 2014b) and therefore, can be used for comparison. Chandanngar is a small city and has maintained its greenery higher than the specified national standard for recreational and open spaces.

Spatiotemporal analysis of NDWI

The result indicated that the NDWI value ranged between—0.18 to 0.28 in 1991,—0.31 to 0.26 in 2001,—0.47 to 0.21 in 2011 and,—0.27 to 0.07 in 2020 (Fig. 5). The results presented in Table 2 indicated that the city had 5.36 percent of the geographical area under urban blue spaces in 1991. The percentage of blue spaces was 9.50, 8.76, and 9.12 in the years

Fig. 5 NDWI derived from Landsat images for the years: (**a**) 1991; (**b**) 2001; (**c**) 2011; (**d**) 2020

2001, 2011, and 2020 respectively with a negative change of -8.0 hectare between 2001 and 2020. The blue space is even higher due to the location of this city on the west bank of river Hoogly. However, the blue space maps show only the visible water features within the Municipal boundary. The water pixels can be seen distributed all over the city. The city has a high number of ponds inside (Fig. 6).

Urban green space distribution at ward level

In order to derive green space information at the ward level, the ward layer was overlaid on and intersected with the urban green space map. Figure 7 shows the green space distribution (expressed in percentage) for the years 2001, 2011, and 2020. The percentage of UGS ranged from 8 to 51 in 2001 and from 6 to 60% in 2020. The central parts of the cities had less than 15 percent of green cover. The highest percentage of the green cover was reported in ward 29 with more than 60 percent, while the lowest was reported in ward 5 with 6

percent of green cover in the year 2020. Wards 28 and 29 had a high percentage of green cover in both years. There were thirteen wards with less than 15 percent of green cover, ten wards with 16–30 percent of green cover, four wards with 31–40 percent, and three wards with 41–50 percent of green cover in the year 2020. Table 3 has categorized the UGS distribution presented in five different classes for the years 2001, 2011, and 2020. A comparison of the percentage of UGS from 2001 to 2011 and from 2001 to 2020 is shown in Fig. 8a, and b. The result indicated that in both the years, there were only four wards such as 13, 18, 22, and 32 which experienced an increase in UGS percentage while the rest of the wards experienced a decrease in UGS between 2001 and 2020. A maximum decrease was reported in the ward numbers 1, 21, and 25 in the last two decades.
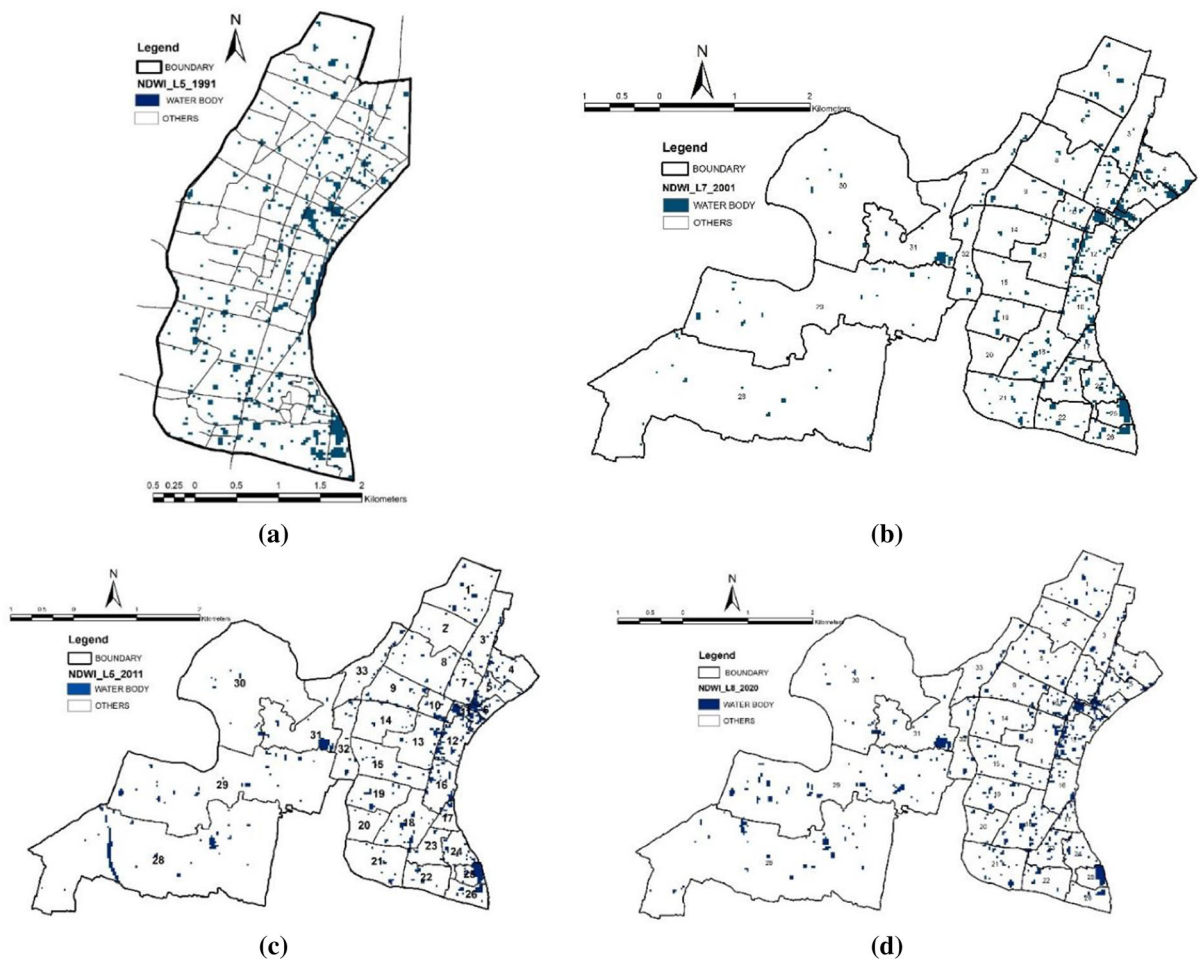
Fig. 6 Blue Space distribution at ward level in the years: (**a**) 1991; (**b**) 2001; (**c**) 2011; (**d**) 2020

Fig. 7 Distribution of UGS expressed in percentage at ward level in the years: (**a**) 2001; (**b**) 2011; (**c**) 2020. Ward numbers are indicated in the map

Per inhabitant UGS distribution at ward level

The World Health Organization (WHO) recommended a minimum of 9 m^2 and an ideal of 50 m^2 of undeveloped or unpaved green and open spaces per inhabitant in every city. It also suggested to develop and design the UGS network in such a way that every inhabitant can live within 15 min of walk to open and

Table 3 UGS distribution in different wards (in different years)

Sl. no	UGS area (%)	Ward numbers (Percentage of UGS in different years is arranged in ascending order)
1	< 15	2001-12, 14, 19, 18, 22, 20, 8, 15, 9, 13, 16
		2011-12, 14, 19, 20, 18, 22, 8, 15, 9, 16
		2020-12, 14, 19, 20, 18, 22, 8, 15, 9, 23, 16
2	15–30	2001-23, 10, 7, 2, 4, 24, 11, 6, 21, 17, 26, 33, 3, 5
		2011-23, 13, 10, 7, 2, 4, 24, 21, 11, 6, 26, 17, 33, 3, 5
		2020-13, 7, 10, 2, 4, 24, 11, 21, 26, 6, 17, 33, 3, 5, 1
3	31–40	2001-32, 25, 1, 31
		2011-1, 32, 25, 31
		2020-25, 32, 31
4	41–50	2001-28, 29
		2011-28, 29
		2020-28, 29, 30
5	> 50	2001-30
		2011-30
		2020-None
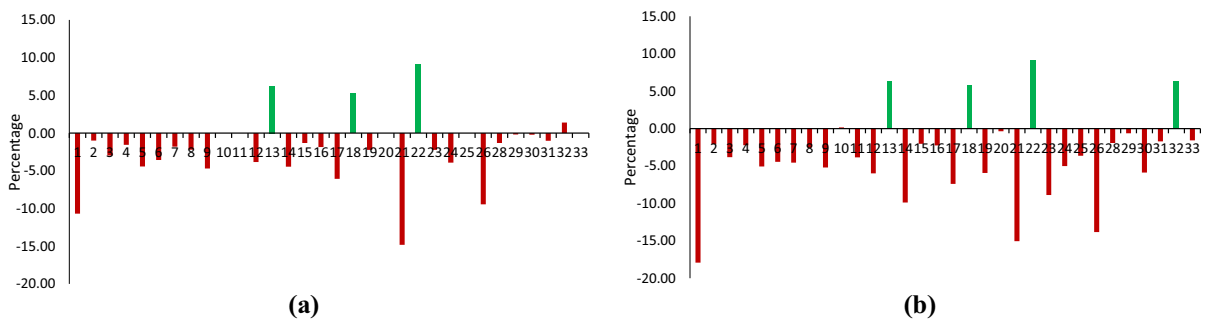
Fig. 8 Comparison of percentage of UGS increases and decreases in wards: (**a**) between 2001 and 2011 and,; (**b**) between 2001 and 2020

UGS (MoUD, 2014b). Since the UGSs are the source of nature-based interaction available within a city, the urban dwellers can live a healthy life if the UGS is more than the minimum (Russo & Cirella, 2018). Per inhabitant UGS for each ward was derived using the population data of 2001 and 2011 and was compared with the international standard. Per inhabitant UGS of the city was 43 m^2, 41.5 m^2, and 41.75 m^2 in the years 2001, 2011, and 2020. Wards 28 and 29 have the highest per inhabitant UGS with more than 300 m^2. On the other hand, there was a total of 11 wards with less than 9 m^2 of UGS in the year 2020 (Table 4 and Fig. 9a, b and c). All these wards are located in the city

core while the wards located in the western part of the city have more than 100 m^2 of UGS (Fig. 9).

Population density and UGS

The relationship between UGS and population density in each ward was revealed a weak and negative relationship between both the variables with R square values of −0.22 and −0.27 for the years 2001 and 2011 respectively (Fig. 10a, and b). The wards with a high population density had less amount of UGS while the wards in the western side which had relatively low population density had a high amount of UGS. The result corroborated the previous studies which had

Table 4 Per inhabitant distribution of UGS in different wards (in different years)

| Sl. no.	Per inhabitant UGS in m^2	Ward numbers (Percentage of UGS in different years is arranged in ascending order)
1	< 9	2001-12, 11, 22, 20, 6, 10, 26, 19, 14
		2011-12, 11, 20, 22, 6, 10, 26, 14, 19, 23, 8
		2020-12, 11, 20, 22, 6, 10, 14, 26, 19, 23, 8
2	9–30	2001-25, 18, 17, 23, 9, 16, 7, 8, 4, 15, 5, 24, 13, 21, 2, 33, 3
		2011-17, 9, 16, 18, 7, 25, 15, 5, 4, 24, 13, 2, 33, 21, 3
		2020-17, 9, 16, 18, 7, 25, 15, 5, 4, 24, 13, 2, 33, 21, 3, 1
3	31–60	2001-32, 1
		2011-1, 32
		2020-32
4	61–90	None in 2001, 2011 and 2020
5	> 90	31, 30, 29, 28 in 2001, 2011 and 2020
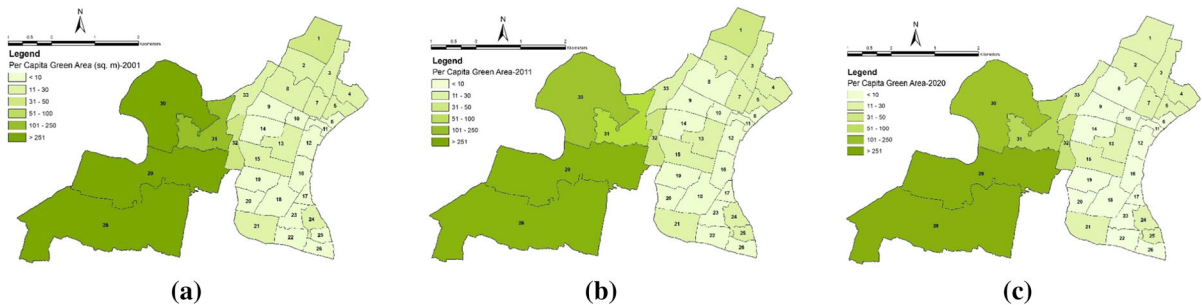
Fig. 9 Per inhabitant UGS (square meters) at ward level in the years: (**a**) 2001; (**b**) 2011; (**c**) 2020
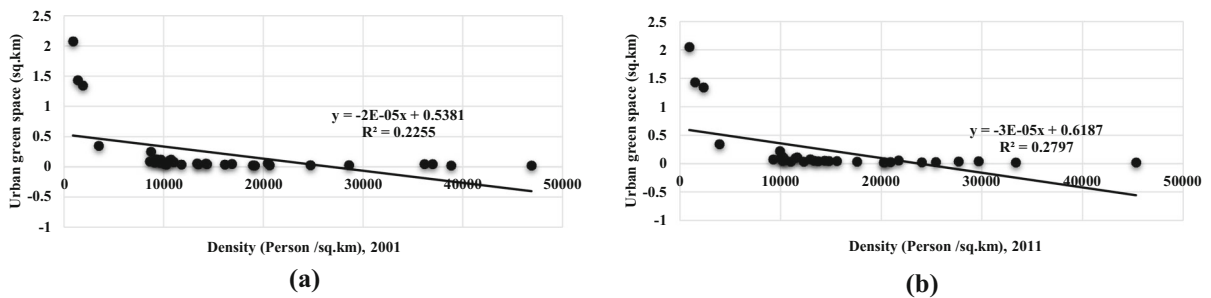

Fig. 10 Ward wise UGS and population density in the years: (**a**) 2001; (**b**) 2011

reported that the percentage and per capita green space was the function of the population density, gross domestic product, and land area (Richards et al., 2017).

Discussion and conclusion

The present study has investigated the spatiotemporal dynamics of urban green and blue spaces in Chandannagar city, India using remote sensing datasets of 1991, 2001, 2011, and 2020. The result reported a reduction of 13 hectares of UGS and 8 hectares of blue spaces in the last two decades. There are 26 wards out

of 31 in which UGS is less than 30%. However, the old city (before the revision of city limits) is facing a reduction in the UGS. The city expanded its territory in 1994 to the western part which was mainly dominated by orchards and agricultural land. Such modification in a city boundary is inevitable due to the pressure of urbanization. However, the demand for residential and commercial activities in the city can have an impact on the UGS of these wards in the future. The city needs an approach to save the orchard-dominated UGS from land-use conversion. The overall UGS in the city was high due to the wards located in the western part of the city otherwise the core of the city is losing its UGS. The UGS per resident in the city is 41.75 m^2 which is close to the standard recommended by WHO. However, all wards with less than 9 m^2 of UGS should be given priority in planning of UGS. UGS management is essential in the central part of the city.

Another observation found during the study was the spatial configuration of the UGS. In the eastern part of the city, along the river, a linear arrangement formed by the trees of the avenue can be seen (although the connection to the road network is interrupted). The connected network of UGS performs multiple functions within the landscape, including the pathway of movement for the people (Ahern, 2007; Mell, 2008).

Throughout the city, green spots made of trees can be seen along with private gardens. The water bodies and pond are surrounded by UGS composed of shrubs and trees. While this paper has attempted to quantify the amount of UGS over different time-periods, future research on the integration of UGS quality, multidimensional usability (Lennon et al., 2017) and spatial metrics may bring more interesting result. Small and medium-sized cities such as Chandannagar can generate different insights into how the UGS is integrated with the socio-ecological and planning system of urban space.

The high amount of green and blue space maintains a city's ecological function and environmental quality and is vital to the well-being of the city's residents. The presence of UGS in the proximity of homes and exposure to the natural environment is found to enhance the mental and physical health of urban dwellers (Bourdeau-Lepage, 2017; Twohig-Bennett & Jones, 2018). Howard (1985), in his urban design, had placed emphasis on the diverse and multi-functional benefits of the UGS and had suggested placing UGS in

close proximity of residential zones for the physical and mental health of people (Singh et al., 2021). People's well-being depends to a large extent on their connection with nature and if the connection is broken then their health is affected (Soga & Gaston, 2016). These spaces can play an important role in preparing policy and plans for a sustainable city (Lahoti et al., 2019). Planning, development, and conservation of UGS require two factors namely availability of land and adequate water supply (Ramaiah & Avtar, 2019). The city of Chandannagar is provided by naturally fertile soil and good water resources in the vicinity. The development of urban nature is linked with the development of the city through its planning stages. Therefore, the natural setting and historical development have shaped the natural component of the city. There is a need to protect urban nature from changing to other land uses in the future.

Most of the big cities face the problem of water scarcity due to which the creation or maintenance of public or private UGS is not given priority by the urban local bodies. However, it may be given priority in cities where water resources are available. Water resources are an integral part of the sustainable urban landscape and play a major role in the development and sustenance of UGS. Many researchers see water resources as a potential sub-category of blue-green infrastructure (Ahern, 2007).

Although this study did not observe many changes with respect to blue spaces, however, there is a need to protect the existing water bodies from any future encroachment. Change in built up spaces from water bodies and open spaces was observed at few places in the city and such practices are likely to increase in future with the increase in demand of land for various uses. Ponds and other water bodies act as a sponge and help the accumulation of rainwater and enhance the groundwater level in an area. These spaces also regulate the heat of a city. Water bodies do not only enhance the environmental quality of a city, but also enhance its aesthetic quality and give an identity to it (Bindu & Mohamed, 2016). In a country like India, people have different values towards nature. These places have not only physical values, but also cultural and biodiversity values (Jaganmohan et al., 2018).

People associate their feelings with nature. Understanding human nature's relationship through this lens can help better formulate strategies to protect urban nature. The western part of the city has orchards which

are contributing to the economy of the city as well as the state. These UGS have the potential to support and improve the quality of the urban environment and meet the social and cultural needs of the people. Wards in the city core with less than 9 m^2 of UGS have high built-up density and therefore, any destruction of existing trees should be avoided. This study is the first of its kind in the preparation of ward-level UGC data for different time periods of Chandannagar city. All maps have identified the areas where conservation or management of UGS is required.

Limitations and future study

Although this study is the first of its kind on micro-scale analysis of urban green spaces in Chandannagar city over different time periods, this study has some limitations. Urban mapping requires high-resolution data, but high-resolution data for different time intervals are not readily available and, therefore, this study faces a limitation of spatial resolution. A similar study can be done using high-resolution satellite data. Apart from quantity, quality of green spaces can give better results on the functionality of UGS. This study quantified the distribution of water bodies in the city, however, ward level data could not be generated due to mixing of water pixels with built up pixels.

Author contributions Both authors contributed to the study concept and design. Data collection and preparation were done by the first author. Data processing, analysis and validation were performed by both the authors. The first draft was written by second author and both authors contributed to the finalization of the manuscript. They approved the final manuscript.

Declarations

Conflict of interest The authors declare no conflict of interest.

Human and animal rights The article does not contain any materials involving human participants or animals during the study.

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