# Impact of rapid urban growth on land use / land cover change and loss of urban green spaces: A comparative study of Guwahati city and Siliguri city, India

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**ABSTRACT**
This article analyzes the impact of the rapid growth of cities in India on their land-use and land-cover patterns. It is based on the case study of cities of Guwahati in the state of Assam and Siliguri in the state of West Bengal. Analyzing Census of India data between 1971 and 2011 and utilizing multi-temporal Landsat data from 1990 to 2020, the article employs GIS techniques, including the maximum likelihood algorithm for supervised classification, to generate comprehensive land use and land cover maps of these two cities. The normalized difference vegetation index (NDVI) method is additionally applied to discern changes in forest cover from 1990 to 2020. The analysis revealed rapid horizontal and vertical urban expansion of both Guwahati and Siliguri, accompanied by the conversion of forest and agricultural lands into built-up areas. The findings emphasize an urgent need for a robust policy framework to facilitate sustainable urban development and address the looming environmental challenges posed by the loss of green spaces in both cities and other urban regions of India.

**KEYWORDS**
urban growth; land use; NDVI; Guwahati City; Siliguri City; India

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## 1. Introduction

For the last few decades, there has been rapid growth and development of urban areas in most parts of the globe. It has become more so in many of the developing countries like India. Such a rapid growth of urban population in India has contributed to an increase in its urban population from 79 million to 388 million during 1961–2011 (Census of India 2011). This phenomenon of urban population growth in the country is mainly due to large-scale migration of people from rural and smaller towns to bigger cities in search of better employment opportunities and better quality of life (Bhat et al. 2017). Moreover, rapid urban population growth combined with unplanned development of urban areas in the country has been exerting tremendous pressure on its limited natural resources and land use and land cover (Sudhira et al. 2004). This type of rapid change in land cover often results in the loss of productive agricultural land, destruction of habitat, decline in the open green spaces, and loss of surface water bodies (Lopez et al. 2001; Alphan 2003; Swanwick et al. 2003; Kong and Nagagoshi 2006). Furthermore, the relentless expansion of urban areas stands as a primary driver behind deforestation, with urban green spaces emerging as a pivotal facet of urban ecosystems. These green havens not only furnish numerous environmental benefits but also serve as vital contributors to the overall well-being of city dwellers. Often regarded as the 'lungs' of urban environments, these green spaces play an indispensable role in upholding a city's sustainability by bolstering essential ecological functions that enhance both the natural and social fabric of urban landscapes. Regrettably, in recent decades, there has been an alarming depletion of urban green spaces, particularly in rapidly urbanizing developing nations like India (Siddique et al. 2020). This trend poses a grave threat to the ecological equilibrium of metropolitan areas, as substantial portions of tree cover, green spaces, and wetlands have been haphazardly transformed into built-up areas through unchecked processes of land use and land cover change, a trend that continues unabated. Accordingly, land use and land cover (LU/LC) changes predominantly caused by anthropogenic activities are one of the key components of local, regional, and global environmental change (Sala et al. 2000; Grimm et al. 2000; Lambin et al. 2003; Jensen 2005; Guan et al. 2011; Wu et al. 2013; Halmy et al. 2015). These human-induced land use and land cover changes also reflect the culmination of interaction between climate, ecosystem processes, biogeochemical cycles, and other biodiversity indicators (IGBP 1999).

The growth of cities is causing increasing stress on many aspects of the urban environment is reflected in many studies undertaken in recent times in different parts of the world. As a coping strategy sustainable development has been considered as a means of ensuring the human impacts within the capacity of the earth's environment (Trinder and Liu 2020). Moreover, a significant impact of land use change on green space loss and consequent environmental problems has been observed in Indian cities. A plethora of research has proved that urban growth resulting from land use and land cover change has adverse effects in the forms of biodiversity degradation, urban heat island formation, habitat fragmentation, drainage and water-logging problem, ground water depletion, micro-climate change, etc among many others (Griggs et al. 2014; de Souza et al. 2016; Son and Thanh 2017; Pawe and Saikia 2020). Thus, the insights obtained from understanding the dynamics of land use/land cover changes and their trajectories, including quantifying the extent of transformation in urban green spaces can help urban developers, planners, and policymakers for a healthy living environment in the urban areas. Moreover, this knowledge is essential for formulating effective planning strategies aimed at fostering the sustainable management of urban systems (Miller et al. 1998; Welch et al. 2002; Parmenter et al. 2003; Wang and Moskovits 2001; Manandhar et al. 2009; Zhang et al. 2017; Huang et al. 2018; Munthali et al. 2019; Parvez and Islam 2019; Abir and Saha 2021; Jahan et al. 2021; Shao et al. 2021).

With above background two growing cities of metropolitan character located in north-eastern region of India, namely Guwahati in Assam (Gateway to north-eastern region) and Siliguri in West Bengal (Gateway to Nepal, Bhutan, Bihar and Sikkim) are considered for comparative analysis of the pattern of urban growth and its impact on land use and land cover change and green space dynamics during the period 1990–2020. During the post-independence period, both cities have experienced a considerably high rate of population growth particularly due to the influx of people from the surrounding areas and other parts of the country, and also neighbouring countries of Bangladesh and Nepal. This phenomenon has greatly changed the demographic scenario of both cities in terms of population and associated characteristics within a short period. For example, Guwahati's city area expanded from 14.24 $km^2$ to 216.79 $km^2$ between 1961 and 1981, while Siliguri experienced growth from 15.54 $km^2$ to 41.90 $km^2$ from 1971 to 1991 (Census of India 1971 and 1991). The urban morphology of both cities and their outskirts has undergone marked changes, characterized by the unregulated growth of urban functions and infrastructure. Substantial portions of water bodies, agricultural lands, forested areas, and barren lands in the city periphery have been converted into residential and commercial zones (Hemani and Das 2016; Pawe and Saikia 2018; Sarkar and Chouhan 2019; Bhattacharjee et al. 2022). Furthermore, the once plentiful urban green spaces, crucial environmental assets comprising open areas primarily covered by vegetation, are facing rapid depletion and destruction at an alarming rate over the last few decades. Therefore, preserving and sustaining these urban green spaces is imperative and necessitates a comprehensive public policy or city development plan. Such initiatives are crucial not only for the conservation of green spaces but also for enhancing the liveability and well-being of the urban communities in the study areas.

## 2. Study area

Looking at similarities in physical and socio-economic background, the growing cities of Guwahati and Siliguri have been selected for a comparative study. Guwahati, the largest city in North-East India, is located on the southern bank of the river Brahmaputra, bounded by Meghalaya hills on the south, Palasbari plain on the west, the Sila Grant reserved forest on the north, and the hills and plains of Chandrapur area on the east. Geographically, it is located at 26°5′N latitude and 91°51′E longitude and 193 feet above mean sea level with an area of 216.79 km$^2$. The city is situated on a flat plain interrupted by small hillocks rising up to a height of 300 m and a large number of wetlands and low-lying areas. It acts as a gateway to the north-east region for its locational advantages. The city experiences a humid sub- tropical climate characterized by the peak summer temperature rising to 38 °C, while in winter, it sometimes falls to 10 °C. The city receives an average annual rainfall of 200 cm. The total population of the city according to 2011 census stands at 9, 62,334 with a sex ratio of 931 females per 1000 males and population density of 4,393 persons/km$^2$. On the other hand, Siliguri city, which is one of the rapidly growing cities in West Bengal and sub-divisional headquarters of Darjeeling District and situated on the banks of river Mahananda and the foothills of the eastern Himalayan region. Geographically, it is located at 26°39′N latitude and 88°47′E longitude and 392 feet above mean sea level with an area of 41.90 km$^2$. The whole city area is very closely located from the countries of China, Bangladesh, Nepal, and Bhutan. Besides, the city forms the entry point to the north-eastern states, and as such it acts as a gateway to north-east India (Fig. 1). The city experiences a humid sub-tropical climate, being characterised by hot summers and dry winters. The average maximum temperature in summer and average minimum temperature in winter range between 38 °C and 15 °C. During the monsoon season (June to September) the city is lashed by heavy rains. The total population of the city according to the 2011 Census is 5, 13,264 with a population density of 12,249 persons/km$^2$. Its sex ratio stands at 946 females per 1,000 males.

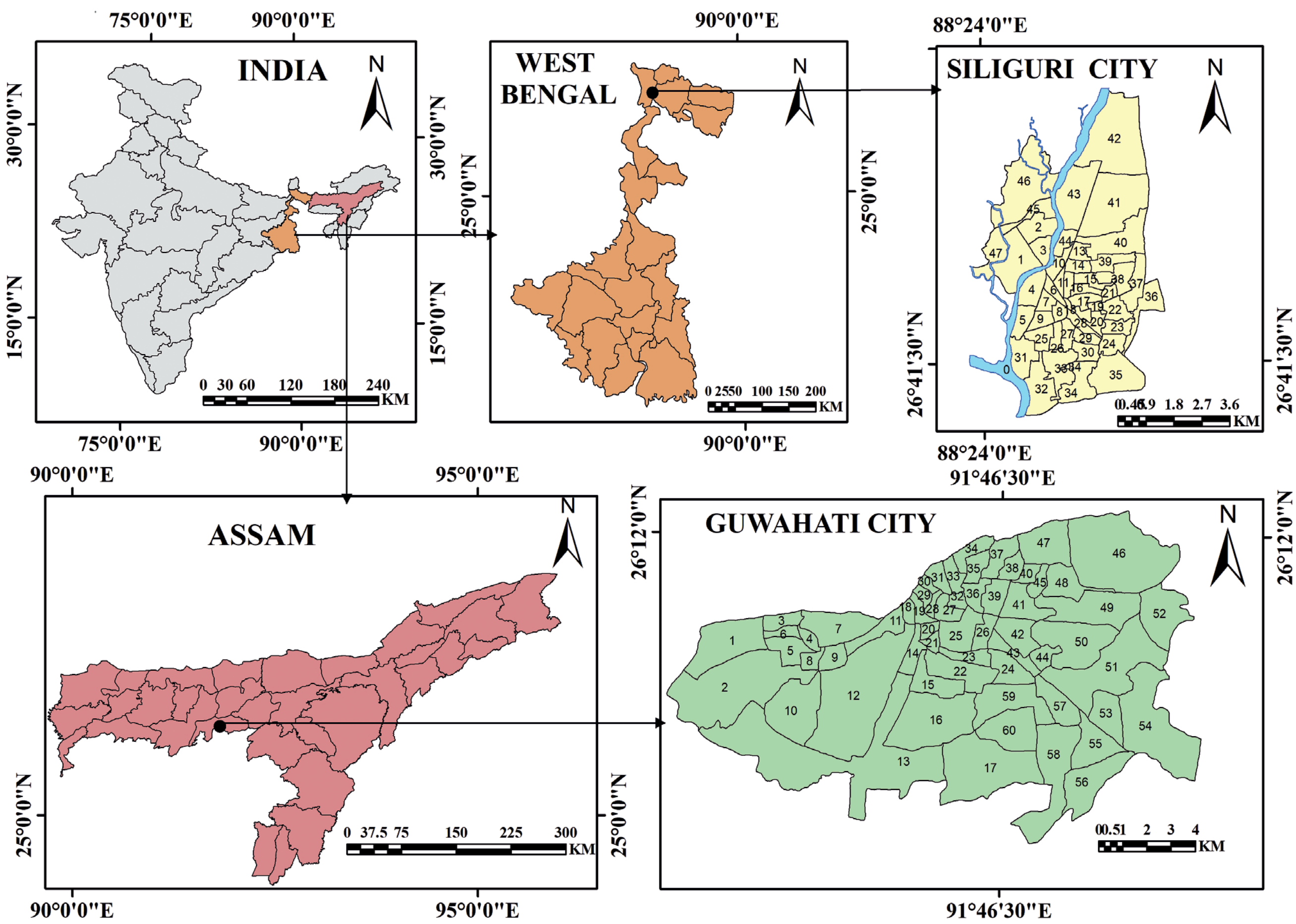



Fig. 1 Location map of the study area (Guwahati city and Siliguri city).

**Tab. 1** List of Landsat data sets used in the study.

| Satellite | | Spatial Resolution (m) | Path/Row | Acquisition Date |
|---|---|---|---|---|
| Gawahati City | Landsat_5 TM | 30 | 139/42 | 6/2/1990 |
| | Landsat_5 TM | 30 | 137/42 | 17/2/2005 |
| | Landsat 8 OLI TIRS | 30 | 137/42 | 11/2/2020 |
| Siliguri city | Landsat_5 TM | 30 | 139/42 | 6/2/1990 |
| | Landsat_5 TM | 30 | 139/42 | 15/2/2005 |
| | Landsat 8 OLI TIRS | 30 | 139/42 | 9/2/2020 |

Source: Landsat data collected from USGS Earth Explorer.

## 3. Materials and methods

The study is largely based on secondary data. The data related to population growth have been collected from Census of India publications for the period 1971–2011. Further, remote sensing data have been acquired from six cloud free Landsat images from the United States Geological Survey website. In order to fulfill the objective of comparing the two cities, all the images have been taken for same season of the year (Tab. 1). Accordingly, in order to understand the dynamics of urban growth pattern land use/land cover change analysis has been done and six land use maps have been prepared with the help of GIS environment (Fig. 2).

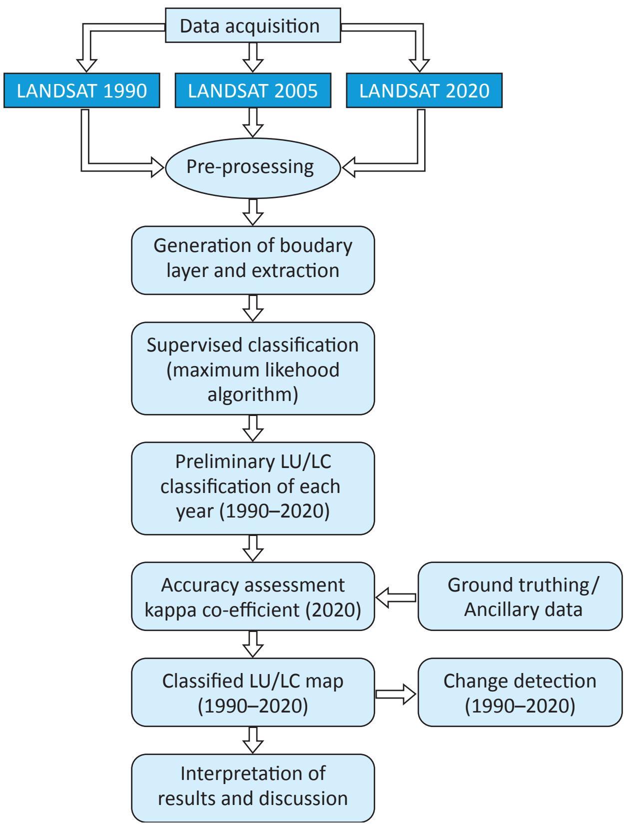



**Fig. 2** Flow chart of the methodology of the study.

### 3.1 Image classification

Image clasification, which helps categorising an image into a smaller number of individual classess based on its spectral reflectance values (Jensen 2005), has been done through supervised classification technique by applying maximum likelihood algorithm. Hence, ground verification has been done by extensive GPS based field survey and ground control points of Google Earth pro software to get accuracy of result obtained for different land use categories. Furthermore, five land use classess like Agricultural land, Barren land, Forest, Built-up and Water body have been identified with the help of image interpretation elements and terrain characteristics of the study area (Tab. 2). Further, Sankey charts were also created using Python programming to illustrate the land use/land cover change matrix.

### 3.2 Accuracy assessment of the images

For validating the digitally classified images ground reference data were collected from google earth map and field visits with GPS. Accordingly, accuracy assessment was done for 2020 image and a total of

**Tab. 2** LU/LC classification scheme used in the study.

| LU/LC Classess | Description |
|---|---|
| Agricultural Land | All cultivated and uncultivated agricultural land areas such as farmlands, crop fields including fallow land. |
| Barren Land | Areas around and within forest protected areas with no or very little vegetation cover including exposed soils, rock, stone quarry, landfill sites and the areas of active excavation. |
| Forest | Decidous forest, mixed forest land, plantation, protected forest. |
| Built-up | Residential, commercial and services, industrial, socio-economic infrastructure and mixed urban and other urban, tranportation, road and railways. |
| Water Body | River, ponds, wetlands and reservoirs |

Source: USGS Classification of land use and land cover, level-I.

**Tab. 3** Confusion (error) matrix for 2020 LU/LC change map of Guwahati city.

| Classified Image Categories | Agricultural Land | Barren Land | Forest | Built -up | Water Body | Row Total | User's Accuracy |
|---|---|---|---|---|---|---|---|
| Agricultural Land | 41 | 0 | 2 | 2 | 0 | 45 | 91.00% |
| Barren Land | 0 | 41 | 6 | 1 | 3 | 51 | 80.39% |
| Forest | 4 | 0 | 45 | 2 | 1 | 52 | 86.54% |
| Built-up | 2 | 0 | 0 | 43 | 3 | 48 | 89.58% |
| Water Body | 7 | 4 | 1 | 0 | 42 | 54 | 77.77% |
| Colum Total | 54 | 45 | 54 | 48 | 49 | 250 | |
| Producer's Accuracy | 75.93% | 91.11% | 83.33% | 89.58% | 85.71% | | |
| Overall Accuracy | | | 84.80% | | | | |
| Kappa Co-efficient | | | 0.68 | | | | |

250 testing pixels were generated randomly. Afterthat, testing pixels were comapared with the classified map. Error matrix was applied to evaluate the user's and producer's accuracy and then compare the relationship between classified map data and reference data. Finally land use / land cover maps were produced with the help of user's accuracy, producer's accuracy, overall accuracy and Kappa coefficient (1, 2, 3, 4) The overall accuracy for 2020 classified maps of Guwahati city and Siliguri city are found to be 84.80% and 83.20% respectively. Hence, higher value of users accuracy in the land use class for Guwahati city is found in agricultural land and built-up area with 91.00% and 89.58% , the lower accuracy was occurred in the water body with 77.77% and and barren land with 80.39% (Tab. 3).

$$K = \frac{N\sum_{i=l}^{r} X_{ii} - \sum_{i=l}^{r}(X_i + * x_{+i})}{N^2 - \sum_{i=l}^{r}(X_i + * x_{+i})} \quad (1)$$

where K = Kappa coefficient of agreement,
N = Total number of observations (sample points),
$X_{ii}$ = Diagonal; $X_{+i}$ = Marginal row total (column i),
$X_{i+}$ = Marginal row total (row i).

$$\text{Overall Accuracy} = \frac{\text{Number of Correctly Classified Pixels (diagonal)}}{\text{Total Diagonal of Reference Pixels}} \times 100 \quad (2)$$

$$\text{User's Accuracy} = \frac{\text{Number of Correctly Classified Pixels in Each Category}}{\text{Total Number of Reference Pixels in Each Category (Row Total)}} \times 100 \quad (3)$$

$$\text{Producer's Accuracy} = \frac{\text{Number of Correctly Classified Pixels in Each Category}}{\text{Total Number of Reference Pixels in Each Category (Column Total)}} \times 100 \quad (4)$$

On the other hand, the higher value of users accuracy in the land use class for Siliguri city is found in agricultural land with 86.67% and forest with 86.27% (Tab. 4). The lower accuracy is found in the case of water body with 77.78% and built-up land with 81.13% for the year 2020. Similarly Kappa coefficient is found to be 0.68 for Guwahati city and 0.64 for Siliguri city. Hence, Kappa coefficient method is used to assess how well the result of the remotely sensed classification matches with referenced data (Cohen 1960; Kar et al. 2018). Therefore, both the maps of the study area have been prepared with the minimum accuracy requirements to be used for the subsequent post-classification operation.

**Tab. 4** Confusion (error) matrix for 2020 LU/LC change map of Siliguri city.

| Classified Image Categories | Agricultural Land | Barren Land | Forest | Built -up | Water Body | Row Total | User's Accuracy |
|---|---|---|---|---|---|---|---|
| Agricultural Land | 39 | 2 | 4 | 0 | 0 | 45 | 86.67% |
| Barren Land | 2 | 40 | 0 | 0 | 5 | 47 | 85.10% |
| Forest | 1 | 3 | 44 | 1 | 2 | 51 | 86.27% |
| Built-up | 0 | 4 | 6 | 43 | 0 | 53 | 81.13% |
| Water Body | 3 | 3 | 0 | 6 | 42 | 54 | 77.78% |
| Colum Total | 45 | 52 | 54 | 50 | 49 | 250 | |
| Producer's Accuracy | 86.67% | 76.92% | 81.48% | 86.00% | 85.71% | | |
| Overall Accuracy | | 83.20% | | | | | |
| Kappa Co-efficient | | 0.64 | | | | | |

### 3.3 Annual rate of change

The annual rates of change of LULC during three different periods (1991–2001, 2001–2015 and 1991–2015) have been calculated according to the procedure introduced by (Puyravad 2003; Teferi et al. 2013 and Batar et al. 2017) (5). This equation provides a benchmark for comparing LU/LC changes that are not sensitive to different periods during the study period.

$$r = \left(\frac{1}{t_1 - t_2}\right) \times ln\left(\frac{A_2}{A_1}\right) \quad (5)$$

where $r$ is the annual rate of change for each class per year, $A_2$ and $A_1$ are the class areas ($km^2$) at time 2 and time 1 respectively and $t$ is time (in year) interval between the two periods.

### 3.4 Gains and losses of LU/LC net change

Net change is the difference between the gain and loss (Teferi et al. 2013). The gains and losses of the land use and land cover during the study period have been derived from the cross tabulation for the year 1990, 2005 and 2020.

### 3.5 Calculation of Enhanced built-up and bareness index (EBBI)

The EBBI is a remote sensing index that applies bands of NIR, SWIR, and TIR. The NIR and SWIR bands are associated with a high contrast level for detecting built-up and bare land areas. In addition, in these bands, there is an inverse reflectance ratio with respect to detecting built-up or bare land areas (As-syakur et al. 2012).

$$\text{EBBI} = \frac{\text{SWIR} - \text{NIR}}{10\sqrt{(\text{SWIR} + \text{TIR})}} \quad (6)$$

### 3.6 Calculation of Normalized difference vegetation index (NDVI)

The calculation of NDVI is performed using the applied method of (Townshend and Justice 1986)

$$\text{NDVI} = \frac{(\text{NIR band} - \text{Rband})}{(\text{NIR band} + \text{Rband})} \quad (7)$$

where NIR means near infrared band and R means red band. For LANDSAT TM data band 3 and 4 and for LANDSAT OLI data band 4 and 5 were used to calculate NDVI. Hence, the NDVI value ranges from −1 to + 1. Values from 0 to +1 indicate vegetation cover. The values near to 0 indicate low vegetation cover and the values close to 1 indicate high density of vegetation.

## 4. Results

### 4.1 Pattern of population growth

The growth of population in terms of space and time is an important parameter to understand the pattern of urban growth, and the functional behaviour of people who live and work in the urban areas (Shanker 2001). So far the cities of Guwahati and Siliguri are concerned, both witnessed a phenomenal growth of population since the pre-independence period due to their geographically significant location and diverse functions. In the case of Guwahati city the population size has increased especially after shifting of the state capital from Shillong to Dispur (Guwahati) in 1972 with the establishment of new administrative centres, educational institutions, industries along with the expansion of trade and commerce (Begum 2010). This resulted in tremendous increase in population in the city during the last four decades (1971–2011).

**Tab. 5** Trend of urban population growth in Guwahati city and Siliguri city (1971–2011).

| | Year | Total Population | Decadal Growth Rate (in %) | Annual Growth Rate (in %) |
|---|---|---|---|---|
| Guwahati city | 1971 | 1,23,783 | – | – |
| | 1981 | Census not held | | |
| | 1991 | 5,84,342 | 372.07 | 8.06 |
| | 2001 | 8,09,895 | 38.60 | 3.32 |
| | 2011 | 9,62,334 | 18.82 | 1.74 |
| Siliguri city | 1971 | 97,484 | 48.90 | – |
| | 1981 | 1,54,378 | 58.36 | 4.70 |
| | 1991 | 2,16,950 | 40.53 | 3.46 |
| | 2001 | 4,72,374 | 117.73 | 8.09 |
| | 2011 | 5,13,264 | 8.66 | 0.83 |

* Census not held due to disturbation

Source: Census of India, 1971–2011, District Census Handbook, Kamrup District (Metro), Assam and Darjeeling District and Jalpaiguri District, West Bengal.

Its population has increased from as low as 1,23,783 in 1971 to as large as 9,62,334 in 2011 with annual growth rate ranges between 8.06% during 1971–1991 and 1.74% during the period 1991–2011 (Tab. 5). After the upgradation as city corporation in 1974, the municipal area of Guwahati increased from 14.24 km$^2$ in 1971 Census to 216.79 km$^2$ in 1991 Census with the inclusion of vast fringe areas within the city limit. At present, although the city area is witnessing a considerable decline in population growth rate, it had been as high as 372.07% during 1971–1991 as against the corresponding growth rate of 64.69% during 1991–2011.

On the other hand, Siliguri city experienced its population growth from as small as 97,484 in 1971 to as large as 5,13,264 in 2011, with the annual growth rate ranging between 8.09% during 1991–2001 and 0.83% the period 2001–2011. At the time of independence, a large number of refugees from the then East Pakistan (now Bangladesh) contributed to the rapid growth of population of Siliguri town, and in 1984 it was declared as a Class I town with a population of more than 1.5 lakhs. Till 1994 the Siliguri municipality had 30 wards with an area of 15.54 km$^2$. In the same year, after declaration of corporation status 17 new wards were added to the city and thereby its total area increased to 41.90 km$^2$. The Siliguri Municipal Corporation (SMC) spreads into the districts of Darjeeling and Jalpaiguri. At present, out of 47 wards of the SMC, 33 fall in Darjeeling district and the remaining 14 wards in the neighbouring district of Jalpaiguri (CDP 2015). It is worth mentioning that although Siliguri city has not experienced marked expansion in its area, its population size has increased at a rapid rate during the period 1971–2011 and the growth rate has always remained higher than the urban population growth rates of the district and state.

## 4.2 Land use / land cover change dynamics

The land use and land cover (LU/LC) pattern of an area is an outcome of the interplay of natural and socio-economic factors shaped by human activities over time and space (Mir and Ahmad 2014). The escalating global population and its surging demands for diverse activities have notably contributed to widespread land use and land cover changes on a worldwide scale (Seto and Kaufmann 2003; Kumar 2011). Notably, anthropogenic activities' impact on LU/LC changes stands as a fundamental driver of environmental transformations at local, regional and global scales (Munthali et al. 2019).

Against this backdrop, the study area encompassing Guwahati and Siliguri has undergone rapid land transformation over an extended period spanning from 1990 to 2020, propelled by mounting population pressure and the expansion of commercial and administrative functions in and around urban areas (Fig. 3). Throughout the study period, which spans from 1990 to 2020, agricultural land and forest areas remained predominant LU/LC classes in the region. In 1990, the total agricultural land area in Guwahati constituted 35.46% of the total area, a proportion that decreased to 33.55% in 2005. Similarly, the forest area decreased from 27.34% in 1990 to 26.66% in 2005. Concurrently, water bodies and barren land areas also experienced some decline in the proportion during the same period. In contrast, the built-up area in Guwahati accounting for only 5.27% in 1990 expanded significantly to 15.53% in 2005, and it became even more noticeable (32.38%) during 2005–2020 at the cost of considerable decline in the proportions of agricultural land, forests and barren land (Tab. 6, Fig. 3). But the long-term annual rate of change notably declined for agricultural land, forest, barren land and

**Tab. 6** LU/LC change trend and annual rate of change in Guwahati city and Siliguri city.

| LU/LC Categories | 1990 (%) | 2005 (%) | 2020 (%) | Change | | | Annual Rate of Change | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1990–2005 | 2005–2020 | 1990–2020 | 1990–2005 | 2005–2020 | 1990–2020 |
| Guwahati City | | | | | | | | | |
| Agricultural Land | 35.46 | 33.55 | 24.36 | −1.91 | −9.19 | −11.1 | −0.37 | −2.13 | −1.25 |
| Barren Land | 26.16 | 19.23 | 14.82 | −6.93 | −4.41 | −11.34 | −2.05 | −1.74 | −1.90 |
| Forest | 27.34 | 26.66 | 23.31 | −0.68 | −3.35 | −4.03 | −0.17 | −0.90 | −0.53 |
| Built-up | 5.27 | 15.53 | 32.38 | +10.26 | +16.85 | +27.11 | +7.20 | +4.90 | +6.05 |
| Water Body | 5.77 | 5.04 | 5.13 | −0.73 | +0.09 | −0.64 | −0.90 | +0.11 | −0.39 |
| Siliguri City | | | | | | | | | |
| Agricultural Land | 31.04 | 28.40 | 19.53 | −2.64 | −8.87 | −11.51 | −0.63 | −2.46 | −1.54 |
| Barren Land | 25.51 | 17.89 | 12.32 | −7.62 | −5.57 | −13.19 | −2.40 | −2.44 | −2.43 |
| Forest | 20.14 | 10.50 | 4.24 | −9.64 | −6.26 | −15.9 | −4.38 | −6.00 | −5.19 |
| Built-up | 13.43 | 37.38 | 56.31 | +23.95 | +18.93 | +42.88 | +6.79 | +2.77 | +4.78 |
| Water Body | 9.88 | 5.83 | 7.60 | −4.05 | +1.77 | −2.28 | −3.56 | +1.81 | −0.87 |

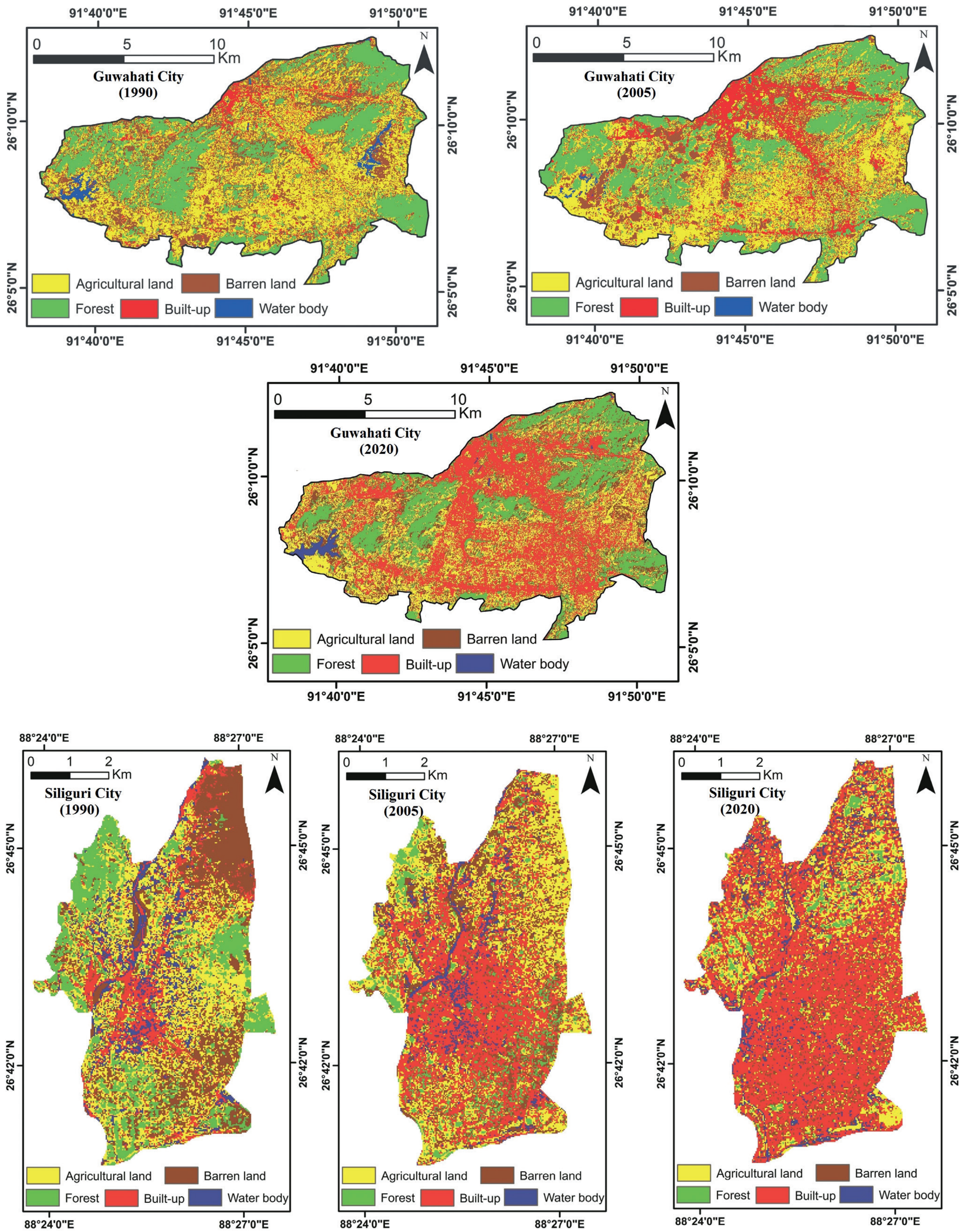



**Fig. 3** Trends in land use / land cover change in Guwahati city and Siliguri city (1990–2020).

water body areas. Conversely, the built-up area experienced an overall increase in annual rates of change during 1990–2020. In the Siliguri city area, the land use transformation has been quite distinct. In 1990, the built-up area constituted 13.43% of the total area, which rose to 37.38% in 2005 (Fig. 3). During this period the proportion of agricultural land, barren land, forest, and water body decreased significantly.

Remarkably, during the subsequent period of 2005–2020, Siliguri city experienced significant land use transformation further expansion of built-up area, underscoring the dynamic nature of urban growth and its associated environmental implications.

In the year 2020, the built-up area covered a large expanse of Siliguri city (56.31%) (Fig. 3). Concurrently, agricultural land, barren land, and forest areas witnessed a marked reduction during 2005–2020. On the other hand, expansion of area under water body to the extent of 7.60% is attributed to the reclamation of dying waterbodies and their better management during that period (Hoque and Rohatgi 2022). Agricultural land, forest, barren land, and water body areas exhibited considerable decline during 1990–2020. In contrast, the built-up area experienced an overall increase in annual rates of change from 6.79% $km^2$ to 4.78% $km^2$ over the same period. This data suggests a trend of increasing built-up areas during 2005-2020, which indicates that both the cities have undergone haphazard growth and sprawl due to unplanned and uncontrolled development of various infrastructural setups. Consequently, this has led to a drastic change in the previous land-use system.

## 4.3 Gain and loss of land use and land cover (net change)

The comprehensive analysis of net change in terms of gains and losses for each LU/LC classes for Guwahati city and Siliguri city during the periods 1990–2005, 2005–2020 and 1990-2020 are depicted in (Tab. 7). In the context of Guwahati city, the data reveals noteworthy transformations in LU/LC during 1990–2020. It is observed that there had been substantial loss of area under barren land (12.82 $km^2$), followed by agricultural land (3.53 $km^2$), forest (1.25 $km^2$) and water bodies (1.35 $km^2$) during 1990-2005. Again, between 2005 and 2020, agricultural land experienced the highest loss of 16.99 $km^2$, followed by barren land (8.16 $km^2$), forest (6.21 $km^2$) and water bodies (0.16 $km^2$). Over the entire period from 1990 to 2020, agricultural land and barren land witnessed the most significant loss to the extent of 20.52 $km^2$ and 20.98 $km^2$ respectively, followed by forest cover (7.46 $km^2$) and water bodies (1.19 $km^2$). This has been largely due to rapid expansion of area under built-up category through addition of 18.97 $km^2$ during 1990-2005 and 31.16 $km^2$ during 2005–2020.

So far Siliguri city is concerned, during the period of 1990–2005, a considerable loss of barren land occurred (8.97 $km^2$), followed by agricultural land (2.92 $km^2$), forest cover (3.66 $km^2$) and water bodies (1.54 $km^2$). Contrarily, there was a gain of 1.06 $km^2$ in built-up area during the same time frame. Later, during 2005–2020, the highest loss in barren land was observed (7.23 $km^2$), followed by forest cover (2.34 $km^2$), agricultural land (2.06 $km^2$) and water bodies (0.68 $km^2$). Conversely, there has been expansion of built-up area totalling 4.35 $km^2$ during 1990–2020 following addition 1.06 $km^2$ during 1990–2005 and 3.29 $km^2$ during 2005–2020.

## 4.4 Change detection analysis of LU/LC of Guwahati city and Siliguri city (1990–2020)

Change detection describes and quantifies the transformations associated with LU/LC changes in the landscape using geo-referenced multi-temporal remote sensing data acquired for the same geographical area between the considered acquisition dates (Ramachandra and Kumar 2004). In the context of change detection analysis conducted in Guwahati and Siliguri cities, the findings underscore significant land use and land cover (LU/LC) transformations over a period of three decades (1990–2020). The results indicate a notable increase in built-up areas during this time frame, driven by the growing urban population and ongoing infrastructure developments in and around both cities. Between 1990 and 2005, Guwahati

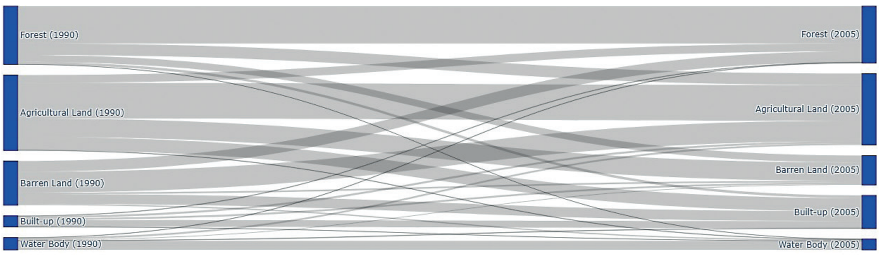
**Tab. 7** Net change of LU/LC categories of Guwahati city and Siliguri city.

| | LU/LC Categories | Net Change (Gain-Loss) (in $km^2$) | | |
|---|---|---|---|---|
| | | First period (1990–2005) | Seccond period (2005–2020) | Third period (1990–2020) |
| Guwahati City | Agricultural Land | −3.53 | −16.99 | −20.52 |
| | Barren Land | −12.82 | −8.16 | −20.98 |
| | Forest | −1.25 | −6.21 | −7.46 |
| | Built-up | 18.97 | 31.16 | 50.13 |
| | Water Body | −1.35 | 0.16 | −1.19 |
| Siliguri City | Agricultural Land | −2.92 | −2.06 | −4.98 |
| | Barren Land | −8.97 | −7.23 | −16.20 |
| | Forest | −3.66 | −2.34 | −6.00 |
| | Built-up | 1.06 | 3.29 | 4.35 |
| | Water Body | −1.54 | 0.68 | −0.86 |

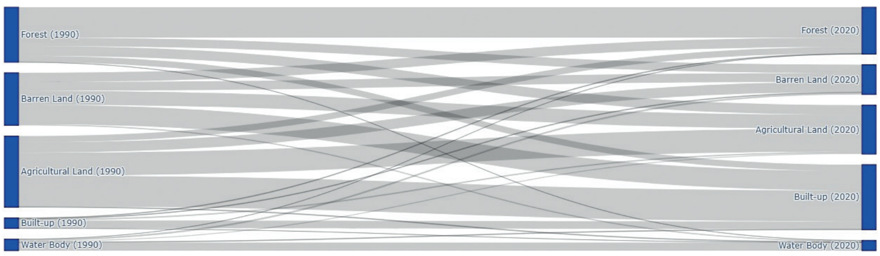
**Tab. 8** Land use / land cover change matrix of Guwahati city during (1990–2020).

| 1990–2005 (in km²) | Forest | Barren Land | Agricultural Land | Water Body | Built-up |
|---|---|---|---|---|---|
| Forest | 32.35 | 5.98 | 10.02 | 0.06 | 2.15 |
| Barren Land | 9.36 | 1.40 | 17.94 | 1.03 | 8.65 |
| Agricultural Land | 6.88 | 15.93 | 30.89 | 0.36 | 11.50 |
| Water Body | 0.29 | 0.66 | 1.48 | 7.77 | 0.45 |
| Built-up | 0.41 | 1.57 | 1.70 | 0.08 | 5.96 |
| **2005–2020 (in km²)** | **Forest** | **Barren Land** | **Agricultural Land** | **Water Body** | **Built-up** |
| Forest | 28.95 | 7.25 | 8.18 | 0.34 | 4.57 |
| Barren Land | 5.47 | 6.12 | 10.02 | 0.53 | 13.41 |
| Agricultural Land | 5.86 | 11.19 | 22.73 | 1.15 | 21.11 |
| Water Body | 0.13 | 1.35 | 0.52 | 7.04 | 0.28 |
| Built-up | 2.67 | 1.48 | 3.61 | 0.42 | 20.54 |
| **1990–2020 (in km²)** | **Forest** | **Barren Land** | **Agricultural Land** | **Water Body** | **Built-up** |
| Forest | 27.96 | 7.73 | 8.84 | 0.10 | 5.93 |
| Barren Land | 8.47 | 8.08 | 12.92 | 1.15 | 17.75 |
| Agricultural Land | 5.94 | 9.42 | 21.09 | 0.63 | 28.49 |
| Water Body | 0.15 | 1.62 | 0.91 | 7.43 | 0.54 |
| Built-up | 0.57 | 0.55 | 1.28 | 0.16 | 7.18 |

LU/LC Class-wise Transition Sankey Diagram of Guwahati City (1990–2005)




LU/LC Class-wise Transition Sankey Diagram of Guwahati City (2005–2020)




LU/LC Class-wise Transition Sankey Diagram of Guwahati City (1990–2020)

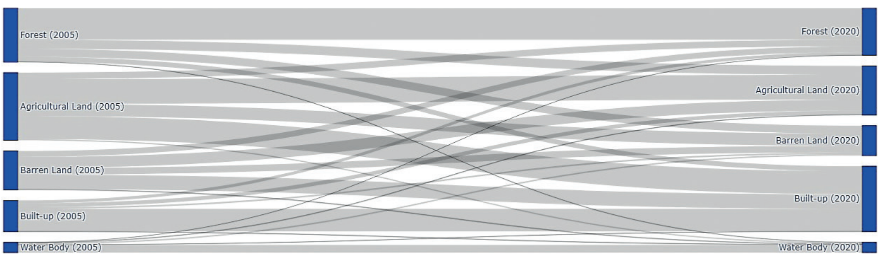


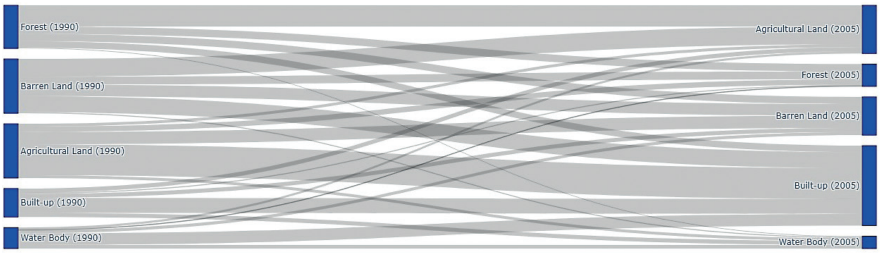

**Fig. 4** Land use / land cover change transitions of Guwahati city (1990–2020).

city witnessed the conversion of 2.15 km² of forest area, 8.65 km² of barren land, 11.50 km² of agricultural land, and 0.45 km² of water body area to built-up areas. Conversely, only 0.41 km² of built-up area got converted to forest, 1.57 km² to barren land and 1.70 km² to agricultural land during the same period. During 2005–2020, the highest transitions occurred in the agricultural land and barren land getting converted to built-up area (Tab. 8, Fig. 4). When the entire period of 1990–2020 is taken into consideration, agricultural and barren lands experienced the most significant transitions with 44.48 km² and 40.29 km²

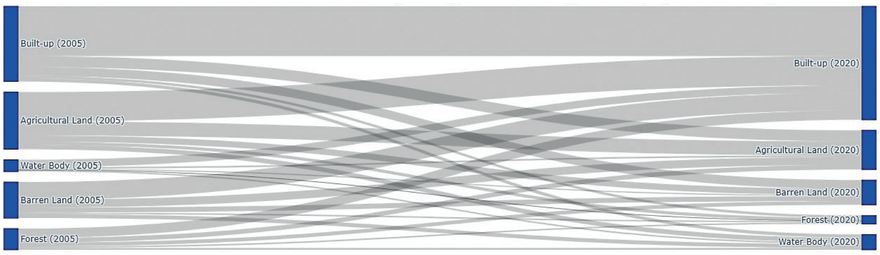
Tab. 9 Land use / land cover change matrix of Siliguri city during (1990–2020).

| 1990–2005 (in km²) | Forest | Barren Land | Agricultural Land | Water Body | Built-up |
|---|---|---|---|---|---|
| Forest | 1.31 | 1.27 | 3.71 | 0.15 | 1.12 |
| Barren Land | 1.37 | 2.02 | 3.12 | 0.20 | 2.82 |
| Agricultural Land | 0.95 | 2.17 | 0.49 | 0.49 | 5.41 |
| Water Body | 0.11 | 0.53 | 0.37 | 0.63 | 2.04 |
| Built-up | 0.18 | 0.71 | 0.76 | 0.70 | 2.64 |
| 2005–2020 (in km²) | Forest | Barren Land | Agricultural Land | Water Body | Built-up |
| Forest | 0.29 | 0.69 | 0.86 | 0.33 | 1.77 |
| Barren Land | 0.26 | 0.94 | 1.47 | 0.75 | 3.29 |
| Agricultural Land | 0.54 | 1.15 | 2.62 | 0.88 | 5.48 |
| Water Body | 0.02 | 0.20 | 0.31 | 0.29 | 1.36 |
| Built-up | 0.47 | 1.64 | 2.04 | 0.60 | 9.28 |
| 1990–2020 (in km²) | Forest | Barren Land | Agricultural Land | Water Body | Built-up |
| Forest | 0.18 | 0.94 | 1.44 | 0.63 | 4.40 |
| Barren Land | 0.74 | 1.32 | 2.49 | 0.68 | 4.41 |
| Agricultural Land | 0.40 | 1.46 | 1.95 | 0.75 | 7.14 |
| Water Body | 0.07 | 0.37 | 0.58 | 0.42 | 2.27 |
| Built-up | 0.19 | 0.54 | 0.89 | 0.38 | 3.03 |

LU/LC Class-wise Transition Sankey Diagram of Siliguri City (1990–2005)




LU/LC Class-wise Transition Sankey Diagram of Siliguri City (2005–2020)




LU/LC Class-wise Transition Sankey Diagram of Siliguri City (1990–2020)

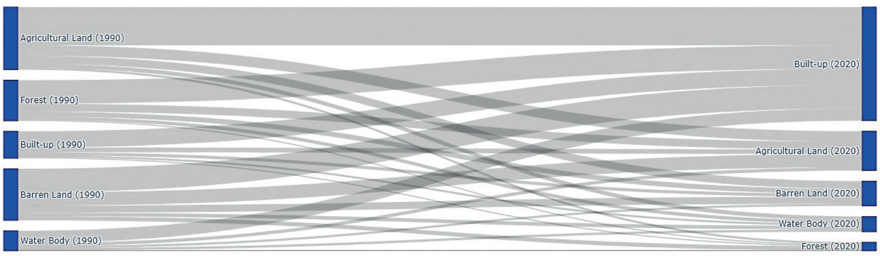



Fig. 5 Land use / land cover change transitions of Siliguri city (1990–2020).

respectively getting converted to other classes. The post-classification comparison reveals that 28.49 km² of agricultural land in 1990 transformed into built-up area by 2020, while 17.75 km² of barren land in 1990 converted to built-up land in 2020. Similarly, 5.93 km² of forest area and 0.54 km² of water bodies in 1990 changed to built-up land in 2020 in Guwahati city.

So far the nature and dimension of LU/LC transformation in Siliguri city is concerned, 1.12 km² of forest area, 2.82 km² of barren land and 5.41 km² of agricultural land got converted to built-up areas as against only 0.18 $km^2$ of built-up area transformed into forest, 0.71 $km^2$ into barren land, 0.76 $km^2$ into agricultural land and 0.70 $km^2$ into water bodies during the period 1990-2005 (Tab.9, Fig. 5). Between 2005 and 2020, agricultural land experienced the highest transition, with 5.48 $km^2$ of its total area in 2020, primarily converting to barren land (3.29 $km^2$), forest (1.77 $km^2$) and water bodies (1.36 $km^2$) transforming into built-up areas. During the entire period of study (1990–2020), agricultural, barren, and forest lands experienced substantial transitions with 9.75 $km^2$, 8.32 $km^2$, and 7.41 $km^2$ respectively being converted to other classes. The post-classification comparison reflects that 7.14 $km^2$ of agricultural land in 1990 transformed into built-up areas by 2020, while only 0.89 $km^2$ of built-up area converted to agricultural land. Similarly, 4.41 $km^2$ of barren land in 1990 converted to built-up land in 2020, while only 0.54 $km^2$ of built-up land transformed to barren land. Additionally, 4.40 $km^2$ of forest area in 1990 was converted to built-up land in 2020, with only 0.19 $km^2$ of built-up land transforming into forest area during the same period. Furthermore, 2.27 $km^2$ of water bodies in 1990 were converted to built-up land in 2020. This relentless conversion of agricultural, barren, and forest lands to built-up areas has exerted immense pressure on the already limited natural resources, posing a threat to ecological balance and giving rise to various environmental challenges in and around the cities.

Although both cities have expanded in all directions, the prominent growth areas have been observed in the north-western, eastern, and southern parts of Guwahati and the southern and south-eastern parts of Siliguri (Fig. 6). This spatial pattern underscores the visible alteration of LU/LC classes due to the rapid urban growth experienced by both cities. While Guwahati exhibits a higher growth rate than Siliguri, both cities manifest similar urban growth patterns and land use changes. Guwahati's accelerated expansion is reflected in the substantial increase in built-up areas, indicating widespread clearing of forests, agricultural lands, and encroachment into barren and wetland areas for commercial and residential purposes. Similarly, Siliguri has witnessed a rapid transformation through the conversion of forested areas, agricultural lands, barren lands, and water bodies into built-up areas.

### 4.5 Spatio-temporal analysis of EBBI

The Enhanced Built-up and Bareness Index (EBBI) is a technique based on remote sensing data to classify and map the extent of built-up areas and barren land. It basically helps to differentiate between the urbanized (built-up) areas and barren areas lacking vegetation. The EBBI is a remote sensing index that applies wavelengths of 0.83 μm, 1.65 μm, and 11.45 μm, (NIR, SWIR, and TIR, respectively) to Landsat ETM+ images. These wavelengths are selected based on the contrast reflection range and absorption in built-up and bare land areas. Therefore, the reflectance values of built-up areas are higher due to the longer sensor wavelengths. The NIR wavelength, which corresponds to band 4 in Landsat ETM+ and band 5 in SWIR, is associated with a high contrast level for detecting built-up and bare land areas (Fig. 7). The TIR can distinguish high and low levels of albedo in built-up objects. Moreover, the utilisation of TIR band is very effective for mapping built-up areas based on a low albedo, which eliminates the effect of shadows and water, while a high albedo demonstrates built-up and bare land areas clearly (Weng 2008). Therefore, the study presents the Enhanced Built-up and Bareness Index (EBBI) values for the years 1990, 2005, and 2020 in Guwahati and Siliguri cities. The built-up area of Guwahati city in 1990 was 45 $km^2$. Over the following 15 years (1990–2005) this area increased to 83 $km^2$ reflecting a growth rate of 47.33% during the period. The built-up area further expanded from 83 $km^2$ to 100 km2 by experiencing an increase of 57.05% puring the period 2005–2020. This increase in built-up area over time highlights the process of rapid urbanization of the city. In contrast, the bare land area in Guwahati city evidenced a significant decrease over the period. In 1990, the total bare land area was 118.08 $km^2$, and by 2005 it had reduced to 86.92 $km^2$ by showing a decrease of 26.29% and further declined to 57.47 $km^2$ by 2020 reflecting a decrease of 34.15% This reduction


Fig. 6 Field photo of built-up areas, (A) Guwahati city, (B) Siliguri city.

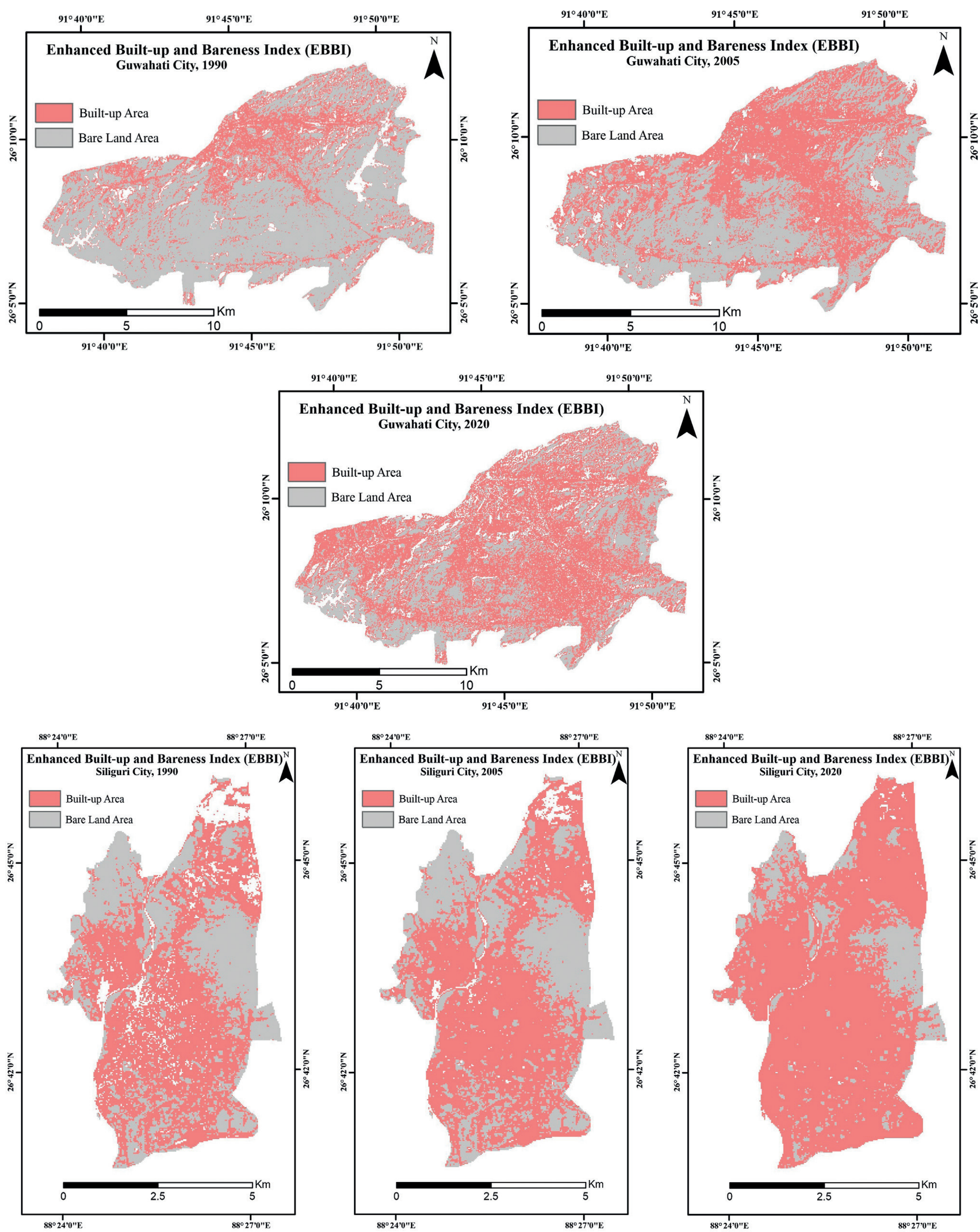



**Fig. 7** Changing pattern of Enhanced built-up and bareness index (EBBI) in Guwahati City and Siliguri City (1990–2020).

in bare land is observed at a rate of 66.08% during 1990–2005 and 32.55% during 2005–2020. The decreasing area of bare land corresponds to the expansion of built-up areas indicating a growing trend of land conversion for urban development.

So far Siliguri city is concerned, the total built-up area in 1990 was 20.87 $km^2$, which increased to 22.79 $km^2$ in 2005, and further expanded to 30.92 $km^2$ by 2020. Accordingly, the proportion of built-up areas in the city, which was 55.24% in 1990, rose to 60.38%

**Tab. 10** The percentage of built-up area and bare land area of EBBI in Guwahati city and Siliguri city (1990–2020).

| Year | Guwahati City | | | | Siliguri City | | | |
|---|---|---|---|---|---|---|---|---|
| | Built-up Areas (in km²) | Increasing Rate of Built-up Areas (in %) | Bare Land Areas (in km²) | Decreasing Rate of Bare Land Areas (in %) | Built-up Areas (in km²) | Increasing Rate of Built-up Areas (in %) | Bare Land Areas (in km²) | Decreasing Rate of Bare Land Areas (in %) |
| 1990 | 45.00 | 26.02 | 118.08 | 66.88 | 20.87 | 55.24 | 15.89 | 42.03 |
| 2005 | 83.00 | 47.33 | 86.92 | 49.23 | 22.79 | 60.38 | 13.87 | 36.78 |
| 2020 | 100.00 | 57.05 | 57.47 | 32.55 | 30.92 | 81.83 | 6.63 | 17.55 |

in 2005 and 81.83% in 2020. This type of steady growth of built-up area indicates the rapid urban development over three decades. In contrast, the total barren land area in the city was 15.89 km$^2$ in 1990, which decreased to 13.87 km$^2$ in 2005 and further reduced to 6.63 km$^2$ in 2020. Similarly, its proportion in the city also decreased over time, from 42.03% in 1990 to 36.78% in 2005 and finally to 17.55% in 2020. This decline in barren land can be attributed to the city's urban expansion, as more areas have been developed for residential, commercial, and infrastructural purposes by converting the unused barren land. When compared between the cities of Guwahati and Siliguri, the degree of transformation into built-up area is higher in Guwahati (122%) than that in Siliguri (48%) (Tab. 10).

## 4.6 Spatio-temporal analysis of NDVI

The study presents the Normalized Difference Vegetation Index (NDVI) values for the years 1990, 2005, and 2020 in Guwahati and Siliguri cities, categorized into different ranges of NDVI. The NDVI represents the coverage and health of vegetation in an area. The NDVI of a Landsat image is generated from the red and near-infrared bands. It is a widely used vegetation index calculated by using (7). The value of NDVI ranges from +1 to −1. The positive values are representative of healthy green vegetation, and the negative NDVI values indicate non-vegetative cover. In the year 1990, the maximum NDVI or vegetative greenness in Guwahati city was primarily found in north-western and north-eastern parts of the city, ranging from 0.26 to 0.61 (Fig. 8). Whereas, the central part of the city has seen highly concretized and therefore has the least NDVI value of (−0.083 to −0.33). The southern part of the city also records a negative vegetative index due to the presence of agricultural waste land and barren land. Again in 2005, the rapid transformation of land and the increase of built-up area have removed a significant quantity of healthy vegetation cover in the city area. As a result, the city core and most parts of the city recorded negative NDVI values ranging from (−0.05 to −0.23). Whereas, the maximum NDVI value of (0.21 to 0.52) has been recorded especially in the north eastern and south western part of the city due to the presence of hills with dense vegetation areas in the peripheral region of the city (Fig. 8). In the later period, a huge transformation in NDVI has been seen during 1990–2020. For instance, the expansion of built-up areas and construction of road and railway networks have greatly influenced the NDVI of the Guwahati city, particularly in the north-western and south-eastern parts of the city, where the vegetative index witnessed a mark decline during 1990–2020, excepting a few patches (Fig. 8). This is indicative of concretization of few patches of green zones in the dense built-up zones of the city. Owing to the imbalance in the built-up and natural land cover in the central and southern parts of the Guwahati city, it largely records negative NDVI. Further, a small patch of high NDVI is found in Maligaon and Gotanagar area at Nilachal hill, located in the north-western part of the city.

Other prominent green patches of high NDVI ranging from 0.18 to 0.38 correspond to Assam national state Zoo at Zoo hill, Kalapahar and Ramsa hill at north eastern part in the city.

On the other hand, in the year 1990, the maximum NDVI or vegetative greenness in Siliguri was primarily found in north-western, south and south-eastern parts of the city ranging from 0.10 to 0.5 (Fig. 8). Whereas, central part of the city has seen highly concretized and therefore has the least NDVI value of (−0.64). The northern part of the city also records a negative vegetative index ranging from 0.03 to −0.21 due to the presence of agricultural waste land and barren land. Again in 2005, as the city area expanded, significant changes took place; the city core and most parts of the city recorded negative NDVI values ranging from (0.02 to −0.14). Whereas, the maximum NDVI value of (0.13–0.44) has been recorded especially in the north western and south-eastern parts of the city due to the presence of dense vegetation areas in the peripheral region of the city (Fig. 8). In the later period, a huge transformation in NDVI has been seen during 1990–2020. For instance, the expansion of built-up areas and construction of road and railway networks have greatly influenced the NDVI of the Siliguri city, particularly in the north-western and south-eastern parts of the city, where the vegetative index witnessed a mark decline during 1990–2020, excepting a few patches (Fig. 8). This is indicative of concretization of few patches of green zones in the dense built-up zones of the city. Owing to the imbalance in the built-up and

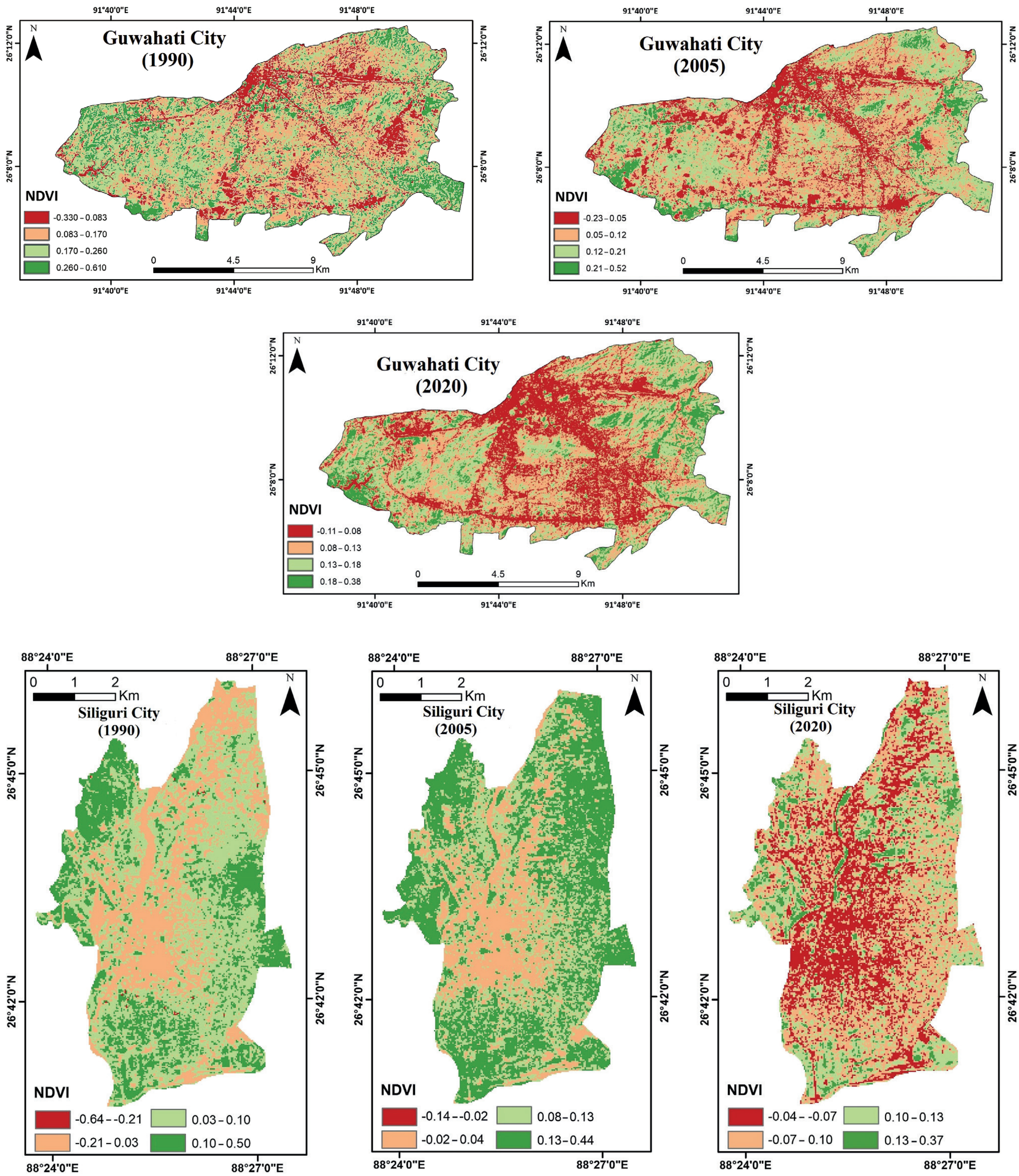



**Fig. 8** Changing pattern of urban green space (NDVI) in Guwahati city and Siliguri city for (1990–2020).

natural land cover in the central and southern parts of Siliguri city, it largely records negative NDVI. Further, a small patch of high NDVI of 0.13 to 0.37 is found near Indira Maidan, located in north-western part of the city. Other prominent green patches of NDVI ranging from 0.10 to 0.13 correspond to Surya Sen Park near the Mahananda river and Surya Sen Maidan near SLG park in the city.

## 4.7 Discussion

The factors responsible for LU/LC changes are many and they vary with respect to different study areas (Turner II and Meyer 1994). In the case of the cities of Guwahati and Siliguri, the factors responsible for changes in LU/LC include deforestation, population growth, migration, multiplicity of urban functions, encroachment of water bodies, and haphazard infrastructure development. This phenomenon is largely associated with socio-economic and demographic changes in both the cities and their surrounding areas. A comparative analysis of population growth between Guwahati and Siliguri cities from 1990 to 2011 reveals that Guwahati consistently maintained a considerably higher total population compared to Siliguri during the entire period. Despite both the cities exhibiting an almost similar pattern of population growth over the decades, Guwahati experienced considerably higher overall annual growth rate (5.26%) during 1971–2011 as compared to Siliguri (4.24%), but the growth rate became considerably higher in this respect in Siliguri particularly during 1991-2001. Such a high rate of population growth in the cities of Guwahati and Siliguri caused by rapid urban development has brought about significant changes in land use and land cover in both the cities. As population expands agricultural and forest areas are often converted into residential, commercial or industrial zones. This transformation impacts vegetation, as seen in NDVI trend, which typically shows a decline in vegetation cover due to increasing built-up areas, infrastructure expansion and conversion of natural lands into residential and commercial zone. The link between these factors highlights how human activity, driven by population growth, alters ecosystems, leading to reduced greenery and changes in land functions, contributing to environmental degradation and altering natural landscape. Although the transformation of land use and land cover between 1990 and 2020 is quite visible in both the cities, the rate of decline in forest area is higher in Siliguri and rate of increase in built-up area is higher in Guwahati.

According to EBBI index, although the proportion of built-up area in Siliguri city (82%) is considerably higher than that of Guwahati city (57%), both of them require careful planning and urban development strategies including infrastructure development in consideration with their varying circumstances and challenges. Despite Guwahati's higher population growth rate, the higher concentration of built-up area in Siliguri city highlights differing urban expansion patterns and development priorities between the two cities. From an urban planning perspective, the higher built-up area in Siliguri indicates prevalence of more intense urbanization, which could lead to greater challenges in managing infrastructure, services and resources. In contrast, Guwahati city, with a lower proportion of built-up area, although appears to have room for further urban expansion, might face its own challenges related to managing the rapid population growth and required infrastructure development, and protection of the natural landscape. Further, from an environmental sustainability standpoint, Siliguri's more densely built environment could lead to greater environmental pressure, including reduced green space, increased pollution, and greater heat island effects, making the city more vulnerable to climate change impacts. Conversely, Guwahati's relatively lower built-up percentage could offer more opportunities for green spaces, although rapid population growth could put pressure on the city's environmental assets if not managed effectively. Both cities will need to focus on sustainable urbanization practices, such as green building initiatives, waste management and maintaining green spaces, to ensure long-term environmental sustainability.

## 5. Conclusion and policy suggestion

The foregoing discussion reveals that both the cities of Guwahati and Siliguri have witnessed significant population growth accompanied by unplanned and rapid outward expansion, along with a diversification of urban functions. This phenomenon has significantly altered the original patterns of land use and land cover, with a discernible decline in agricultural land, vegetation cover, and barren land being converted into built-up areas. Consequently, both city areas are confronted with substantial ecological imbalances and heightened human footprints, leading to environmental stress. Over the past three decades (1990–2020), the spatial extent of these cities has expanded by more than four to six times, triggering swift and substantial alterations in land use, particularly at the cost of green cover. The observed progressive decline in NDVI values in both cities suggests possible environmental shifts, including the emergence of urban heat island (UHI) effects and the formation of localized microclimates. As natural land cover is replaced by impervious surfaces like concrete and asphalt, local temperatures intensify. The corresponding reduction in vegetation slows down the natural cooling process through shade and evapotranspiration, exacerbating the UHI effect and reducing the air-purifying functions of urban green spaces, ultimately degrading air quality and public health. To address these challenges, there is a pressing need for the systematic and optimal utilization of land resources in both urban areas to curb unregulated growth. This can be achieved through the stringent implementation of appropriate urban planning strategies and afforestation initiatives, supported by scientific land use zonation, which is a data-driven, evidence-based approach to planning and allocating land uses in a city. Unlike traditional zoning, it relies on legacy administrative decisions, and employs tools such as satellite imagery, environmental assessments, population density studies, and urban growth modelling in GIS platform to determine the most sustainable and appropriate land use patterns. For Guwahati, scientific land use zonation would include identifying and preserving environmentally sensitive zones such as hillocks, flood-prone areas, and wetlands like Deepor Beel. It would involve establishing urban growth boundaries, defining buffer zones around ecologically and infrastructural critical areas, and conducting suitability analysis based on topography, drainage, accessibility, and infrastructure availability. Although Guwahati falls under the Smart City Mission and is guided by the Master Plan 2025, the progress of implementation has been sluggish and inconsistent, limiting the potential impact of these initiatives. There is an urgent need to expedite and effectively enforce these frameworks in line with updated geospatial and demographic data. In contrast, Siliguri is not included under the Smart City Mission, although a City Development Plan (CDP) has been launched. The government has taken several initiatives toward systematic land use planning, but the absence of a formally implemented Master Plan or integration with a Smart City framework hampers long-term sustainability. Thus, there is a critical need for the preparation and implementation of a comprehensive Master Plan, ideally supported by smart city principles, to guide urban development and ecological conservation in Siliguri. Ultimately, integrating scientific land use zonation with existing urban planning frameworks will be key to ensuring environmentally sound, resilient, and liveable cities in both Guwahati and Siliguri.

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## References

Abir, F. A., Saha, R. (2021): Assessment of land surface temperature and land cover variability during winter: a spatio-temporal analysis of Pabna municipality in Bangladesh. Environmental Challenges 4: 100167, https://doi.org/10.1016/j.envc.2021.100167.

Ahmed, M. A., Ahmed, P. (2014): Microwatershed Level Conservation Strategies for Effective Land Management in Haheom Watershed, Kashmir Valley (J & K). In: Singh, M., Singh, R., Hassan, M. (Eds.), Landscape Ecology and Water Management. Advances in Geographical and Environmental Sciences. Tokyo: Springer, https://doi.org/10.1007/978-4-431-54871-3_24.

Alphan, H. (2003): Land-use change and urbanisation of Adana, Turkey. Land Degradation and Development 14(6), 575–586, https://doi.org/10.1002/ldr.581.

As-syakur, A. R., Wayan S. A., Wayan A. N. (2012): Enhanced Built-Up and Bareness Index (EBBI) for Mapping Built-Up and Bare Land in an Urban Area. Remote Sensing 4(10), 2957– 2970, https://doi.org/10.3390/rs4102957.

Batar, A. K., Watanabe, T., Kumar, A. (2017): Assessment of Land-Use/Land-Cover Change and Forest Fragmentation in the Garhwal Himalayan Region of India. Environments 4(2): 34, https://doi:10.3390/environments4020034.

Begum, S. W. (2010): Pattern of socio-economic change and development in the fringe areas of Guwahati City, Assam, An unpublished PhD Thesis, Department of Geography, Gauhati University.

Bhat, S., Shafiq, M., Mir, A. A., Ahmed, P. (2017): Urban sprawl and its impact on land use/land cover dynamics of Dehradun City, India. International Journal of Sustainable Built Environment 6(2), 513–521, https://doi.org/10.1016/j.ijsbe.2017.10.003.

Bhattacharjee, J., Mishra, S., Acharjee, S. (2022): Monitoring of land use/land cover changes and its implications in the peri-urban areas using multi-temporal landsat satellite data: a case study of Guwahati city, Assam, India. Proceedings of the Indian National Science Academy 88, 778–789, https://doi.org/10.1007/s43538-022-00130-0.

Census of India (1971): District Census Handbook: Kamrup District, Series-3 Assam. Part X- A (Village and Town Directory) and Part X-B (Primary Census Abstract), Directorate of Census Operations, Assam, 1–585.

Census of India (1971): District Census Handbook: Darjeeling District, Series-22 West Bengal. Part X-C (Village and Town Directory) and (Primary Census Abstract), Directorate of Census Operations, West Bengal, 1–409.

Census of India (1991): District Census Handbook: Kamrup District, Series-4 Assam. Part XII-A (Village and Town Directory) and (Primary Census Abstract), Directorate of Census Operations, Assam, 1–147.

Census of India (1991): District Census Handbook: Darjeeling District, Series-26 West Bengal. Part XII-A (Village and Town Directory) and (Primary Census Abstract), Directorate of Census Operations, West Bengal, 1–139.

Census of India (2001): District Census Handbook: Kamrup District, Series-19 Assam. Part XII-A (Village and Town Directory) and Part XII-B (Primary Census Abstract), Directorate of Census Operations, Assam, 1–893.

Census of India (2001): District Census Handbook: Darjeeling District, Series-20 West Bengal. Part XII-A (Village and Town Directory) and Part XII-B (Primary Census Abstract), Directorate of Census Operations, Assam, 1–571.

Census of India (2011): District Census Handbook: Kamrup Metro District, Series-19 Assam. Part XII-A (Village and Town Directory) and Part XII-B (Primary Census Abstract), Directorate of Census Operations, Assam, 1–394.

Census of India (2011): District Census Handbook: Darjeeling District, Series-20 West Bengal. Part XII-A (Village and Town Directory) and Part XII-B (Primary Census Abstract), Directorate of Census Operations, West Bengal, 1–726.

Cohen, J. (1960): A Co-efficient of agreement for nominal Scales. Educational and Psychological Measurement 20, 37–46, http://dx.doi.org/10.1177/001316446002000104.

De Souza, D. O., dos Santos Alvalá, R. C., do Nascimento, M. G. (2016): Urbanization effects on the microclimate of Manaus: A modeling study. Atmospheric Research 167, 237–248, https://doi.org/10.1016/j.atmosres.2015.08.016.

Griggs, D., Stafford Smith, M., Rockstrom, J., Öhman, M. C., Gaffney, O., Glaser, G., Kanie, N., Noble, I., Steffen, W., Shyamsundar, P. (2014): An integrated framework for sustainable development goals. Ecology and Society 19(4): 49, https://doi.org/10.5751/ES-07082-190449.

Grimm, N. B., Grove, J. M, Pickett, S. T. A., Redman, Ch. L. (2000): Approaches to Long-Term Studies of Urban Ecological Systems: Urban ecological systems present multiple challenges to ecologists – pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory, BioScience 50(7), 571–584, https://doi.org/10.1641/0006-3568(2000)050[0571:IATLTO]2.0.CO;2.

Guan, D., Li, H., Inohae, T., Su, W., Nagaie, T., Hokao, K. (2011): Modelling urban land use change by the integration of Cellular Automaton and Markov Model. Ecological Modelling 222(20–22), 3761–3772, https://doi.org/10.1016/j.ecolmodel.2011.09.009.

Halmy, M. W. A., Gessler, P. E., Hicke, J. A., Salem, B. B. (2015): Land use/land cover change detection and prediction in the north-western coastal desert of Egypt using Markov-CA. Applied Geography 63, 101–112, https://doi.org/10.1016/j.apgeog.2015.06.015.

Haque, I., Rohatgi, S. (2022): Assessment of Urban Morphology through Local Climate Zone Classification and Detection of the Changing Building States of Siliguri Municipal Corporation and Its Surrounding Area, West Bengal. Journal of Geographical Research 5(2), 28–43.

Hemani, S., Das, A. (2016): City profile: Guwahati. Cities 50, 137–157, https://doi.org/10.1016/j.cities.2015.08.003.

Herold, M., Roberts, D. A., Gardner, M. E., Dennison, P. E. (2004): Spectrometry for urban area remote sensing – Development and analysis of a spectral library from 350 to 2400 nm. Remote Sensing of Environment 91(3–4), 304–319, https://doi.org/10.1016/j.rse.2004.02.013.

Huang, X., Wang, C., Li, Z. (2018): A near real-time flood-mapping approach by integrating social media and post-event satellite imagery. Annals of GIS 24(2), 113–123, https://doi.org/10.1080/19475683.2018.1450787.

IGBP (1999): Land-use and land-cover change (LUCC) implementation strategy, IGBP Report No. 48/IHDP Report No 10. Stockholm (Sweden): International Geosphere-Biosphere Programme (IGBP), International Human Dimension Programme on Global Environmental Change (IHDP). Available online: http://www.igbp.net/documents/resources/report-48.pdf (accessed on 28 October 2021).

Jahan, K., Pradhanang, S. M., Bhuiyan, M. A. E. (2021): Surface Runoff Responses to Suburban Growth: An Integration of Remote Sensing, GIS, and Curve Number. Land 10(5): 452, https://doi.org/10.3390/land10050452.

Jensen, J. R., Cowen D. C. (1999): Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes. Photogrammetric Engineering and Remote Sensing 65(5), 611–622. Available online: https://www.asprs.org/wp-content/uploads/pers/99journal/may/1999_may_611-622.pdf (accessed on 16 October 2022).

Kar, R., Reddy, G. P. O., Kumar, N., Sing, S. K. (2018): Monitoring spatio-temporal dynamics of urban landscape using remote sensing and GIS: A case study from Central India. The Egyptian Journal of Remote Sensing and Space Science 21(3), 401–411, https://doi.org/10.1016/j.ejrs.2017.12.006.

Kumar, A. (2011): Land use land cover change detection using remote sensing data and GIS tools: A case study of Delhi state. Unpublished M.Sc. thesis.

Kong, F., Nagakoshi, N. (2006): Spatial-temporal gradient analysis of urban green spaces in Jinan, China. Landscape and Urban Planning 78(3), 147–164, https://doi.org/10.1016/j.landurbplan.2005.07.006.

Lambin, E. F., Geist, H., Lepers, E. (2003): Dynamics of Land-Use and Land-Cover Change in Tropical Regions. Annual Review of Environment and Resources 28, 205–241, https://doi.org/10.1146/annurev.energy.28.050302.105459.

Lopez, E., Bocco, G., Mendoza, M., Duhau, E. (2001): Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico. Landscape and Urban Planning 55(4), 271–285, http://dx.doi.org/10.1016/S0169-2046(01)00160-8.

Lu, D., Weng, Q. (2006). Use of impervious surface in urban land-use classification. Remote Sensing of Environment 102(1–2), 146–160, https://doi.org/10.1016/j.rse.2006.02.010. Manandhar, R., Odeh, I. O. A., Ancev, T. (2009): Improving the Accuracy of Land Use and Land Cover Classification of Landsat Data Using Post-Classification Enhancement. Remote Sensing 1(3), 330–344, https://doi.org/10.3390/rs1030330.

Miller, A. B., Bryant, E. S., Birnie, R. W. (1998): An analysis of land cover changes in the Northern Forest of New England using multitemporal Landsat MSS data. International Journal of Remote Sensing 19(2), 215–265, https://doi.org/10.1080/014311698216233.

Munthali, G. M., Botai, O. J., Davis, N., Adeola, M. A. (2019): Multi-temporal analysis of land use and land cover change detection for Dedza District of Malawi using geospatial techniques. International Journal of Applied Engineering Research 14(5), 1151–1162. Available online: https://www.ripublication.com/ijaer19/ijaerv14n5_16.pdf (accessed on 20 July 2021).

Parmenter, A. W., Hansen, A., Kennedy, R. E., Cohen, W., Langner, U., Lawrence, R., Maxwell, B., Gallant, A., Aspinall, R. (2003): Land use and land cover change in the Greater Yellowstone Ecosystem. Ecological Applications 13(3), 687–703, https://doi.org/10.1890/10510761(2003)013[0687:LUALCC]2.0.CO;2.

Parvez, M., Islam, S. (2019). Sites Suitability Analysis of Potential Urban Growth in Pabna Municipality Area in Bangladesh: AHP and Geospatial Approaches. Journal of Geographical Studies 3(2), 82–92, https://doi.org/10.21523/gcj5.19030204.

Pawe, C. K., Saikia, A. (2018): Unplanned urban growth: land use/land cover change in the Guwahati Metropolitan Area, India. Geografisk Tidsskrift-Danish Journal of Geography 118(1), 88–100, https://doi.org/10.1080/00167223.2017.1405357.

Pawe, C. K., Saikia, A., (2020): Decumbent development: Urban sprawl in the Guwahati Metropolitan Area, India. Singapore Journal of Tropical Geography 41(2), 226–247, https://doi.org/10.1111/sjtg.12317.

Puyravaud, J. P. (2003): Standardizing the calculation of the annual rate of deforestation. Forest Ecology and Management 177(1–3), 593–596, https://doi.org/10.1016/S0378-1127(02)00335-3.

Ramachandra, T. V., Kumar, U. (2004): Geographic resources decision support system for land use, land

cover dynamics analysis. Proceedings of the FOSS/ GRASS Users Conference – Bangkok, Thailand, 12–14 September. Available online: https://scispace.com/pdf /geographic-resources-decision-support-system-for -land-use-2schrzf1x2.pdf (accessed on 20 July 2021).
Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Wall, D. H. et al. (2000): Global Biodiversity Scenarios for the Year 2100. Science 287(5459), 1770–1774, https://doi.org/10.1126/science.287.5459.1770.
Sarkar, A., Chouhan, P. (2019): Dynamic simulation of urban expansion based on Cellular Automata and Markov Chain Model: a case study in Siliguri Metropolitan Area, West Bengal. Modeling Earth Systems and Environment 5, 1723–1732, https://doi.org/10.1007 /s40808-019-00626-7.
Seto, K. C., Kaufmann, R. K. (2003): Modeling the Drivers of Urban Land Use Change in the Pearl River Delta, China: Integrating Remote Sensing with Socioeconomic Data. Land Economics 79(1), 106–121, https://doi.org /10.2307/3147108.
Shao, Z., Sumari, N. S., Portnov, A., Ujoh, F., Musakwa, W., Mandela, P. J. (2021): Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data. Geo-Spatial Information Science 24(2), 241–255, https://doi.org /10.1080/10095020.2020.1787800.
Siddique, G., Roy, A., Mandal, M. H., Ghosh, S., Basak, A., Singh, M., Mukherjee, N. (2020): An assessment on the changing status of urban green space in Asansol city, West Bengal. GeoJournal 87, 1299–1321, https:// doi.org/10.1007/s10708-020-10312-2.
Son, N. T., Thanh, B. X. (2017): Decadal assessment of urban sprawl and its effects on local temperature using Landsat data in Cantho city, Vietnam. Sustainable Cities and Society 36, 81–91, https://doi.org/10.1016/j.scs.2017 .10.010.
Sudhira, H. S., Ramachandra, T. V., Jagadish, K. S. (2004): Urban sprawl: metrics, dynamics and modelling using GIS. International Journal of Applied Earth Observation and Geoinformation 5(1), 29–39, https://doi.org /10.1016/j.jag.2003.08.002.
Swanwick, C., Dunnett, N., Woolley, H. (2003): Nature, Role and Value of Green Space in Towns and Cities: An Overview. Built Environment 29(2), 94–106, https:// doi.org/10.2148/benv.29.2.94.54467.
Teferi, E., Bewket, W., Uhlenbrook, S., Wenninger, J. (2013): Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modelling of systematic transitions. Agriculture, Ecosystem and Environment 165, 98–117, https://doi.org/10.1016/j.agee .2012.11.007.
Townshend, J. R., Justice, C. O. (1986): Analysis of the dynamics of African vegetation using the normalized difference vegetation index. International Journal of Remote Sensing 7(11), 1435–1445, https://doi.org /10.1080/01431168608948946.
Trinder, J., Liu, Q. (2020): Assessing environmental impacts of urban growth using remote sensing. Geo-Spatial Information Science 23 (1), 20–39, https://doi.org /10.1080/10095020.2019.1710438.
Wang, Y., Moskovits, D. K. (2001): Tracking Fragmentation of Natural Communities and Changes in Land Cover: Applications of Landsat Data for Conservation in an Urban Landscape (Chicago Wilderness). Conservation Biology 15(4), 835–843, https://doi.org/10.1046 /j.1523-1739.2001.015004835.x.
Welch, R., Madden, M., Jordan, T. (2002): Photogrammetric and GIS techniques for the development of vegetation database of mountainous areas: Great Smoky Mountains National Park. ISPRS Journal of Photogrammetry and Remote Sensing 57(1–2), 53–68, https://doi.org /10.1016/S0924-2716(02)00118-1.
Weng, Q. (2008): Remote Sensing of Impervious Surfaces: An Overview. In: Weng, Q. (Eds.), Remote Sensing of Impervious Surfaces, Boca Raton: CRC Press, Taylor & Francis Group.
Wu, Y., Liu, S., Sohl, T. L., Young, C. J. (2013): Projecting the land cover change and its environmental impacts in the Cedar river basin in the Midwestern United States. Environmental Research Letters 8, 1–13, https:// doi.org/10.1088/1748-9326/8/2/024025.
Zhang, B., Zhang, Q., Feng, C., Feng, Q., Zhang, S. (2017): Understanding Land Use and Land Cover Dynamics from 1976 to 2014 in Yellow River Delta. Land 6(1): 20, https://doi.org/10.3390/land6010020.