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RESEARCH ARTICLE

An analysis of land dynamics in relation to urban sprawl in the Guwahati city of Assam, India

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Abstract – Urban sprawl is the growth of a settlement that occurs during urbanization. Guwahati city, located in the Kamrup Metropolitan District of Assam, India, is the hub of the northeastern states. To examine urban sprawl and the rate of population expansion during the past 30 years, research has been conducted to determine the built-up land characteristics. A temporal study using satellite images for two different years (1990 and 2020) has been carried out through GIS and remote sensing techniques, supervised classification using maximum likelihood for land use land cover preparation and raster calculator has been used to delineate NDVI and the Urban Index. The city has been divided into five buffer zones from the central growth point, and the sprawl has been analyzed for each buffer zone. The city's growth is so drastic that the built-up area has increased from 27.18% in 1990 to 47.87% in 2020. Zone-wise, the most remarkable changes have been seen in zone 2 and zone 5, up to 28.95% and 22.62%, respectively. Zone-3 counts as the minor changes in the built-up area, i.e., 6.2% due to the Ramsar site named Deeparbeel. This study will help urban planners understand the nature of sprawl and develop a feasible solution.

Keywords – Buffer zones, GIS and Remote Sensing, Land use/land cover, Urban Sprawl, Urban Index.

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INTRODUCTION

In the community development and administration of several countries in the industrialised and developing world, urban sprawl has become a hot topic. Several authors have defined "sprawl" in a variety of ways. The impact of urban sprawl can be concluded with three conditions that define the adverse effects of sprawl i.e., leapfrog development, low-density, and unlimited outward expansion (Burchell et al, 1997); sprawl has been equated to the natural expansion of metropolitan areas as the population grows (Sinclair 1967) and to "haphazard" or unplanned growth, whatever form it may take (Ewing 2008); urban sprawl means more growth than the usual and what makes it different from urban growth is this excessive nature (Habibi and Asadi 2011); Urban sprawl is the term for the rapid and unconstrained growth of cities' or urban regions' outer limits in a way that is detrimental from an economic, social, and environmental perspective (Amponsah et al., 2022). According to a consensus, urban sprawl is characterised by unplanned and uneven patterns of growth, driven by inefficient resource utilisation (Bhatta 2010). The characterizations of sprawl, however, are not similar across the world (Hamidi and Ewing 2014).

Monitoring of changes using remote-sensing technology is widely used in different applications such as land use/land cover change, urban sprawl, and vegetation change (Natesh et al., 2022) become necessary to study the pattern of change in various regional types and various spatial scales for discussion of the mechanism of land use change (Yuvaraj 2020; Pandey 2021). Conversion of these natural lands into these impervious built-up lands can have significant impacts on the ecosystem, thus affecting the hydrologic system, biodiversity, and climate, and consequently may have a negative impact such as the urban heat island phenomenon (Xu 2008). Hence, accurate mapping of urban environments and monitoring of urban growth are becoming increasingly important at the global level (Guindon et al., 2009). Although the rich biodiversity areas nearer to the central growth points were converting toward infrastructural development and changing the nature of the ecosystems, so, the growth must be studied properly to reduce the burden on the environment.

Evaluating the transition in land use from non-residential to residential is one of the biggest issues in mapping metropolitan areas. In certain instances, bare land may also be added to a metropolitan area by construction. It is necessary to evaluate the built-up and bare land in urban areas so that it is possible to use the presence of these land types as an indication of urban growth and environmental quality. To prepare the different maps and their processes, it requires different remotely sensed data and spectral values based on the land utilisation categories. Indices for mapping the built-up and bare land in urban areas, such as Urban Index (UI), Normalized Difference Vegetation Index (NDVI), and Buffer Zone, have been employed in studies. UI is based on the high-speed mapping of built-up or bare land areas.

This paper uses these two spectral indices for the extraction of built-up features to study the urban sprawl in Kamrup Metropolitan District, Assam, for two time periods, i.e., 1990 and 2020. In the previous studies, it is seen that the city has gone through massive changes in its LULC pattern with a high degree of urbanisation during recent periods (Chetia et al., 2020). Over the past several years, there has been an increasing trend of built-up land and cultivated and managed areas in the peripheral areas of the city, while there is a diminishing rate of natural and semi-natural vegetated land (Pawe and Saikia 2018) and a highly decreasing rate in the core area. An increase in the growth of the concrete and fast-growing infrastructure in the city implies a higher land surface temperature as compared to the previous years. The study of sprawl will allow the planners to prepare preventive measures (Habibi and Asadi 2011) and will give them better knowledge to identify the growth of sprawl in the Kamrup Metropolitan District.

STUDY AREA

Guwahati city (91°45'30.37"E, 26°10'1.96"N) is located in the Kamrup Metropolitan district of Assam of India [Figure 1]. Guwahati city is the hub of all North-eastern states which plays a vital role in the growth of all states in every aspect. On the northern side of the city the mighty Brahmaputra River is flowing towards the western side, along the southern boundary touches the Meghalaya state, on the eastern side Morigaon district is situated, and in the western side the Kamrup rural district is situated. It is one of the fast-growing cities among all mega cities in the country. The total population of Guwahati city is about 9, 62, 334 (2011 census) and the total area of the city is around 22,062.41 hectares. The city's population density is around 3462 persons/sq.km.

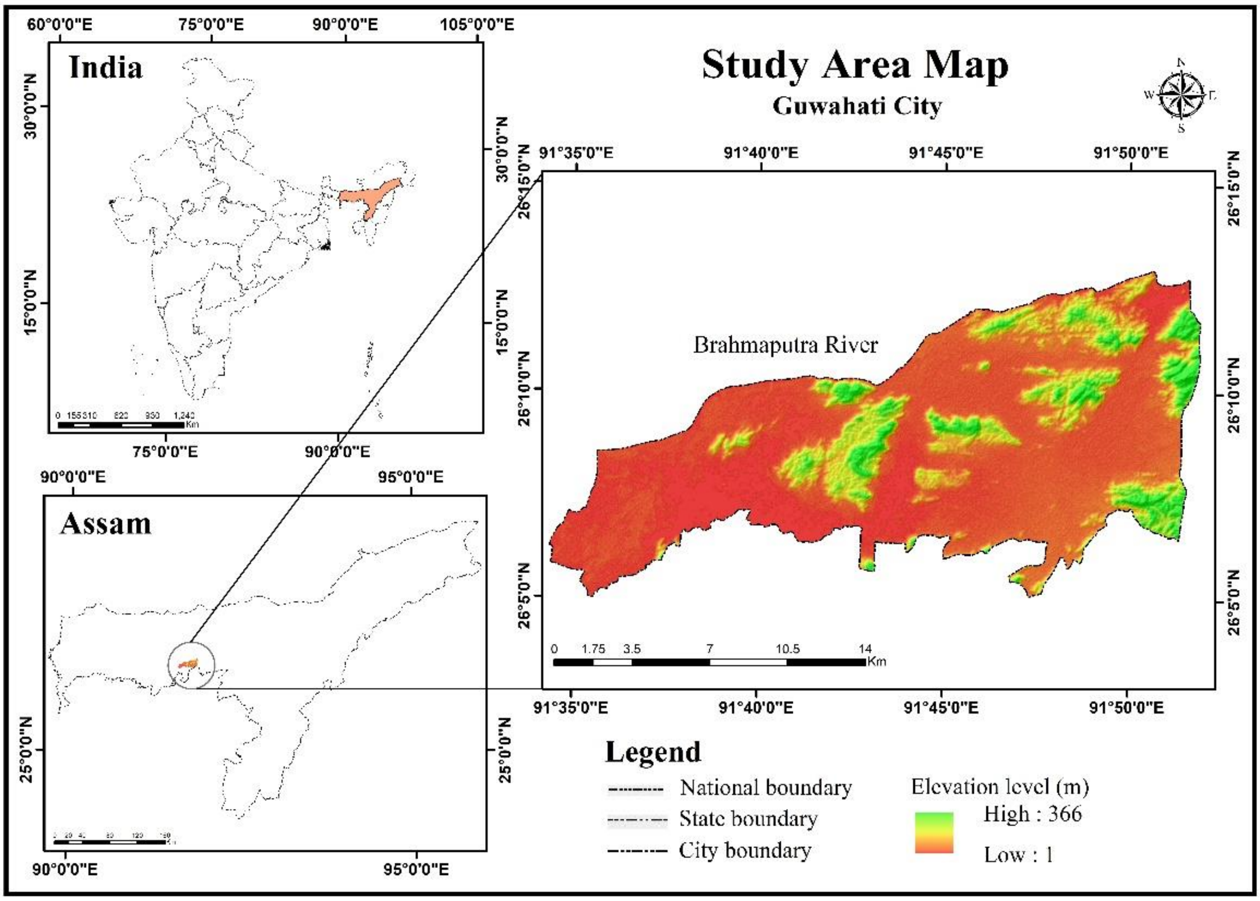

Figure 1: Study area base map

MATERIALS AND METHODS

Material used

Satellite Data were collected from Landsat 4-5 TM for 1990 and Landsat 8 for 2020. These particular data sets are collected from the United States Geological Survey (USGS). To process these satellite data ArcGIS 10.8 and Erdas Imagine 2015 have been used.

Methods

The concentration of the urban population is divided according to the different buffer zones from the center point of the city. Different thematic layers were prepared to analyze the urban sprawl like LULC, NDVI, and UI. After calculations of indices, the built-up area has been extracted using the overlay method.

LULC

The land use land cover classification has been done through maximum likelihood classification using supervised classification (Regasa 2021) using the Landsat 4, 5 and Landsat 8. Maximum likelihood classification considers that the statistics for each class in each band are evenly distributed, and calculating the likelihood that a given pixel belongs to a particular category (Khwarahm 2021). The prepared land use land cover map has been validated with the Accuracy Assessment method and the Kappa co-efficient (Eq.1). The Kappa co-efficient have been calculated using the following methods (Shimrah 2022).

$$Kappa\ Coefficient\ (T) = \frac{(TS \times TCS) - \sum(Column\ total \times row\ total)}{TS^2 - \sum(Column\ total - row\ total)} \times 100 \quad \text{...Eq.1}$$

Where,

TS = Total Sample

TCS = Total Corrected Sample

NDVI (Normalized Difference Vegetation Index)

NDVI shows the normalized vegetation cover on the land surface over wide areas. NDVI is known to be affected by background, aerosol effects, and saturation in high biomass regions (Huete et al, 2002), it is highly sensitive to small increases in the amount of photosynthetic vegetation (Bellón et al, 2017). The NDVI algorithm is computed by subtracting the red reflectance values from the near-infrared and dividing them by the sum of near-infrared and red bands (Sumanta 2016). NDVI values are ranging from -1 to 1 where, a very low value corresponds to barren areas of rock, sand, snow, cloud, etc., moderate values represent shrubs and grassland while a high value indicates temperate and tropical rainforests.

$$NDVI = \frac{NIR\ (Band\ 5) - RED(Band\ 4)}{NIR(Band\ 5) + RED(Band\ 4)} \quad \text{...Eq.2}$$

Where,

NDVI = Normalized Difference Vegetation Index;

NIR = Near Infrared (R M, Yuvaraj. 2020)

UI (Urban Index)

Urban Index is calculated to find out the concentration of urban areas over a region. The Urban Index is ranging from -1 to 1, where high values indicate a higher concentration of urban areas and lower the value of the low urban areas. UI is an index for quickly mapping built-up areas (As-Syakur, et al, 2012).

$$UI = \frac{SWIR2(Band\ 7) - RED(Band\ 4)}{SWIR2(Band\ 7) - RED(Band\ 4)} \quad \text{...Eq.3}$$

Where,

UI = Urban index;

SWIR = Shortwave Infrared

RESULTS

Land use/land cover (LULC)

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year. As for the study the NRSC level-1 (NRSC, 2014) land use/land cover classification have been applied for both period.

The land use/land cover map [Figure 3 (a) & (b)] has shown the difference of 30 years and it is noteworthy from the above analysis that the concentration of built-up has emerged during the gap. In the year 1990, the built-up area was around 27.18% and it increased to 47.87% in 2020. As can be observed, the bulk of the forest has been removed and turned into structured assets.

Table 1: Land use/land cover area for the years 1990 and 2020

Class Name	**Year 1990** (Area in ha)	**Area** (in%)	**Year 2020** (Area in ha)	**Area** (in%)
Barrenland	7001.35	30.36	5650.65	24.50
Waterbody	1270.23	5.51	1171.47	5.08
Forest	8523.50	36.96	5201.06	22.55
Built-up	6267.69	27.18	11039.59	47.87

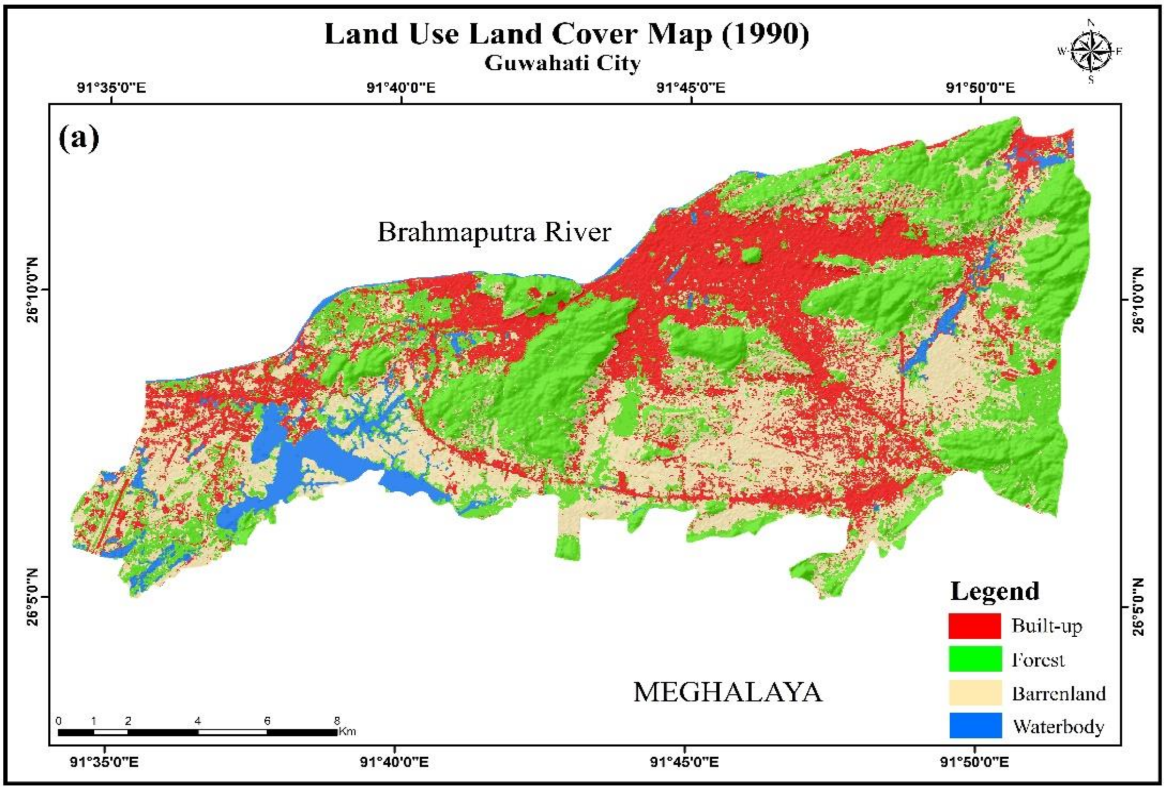

Figure 2 (a): Land use/land cover map for the year 1990

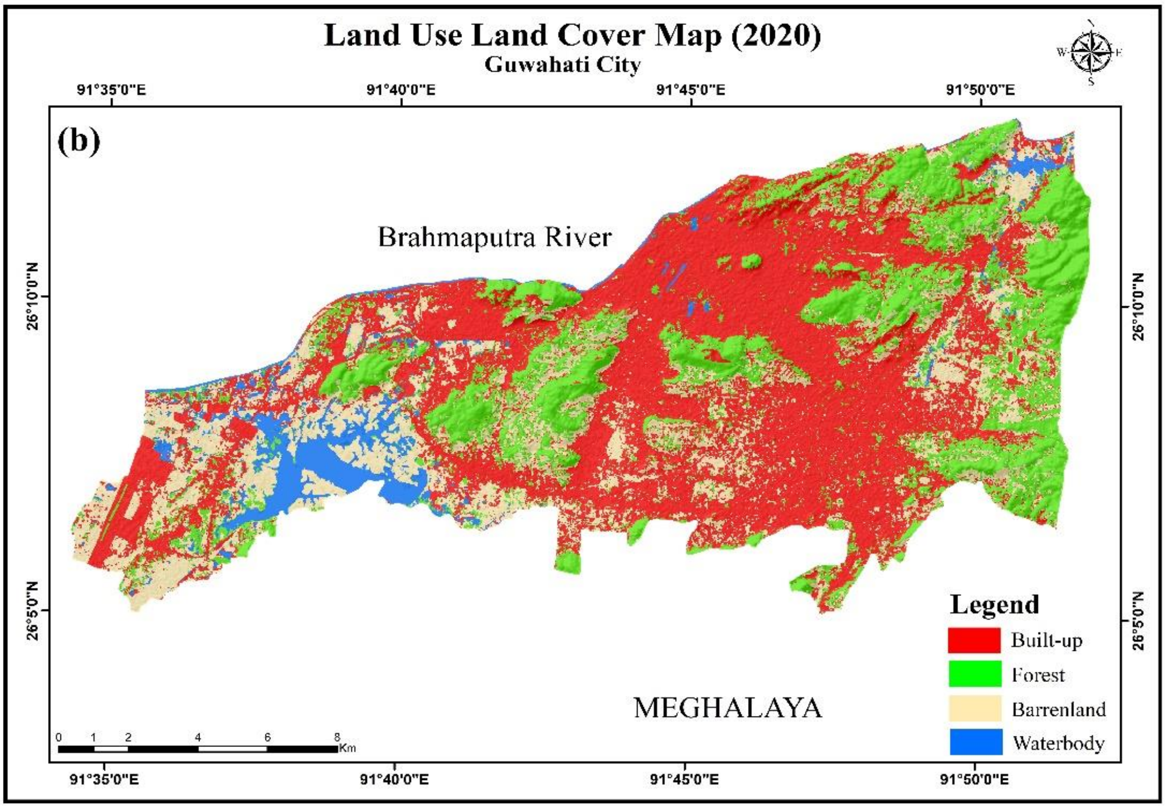

Figure 2 (b): Land use/land cover map for the year 2020

The forest cover area was 37% in the year 1990 and in 2020 it became around 24% which very indicative feature of urban growth The Digital Elevation Model (DEM) has been overlayed in the land use pattern and it is seen [Figure 2(a)] the green patch has the higher elevation reduced in the [Figure 2(b)] year 2020. The area has been calculated from the LULC of both year and the area has been shown above.

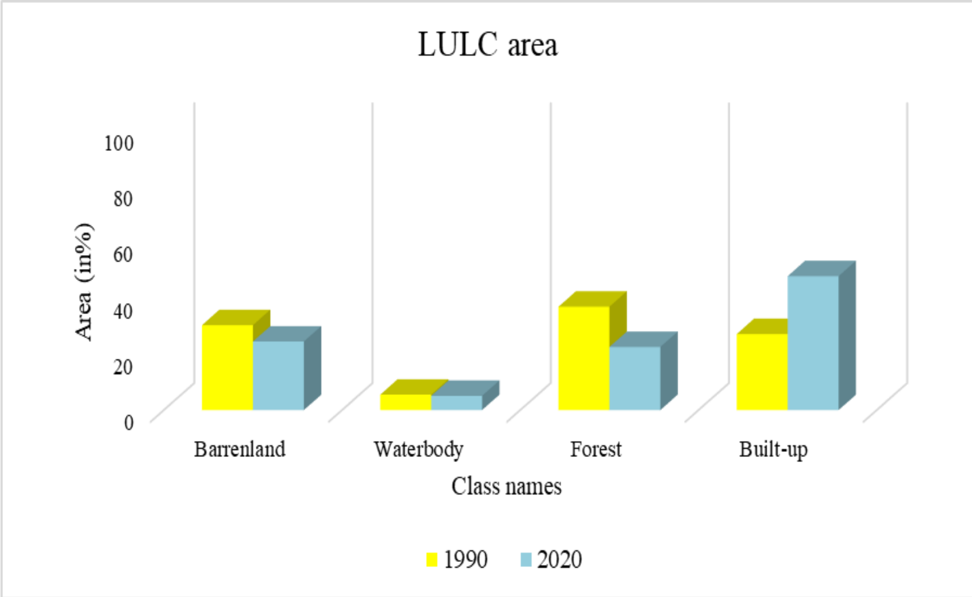

Figure 3: Growth rate of each class in two respective years 1990 and 2020

Table 2: Accuracy assessment for the years 1990 and 2020

Class	1990		2020	
	Producer Accuracy	User Accuracy	Producer Accuracy	User Accuracy
Built-up	91.33%	91.33%	97%	89%
Forest	95%	95%	82%	86%
Barren land	96.83%	95.31%	94%	95%
Water body	93.50%	94%	86%	88%
Overall Classification Accuracy	97.25%		90.25%	
Kappa statistics	0.9459		0.815	

The accuracy Assessment has been calculated for both the year of land use and land cover of the study to validate the accuracy of the classified area. After the calculation of accuracy assessment, it is found that the Overall Classification Accuracy is 97.25% for the year 1990 and for 2020 it is found that 90.25%. The classification accuracy is found to the satisfactory as the Kappa statistics [Eq.1] is likely to be 0.9 as shown in Table 2.

Normalized Difference Vegetation Index (NDVI)

The NDVI has been calculated using [eq.2] for the study area and it is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum and is adapted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

The map [Figure 4 (a) & (b)] shows the NDVI of Guwahati city for both years. The city is comprised of an undulating surface and is located nearby the river, so the vegetation was quite rich in 1990. But due to the immense growth during the last two decades, most of the area has been cleared and changed to settlement areas. In the figure, the green color shows the vegetation where the normalized values are between 0-1 and the values between 0 to -0.308.

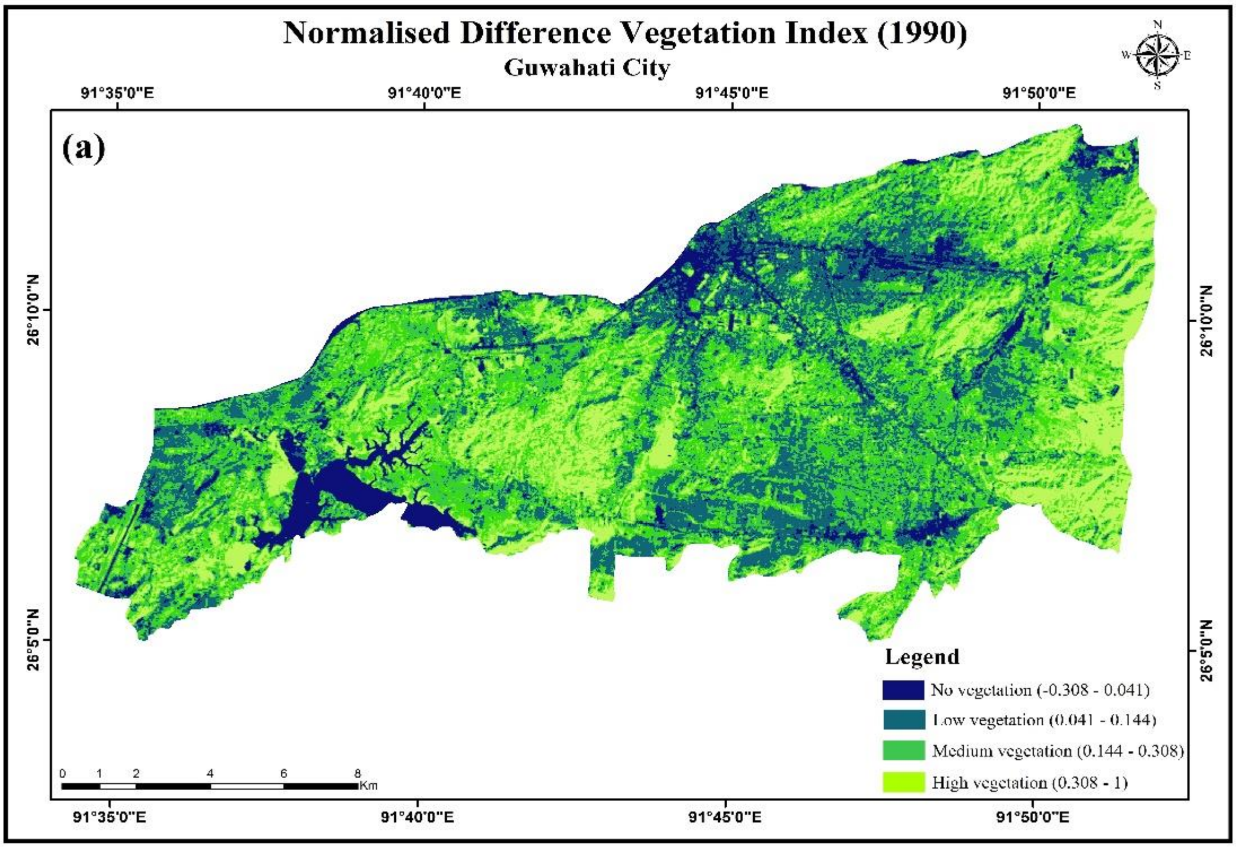

Figure 4 (a): NDVI for the year 1990

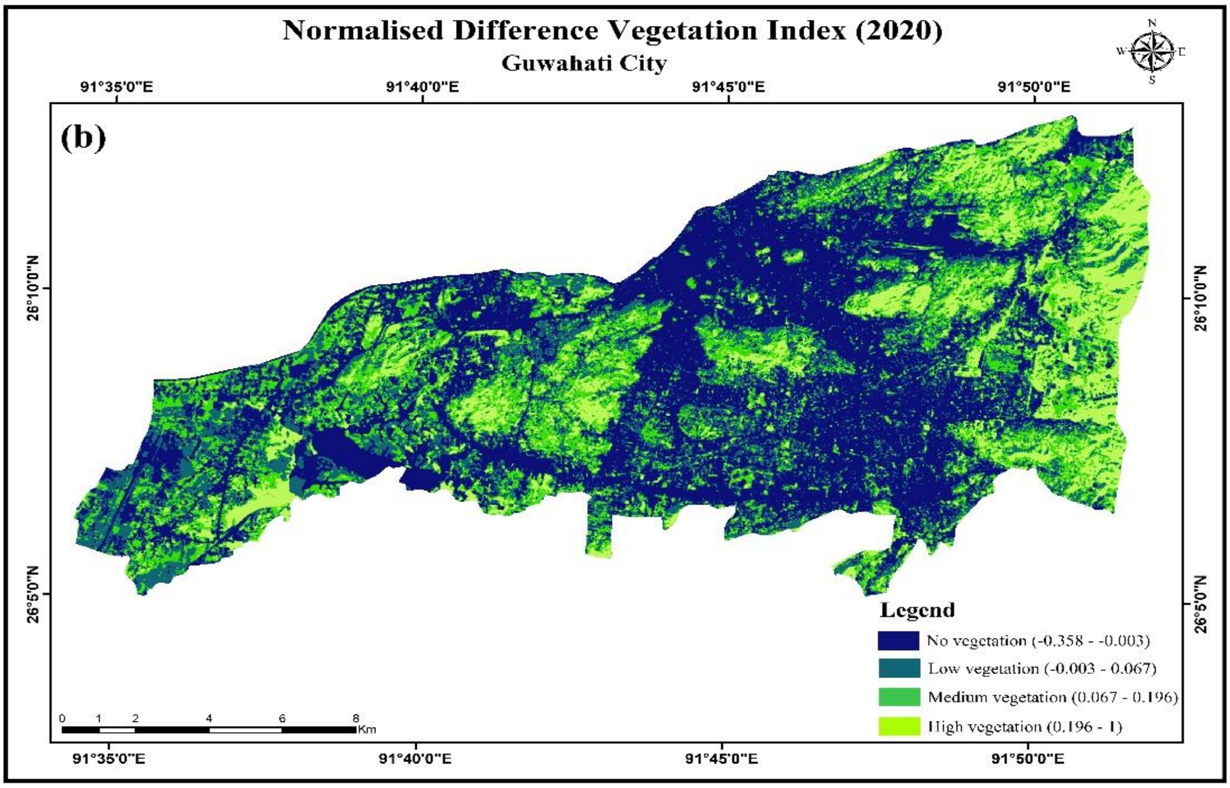

Figure 4 (b): NDVI for the year 2020

Urban Index (UI)

For the high accuracy built-up area extraction, it is required for high-resolution ground truth data. For the study area, the Urban Index has been calculated using the above-mentioned equation [eq. 3], and the result is an acceptable rate. The spectral identities of the urban areas mostly show heterogeneous spectral characteristics and significant spectral confusion between land cover classes results reduce

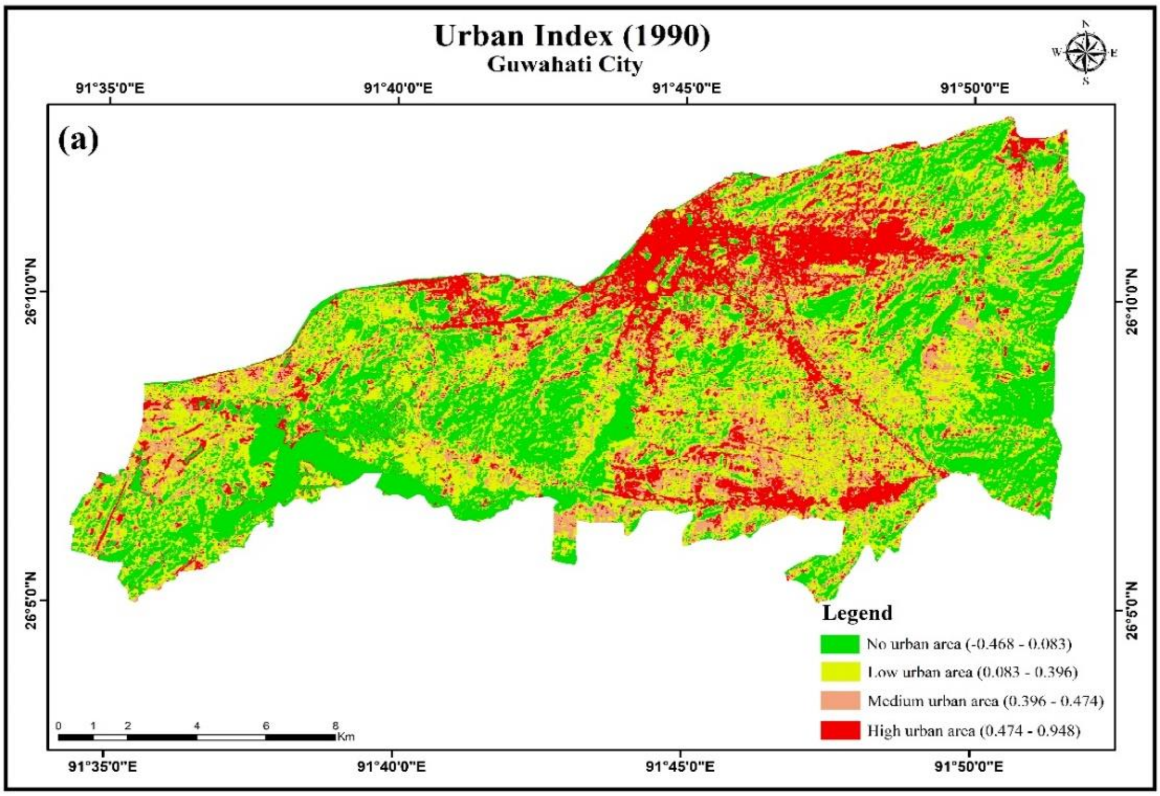

Figure 5 (a): Urban Index for the year 1990

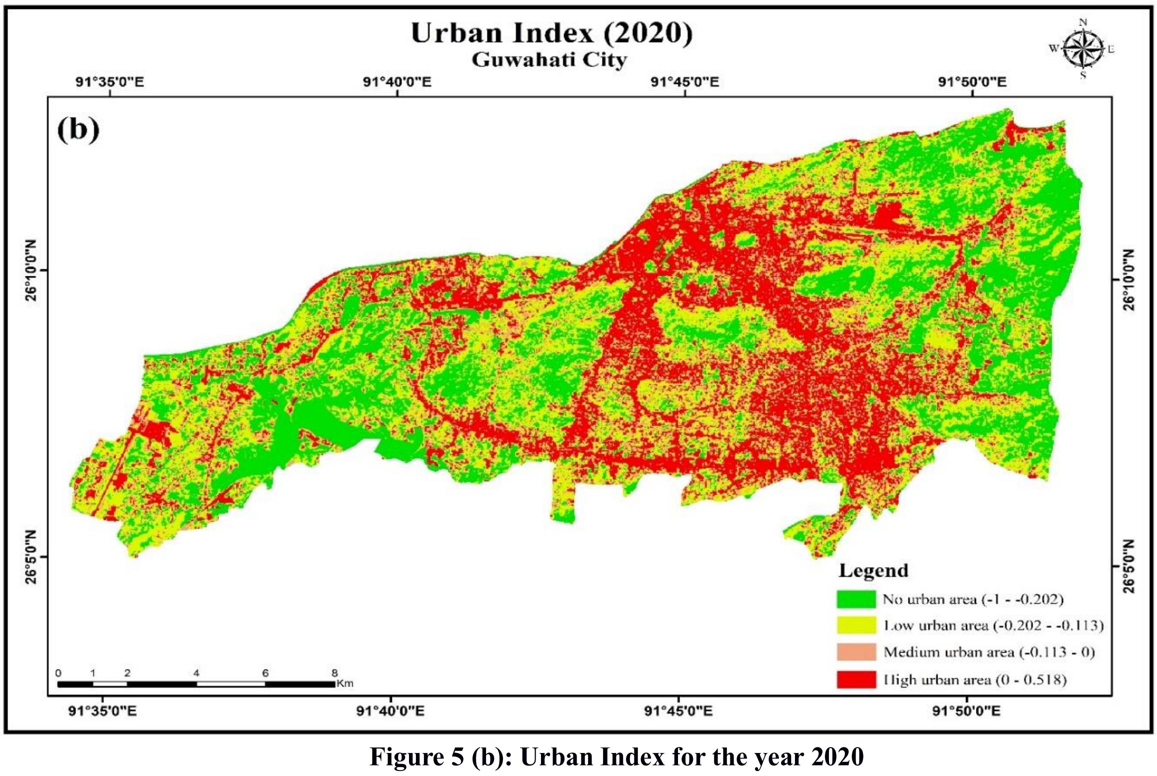

Figure 5 (b): Urban Index for the year 2020

the mapping accuracy. To overcome this spectral confusion, several techniques can be applied: classification-based, which involves the use of different classification algorithms to improve mapping accuracy at the pixel and object levels (Cleve et al., 2008), and index-based, which involves the development of different indices to enhance a particular built-up area and the determination of an optimal threshold level to separate built-up areas from other land cover types (He et al., 2010; Guindon et al., 2009).

Multi-Ring Buffer Analysis

The multi-ring buffer analysis method has been applied in this study to identify the changes in the built-up areas. The built-up areas have been extracted using a basic thresholding approach to urban land concerning land use/land cover. In the study area, there are 5 ring buffers taken at a distance of 4 km [Figure 6] based on the shape of the study area. As the study is seen to be in the elongated shape, by following the spatial extent of the city from the major growth point the buffer zone has been divided. Each zone consists of 4 km, which is most suitable to show the built-up areas in an effective way. The centre point of the buffer zone is located in the main centre of the city, i.e., Dispur. The main centre of the buffer ring is pointed at the Dispur which is regarded as the major growth point in the city.

After dividing the city into 5 different zones according to geographical extent, ring 1 consists of 3204.47 hectares, ring 2 consists of the highest area of 8334.35 hectares, ring 3 consists of 8114.13 hectares, ring 4 consists of 2037.20 hectares, and ring 5 consists of 1372.25 hectares. Ring 1 is located in the core area of the city and other zones are consecutively increasing their distance from the centre point. After the extraction of built-up areas, the built-up was mostly seen in the plain area during the 1990s [Figure 7 (a)], where there is a huge amount of encroachment in the hilly areas in the year 2020 [Figure 7 (b)].

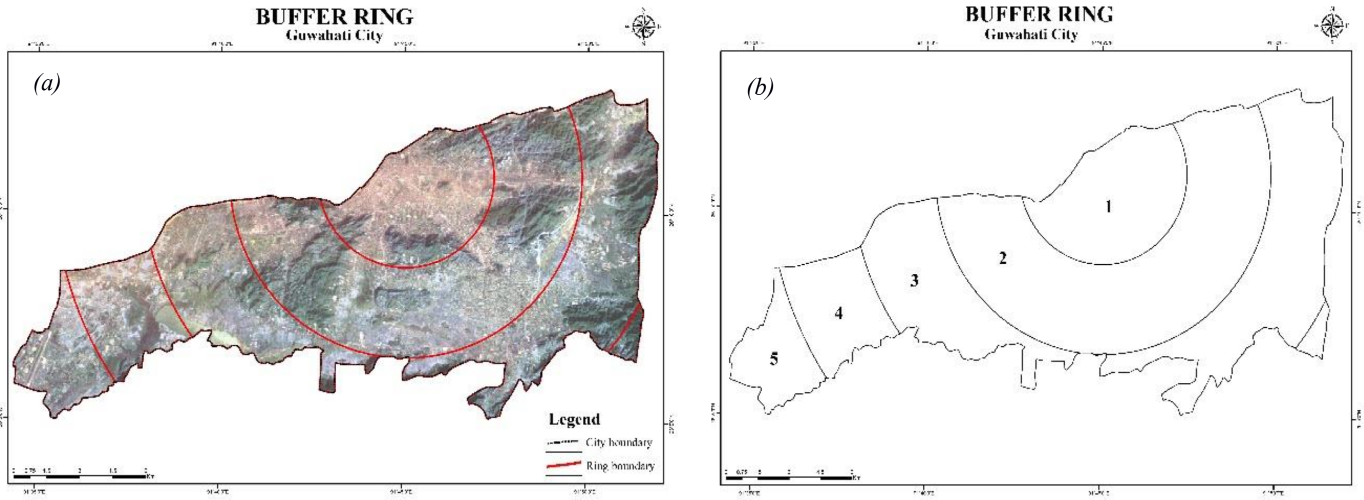

Figure 6: Multi ring overlay in the city (a) Topographical overview (b) buffer zones from the center

The urban areas have been divided separately according to different zones and studied precisely for better understanding. Each zone has distinctive changes over the stipulated period. As for the core region, i.e., the ring 1 of 1990 [Figure 8 (a)], it has nearly 75.70% of built-up areas, where there are minor changes in the area of 14% concerning the year 2020 [Figure 8 (b)]. Ring 2 has a distinctive change in the year 2020, where there is a change of 28.95%, which is shown as the highest recorded zone among all other zones.

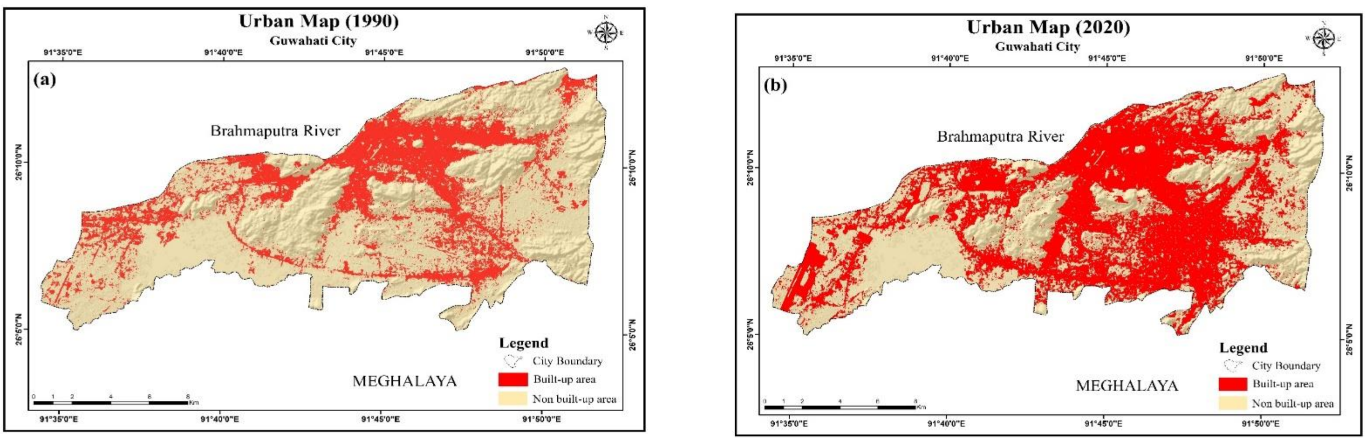

Figure 7: Urban map with built-up and non-built-up area for the year (a) 1990 (b) 2020

The ring 2 [Figure 9] has the highest total area of 8334.35 hectares, and among the total area, only 26% of the area was built-up in the year 1990, and that changed to 55% in the year 2020. The built-up area is quite small in this zone because of the undulations in the terrain. But as for the growth of the city, there are a huge number of encroachments in this zone, and numerous construction projects are going on near the hillsides.

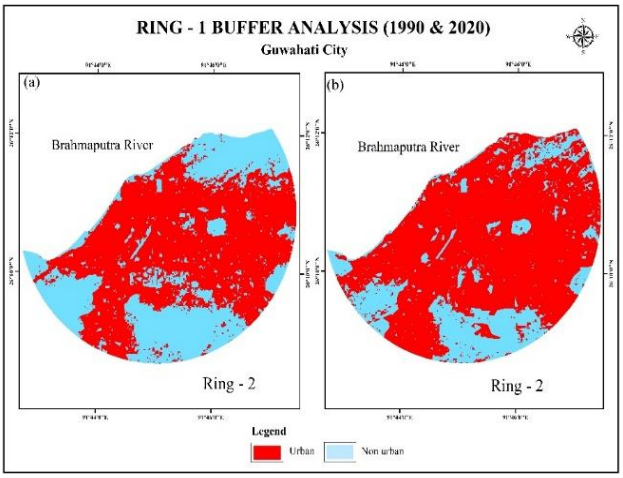

Figure 8: Urban map of Ring-1 built-up (a) Year 1990, (b) Year 2020

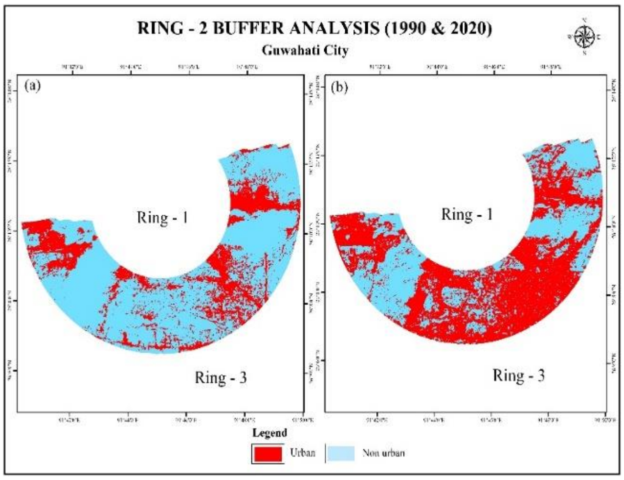

Figure 9: Urban map of Ring-2 built-up (a) Year 1990, (b) Year 2020

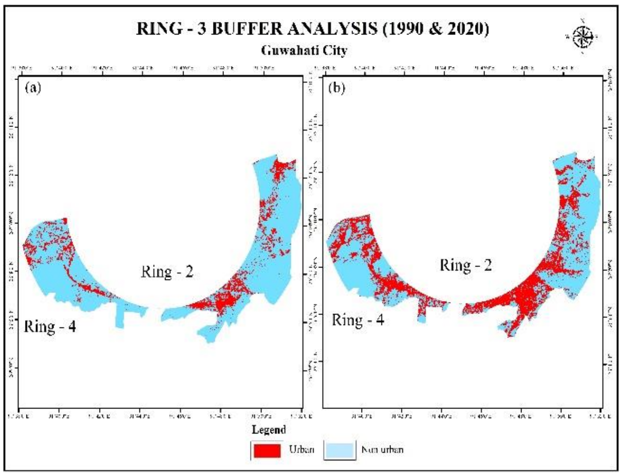

Figure 10: Urban map of Ring-3 built-up (a) Year 1990, (b) Year 2020

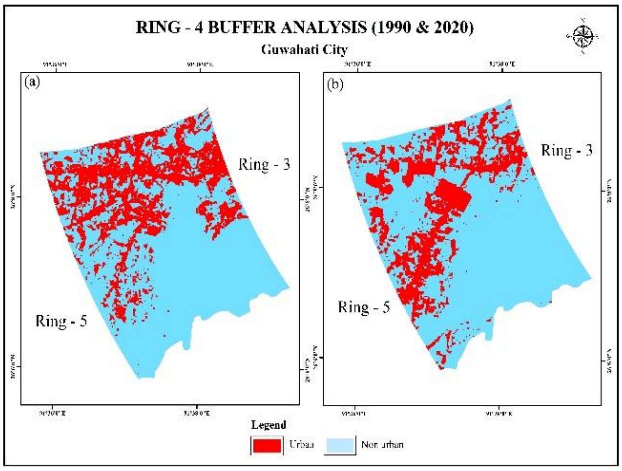

Figure 11: Urban map of Ring-4 built-up (a) Year 1990, (b) Year 2020

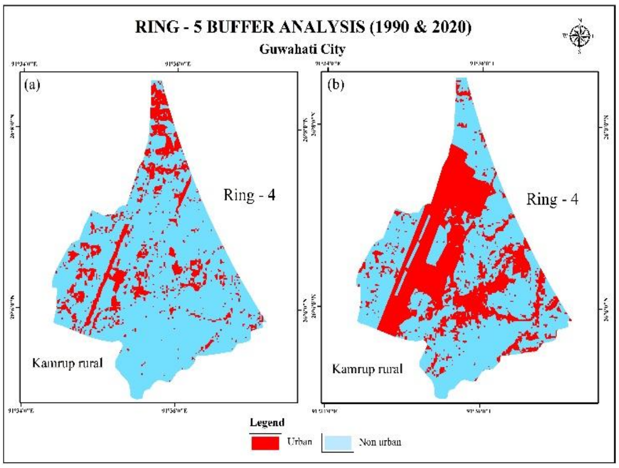

Figure 12: Urban map of Ring-5 built-up (a) Year 1990, (b) Year 2020

Table 3: Ring-wise built-up area matrix for the years 1990 and 2020

Zones		Ring-1	Ring-2	Ring-3	Ring-4	Ring-5	Total area (ha)
Distance (km.)		0 - 4	5 - 8	9 - 12	13 - 16	17 - 20	
Total zone area (ha)		3204.47	8334.35	8114.13	2037.20	1372.25	
1990	built-up	1970.77	2203.57	1322.54	540.07	230.55	6267.49
	non-built-up	1233.70	6130.78	6791.60	1497.13	1141.70	16794.92
2020	built-up	2425.75	4616.23	2783.25	666.40	541.01	11032.63
	non-built-up	778.72	3718.12	5330.88	1370.81	831.24	12029.77
Area difference (ha)		454.98	2412.66	1460.72	126.33	310.46	
Area difference in %		14.20	28.95	18.00	6.20	22.62	

As for the ring-3 [Figure 10], the total area is nearly 8114.13 hectares, of which only 16% is covered with built-up areas. The major areas are occupied by the highly elevated, steeper hills, although they rose to 34% in the year 2020. In ring 4 [Figure 11], the total area is quite small, and the built-up area grows only 6%, which is very little as compared to the other zones, and ring 5 [Figure 12] has the second highest growth percentage, which is 22.62%. The total built-up area of the whole city will be 11032.63 hectares in the year 2020, where nearly 4765.12 hectares have increased over the last three decades [Table 3].

DISCUSSION

The *land use/land cover* patterns show enormous changes over the period. The plain surface areas are pre-filled with the built-up areas in the archive period whereas, in the year 2020, even the foothills and the hilly areas were also filled with the population. The increasing built-up area can be justified by the decrease in forest and barren land because of the encroachment. The accuracy of any map may be tested by comparing the positions of points whose locations or corresponding positions were captured at 100 ground points (Narmada et al., 2021). The accuracy assessment also shows an accuracy level of more than 90%, which is higher than the acceptable rate (Story et al., 1986) for both years. The drastic changes in the study area are due to the continuous changes in the urban landscape due to rapid migration from different locations for better working opportunities. The major growth has been seen in ring 1, where most of the financial activities are going on, while in the surrounding areas some major industries have grown due to the high congestion in the central areas.

The *NDVI* of both years indicates a reduced rate of forest cover due to human encroachment. The NDVI value ranges between -0.30 and 1 (1990) and -0.35 and 1 (2020), and the threshold value for 1990 is 0.19 and for 2020, it is 0.06. If the NDVI cannot meet the needs of vegetation assessment or other purposes, one may consider using other vegetation indices. It is worth noting that every vegetation index has atmospheric and sensor effects, and thus it also has high variability and low repeatability or comparability (Huang et al., 2021).

In the case of *UI* where the urban areas show high values with a red colour and the non-urban areas show a decreasing order with a green color. For the urban index, the value ranges between -0.31 and 0.58 (1990) and -1 and 0.58 (2020). The threshold value for 1990 is -0.127, whereas for the year 2020 it is -0.17.

In the *Multi-Ring Buffer Analysis*, it is observed that due to the period, the city is growing fast and increasing the sub-urban region near the city. The built-up area is generally considered the parameter for quantifying urban sprawl (Sudhira et al., 2004). Hence, the increasing population creates illegal natural resources that deteriorate like deforestation and cause man-made disasters. Due to the steep slope on the eastern and southern sides, there is a huge change in ring 2, where the small hills have been excavated and buildings constructed, though it is too dangerous. Several landslides occurred in those areas from time to time and caused a few casualties. Hence, the combined approach using remote sensing and spatial metrics is powerful and proves a productive new direction for the improved understanding and representation of the spatio-temporal forms due to the process of urbanisation (Martin et al., 2003).

This growth inside the city reduces the space for environmental sustainability and converts towards concrete space. This concrete space will lead to an increase in the urban temperature. The increasing urban activities and heavy construction are impacting people’s health due to the increase in pollution.

CONCLUSION

Remote sensing techniques provide an opportunity to study the spatial distribution of different areas. The above study gave us a distinctive report of Guwahati city and it will help the policymakers to identify the protective measures to control the increasing population. This kind of increasing population in urban areas will push nature into a state of danger where different natural calamities may result. It is noticeable that every year the area has a stormwater logging problem during the monsoonal season. The main root cause of the stormwater problem is the unplanned rapid growth of the buildings and the encroachment on the hillside slope areas. Mostly in the storm water problems appears in the ring-1 and ring-2 due to the high congestions of buildings. The total built-up area counts in the ring 1 are nearly 2425.75 ha out of 3204.47 ha, where 75% of the area is covered with built-up, including administrative, economic, residential, and slum areas. In the 1990s, the growth of the city was very slow and mostly occupied by the original residents of the area, but later on, with the growth of various pull factors, people were migrating from various places. These pull factors adversely affect the reduction of the forest cover area from 36.96% in 1990 to 22.55% in 2020 due to heavy encroachment. It is also noticed that several landslides are experienced by the resident of the hillside people. So, the study will give ideas for inventory measures to solve these problems.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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