An Assessment of Built-Up Area in Madurai City using Geospatial Technology

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Abstract

Madurai, one of the ancient cities in India is undergoing fast transformations to meet up the requirements of a vibrant and live city by providing infrastructure and liveability standards to the residents. This has been ignited by the Smart City Program by the Government of India and the city has been selected in third round to be one among the 100 smart cities of the nation. From the time of announcement, there have been significant changes in the city and it is worthy to keep an eye on the changes in the built-up area in the city limit after the announcement of Mission. It is useful to assess the changes in built up occurred in the city during the phase of smart city mission. Though infrastructure is secondary, it can be a direct indicator towards the progress city is achieving and helps to know the direction of development within the city. Here using NDBI and EBBI a change in the built-up area is analysed. EBBI helps in acquiring both built up and bare land in a single step. A comparison and efficiency test between these two indices is also done. The study is done zone wise to get the planning perspective too.

Keywords: Smart City; Enhanced Built Up and Bareness Index; Normalized Difference Built Up Index; Built Up

Introduction

Urban centres serve as hubs of progress and efficiency. Cities can be the most productive spatial unit in the earth surface as multiple activities at a single time operate in a city which culminates in the virtue of humans. Though pandemic had slowed down the growth rate of urbanizations, World Cities Report 2022 states that "future of humanity is undoubtedly urban" with the supporting facts such as 56% of urban world will be reaching to 68% in 2050. The urban population in the world is increasing from 3981 million in 2015 to 4774 in 2025 to 6680 in 2050. Cities are defined as a settlement of at least 50000 inhabitants in a high-density cluster of grid cells which is greater than 1500 inhabitants per sq.km. (UNHabitat, 2022). Cities act as a workplace, residence, recreational and at times as cultural and religious hubs. Absolute growth of cities is not demographical, but physical, assessed by the increase in the intensity of urbanization the city had achieved.

A clear sign of rising urbanization in cities is the expansion of built-up areas within the city limits. Urban built up encompasses not only buildings but also other man-made structures such as roads, railways, transportation hubs, industrial facilities, commercial establishments, recreational areas, bridges and various other physical infrastructures. Gathering data related to built-up areas can be valuable for informing and guiding planning endeavours. Estimation of the present built up will provide the planners to think of the

alternate spaces to accommodate the in fluxing migrated people to a city landscape. When the Smart City Programme enacted in India in 2015, the first and foremost objective was to improve the infrastructure of the cities to make them liveable and ease for the citizens to reside and operate. Madurai, a cultural and religious town is also expecting to accommodate the new smarter outlook with preserving the traditional nature of the city. The first phase of the project was emphasizing on the physical infrastructure of the city. Hence there could be a change in the built ups in the city which could assessed through this research paper.

Remote sensing data as well as techniques have become inevitable in urban studies. The earlier form of measuring urbanization was of land use land cover classification, which is followed by different spectral indices that can distinguish between urban and non-urban land use. Remote sensing in urban environment is basically concerned with recording and interpreting an image produced by radiant flux. (Bansal, 1992) .The ways which an urban area or surface react to the source of light is different and that difference is manipulated as spectral reflectance for each object; hence it depends on multiple factors such as spatial and spectral resolution of the satellite, climatic conditions of the acquired time. Satellite remote sensing has been used for urban studies in India from 1980 (Gupta & Munshi, 1985). Continuous monitoring and repetitive acquisition of data is essential to study urbanization such a dynamic process. Several indices are being used by spatial analysts for studying the urban areas. Among the different methods, for urban studies, index-based methods are easy to implement practically (Yugang Tian, 2018).

Materials and methods

Study Area: Madurai is one of the ancient cities in India which is said to be existing from 6th century BC. The city has been mentioned by Ptolemy, Mahavamsa and in local Sthalapuranas (Gopalakrishnan, 1998). Known for the Madurai Meenakshi temple, the nucleus, the city has been providing residence for people from the earlier times. It was categorized as a Metropolitan City from 1981.

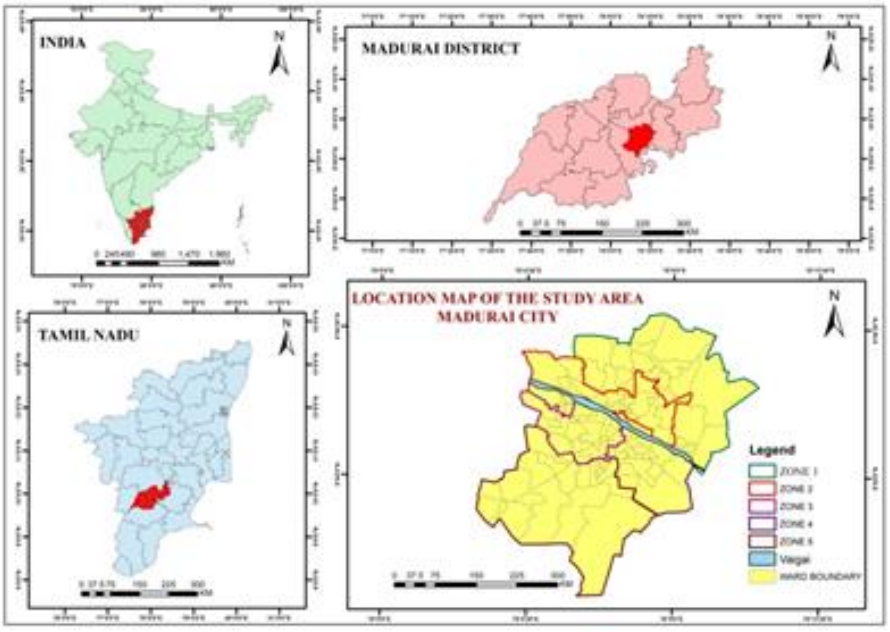

Fig. 1 Study Area.

Madurai City is the third largest city in Tamil Nadu in terms of population and second largest in terms of size. The city lies between 9^0 48'17'' to 9^0 59'26'' N latitude and from 78^0 02' 58'' to 78^0 11'34'' E longitude. City had grown in terms of area as well as population throughout the period. The city sprawls through an area of 147. 97 sq.km is divided into five zones for the ease in administration. The city has witnessed expansion throughout the history and the latest expansion happened in 2010 adding, 25 more wards to the city limit making it a total of 100. The total population of the city is 15, 73,625 according to 2011 Census with a population density of 10, 634. The city has been divided into five zones for the ease of administration.

Datasets: The study is conducted using secondary data. For this purpose, satellite images from USGS were downloaded. For 2015 and 2023, LANDSAT 8 data was retrieved from USGS for the path and row number 153/53. The image acquired for analysis 2023 is captured on 05-06-2023 with a cloud cover of 1.74. The image for 2015 is acquired by the sensor on 22-01-2015. Besides the thermal bands, all other bands were having a spatial resolution of 30 meters. The images collected from the platform were pre-processed and the thermal bands were resampled into 30-meter resolution. Then, through Arc GIS 10.1 software, with the help of raster calculator function EBBI and NDBI are calculated for both 2015 and 2023. Accuracy assessments of the indices were performed using Kappa coefficient method. Google Earth Images are used for accuracy assessment for the corresponding time periods. Results were mapped as well as tabulated and results are analyzed.

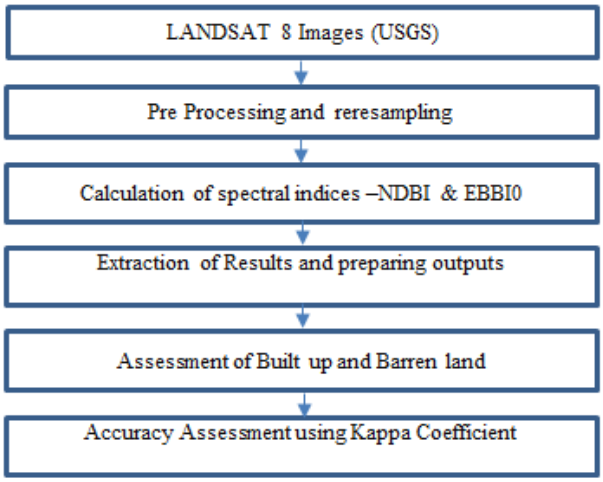

Fig. 2 Methodology.

Results and Discussions

For this study, Normalized Difference Built up Index and Enhanced Built up Bareness Index are used to understand the area under built up in the study area for two times; 2015 and 2023. It was in the year 2015 Smart City Program initiated in Madurai. And 2023 calls for the closure of first phase. Being an expanding city, there might be changes in the built up which is extracted through the analysis. A comparison of NDBI and EBBI is also executed here to see the presence of barren land in the study area. Normalized Difference Built-up Index (NDBI), uses Short Wave Infrared and Near Infra-Red bands to find out the urban areas. NDBI was first proposed by Zha et al. (2003) using Landsat Thematic Mapper. Built up areas reflect more SWIR than NIR. The general formula used is

$$\mathrm{NDBI} = (\mathrm{SWIR1} - \mathrm{NIR})/(\mathrm{SWIR1} + \mathrm{NIR})$$

The value of NDBI ranges from +1 to -1, indicating positive values for urban lands and negative values for non-urban land. Enhanced Built Up Bareness Index, EBBI is proposed first by As-Syakur et al. in 2012 using three bands; SWIR, NIR and TIR of Landsat ETM+. The equation deployed is as given below

$$\mathrm{EBBI} = \frac{\mathrm{SWIR1} - \mathrm{NIR}}{10(\sqrt{\mathrm{SWIR1}} + \mathrm{TIR1})}$$

The value for EBBI also ranges from +1 to -1. This is able to map built up as well as bare land areas in a single attempt. The index gives 0 value for water bodies, negative values for vegetation and positive values for built up and barren pixels (As-Syakur et al., 2012).

NDBI and EBBI for 2015 for Madurai: For EBBI, limit for built up is 0.1 to 0.350 where for NDBI, it is 0.100 to 0.3 for built up and >.300 is barren land (As-Syakur et al., 2012) (Figure 3). The figure clearly depicts the presence of built up concentrated in the centre portion of the city and is scattering towards the north and north eastern part dominantly than the southern and western portions. The river Vaigai is mostly a dried channel because of the image captured in the driest time of Madurai , visible as a linear barren stretch.

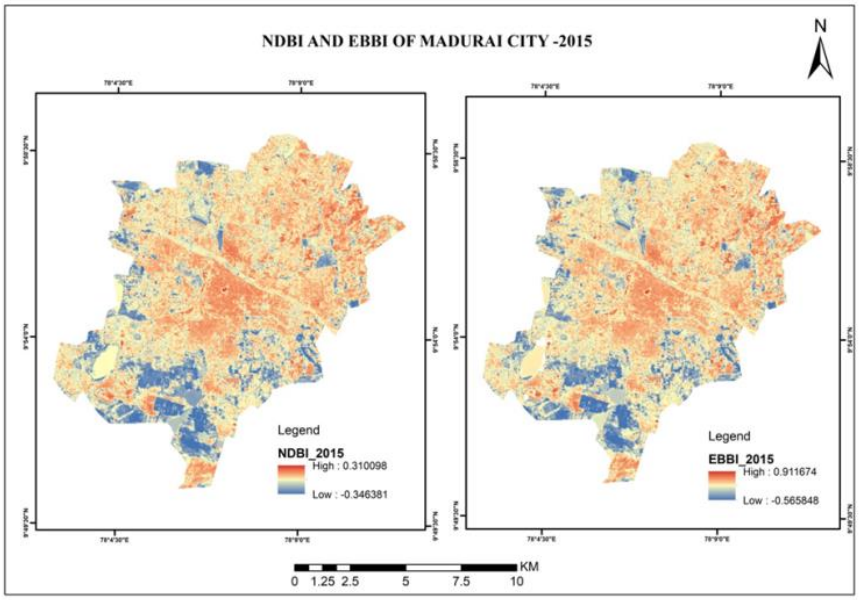

Fig. 3 NDBI and EBBI of Madurai City.

Table 1: Zone wise distribution of NDBI and EBBI for 2015 BU, NB and BL (in sq.km).

Zones	North		South		West		East		Central		City	
LU	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**
BU	26.84	23.07	16.23	15.41	13.65	8.78	18.46	16.46	21.87	19.87	74.78	79.97
NB	5.21	8.81	9.56	9.29	19.57	24.55	14.64	16.28	3.71	5.63	71.41	67.35
BL	0.15	0.21	0.001	0.882	0.03	0.21	0.13	0.31	0.05	0.12	.3	0.26
Total	**32.2**		**25.791**		**33.25**		**33.23**		**25.63**		**147.48**	

LU: Land Use, BU: Built Up, NB: Non-Built up, BL: Barren land

Table 1 shows the area wise distribution of built up, non – built up as well as barren land for all the five zones in both the indices. Both NDBI and EBBI show that built up constitutes 79.97 sq. km and 74.78 sq. km respectively. On Built up constitutes 67.35sq.km in EBBI and 71.41 sq.km in NDBI. Even for the year 2015, the area under barren land is too less in the city. NDBI shows it as 0.3 sq.km, where EBBI shows it as 0.26sq.km. Figure 4 gives zone wise built up, non-built and barren in NDBI and EBBI. The distribution of NDBI and EBBI values across different zones indicates that the North and Central zones exhibit a higher extent of built-up areas, with 26.84 sq.km and 21.87 sq.km respectively. In contrast, the south and west zones show smaller extents of built-up areas. With 13.65 sq.km and 15.41 sq. kms, respectively. The west zone stands out for having a larger area classified as non-built up, covering 24.55 sq.km, while the Central Zone has the smallest non-built-up area at 3.71 square kilometres. Additionally, the South zone has a notable dominance of barren land, spanning an area of .882 square kilometres. The North and Central zones in the study area have been incorporated into the city for an extended period, indicating a more urbanized character. In contrast, the South and West zones were annexed to the city in 2010 and still retain a rural-urban fringe quality. This is the underlying cause for the lower extent of built-up areas and the higher prevalence of barren land observed in the western and southern zones within the study area.

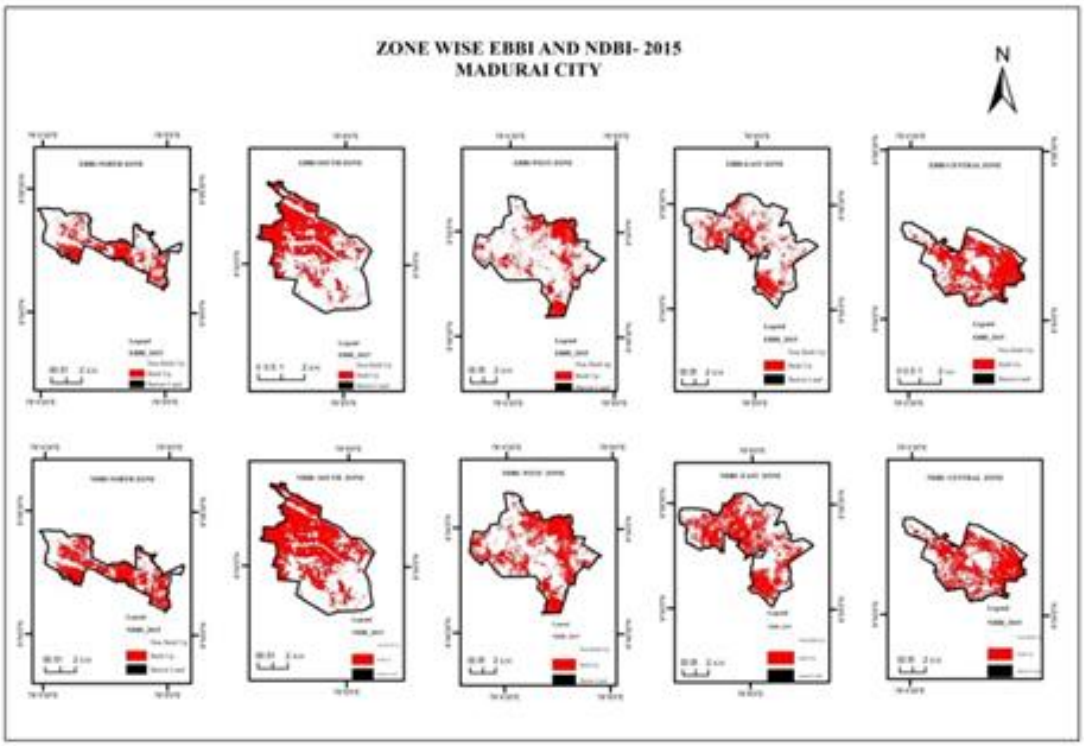

Fig. 4 Zone Wise NDBI and EBBI -2015.

NDBI and EBBI for 2023 for Madurai: In 2023, the NDBI values span from -0.395 to 0.204, while the EBBI values range betwee -0.804 to 0.534. in contrast to the 2015 scenario, the urban development within the city is now notably extending towards the southern and western regions, as clearly depicted in the figure 5. In these areas, there are only a few scattered patches of non built up land remaining. In the year 2023, when we consider both

NDBI and EBBI data, the combined area classified as built up surpasses the area categorized as non-built up. Specifically NDBI indicates a built up area of 83.52 sq.km, while EBBI records it as 85.10 sq.km. On the other hand, non-built up areas cover 62.13 sq.km according to EBBI and 59.85 sq.km according to NDBI.

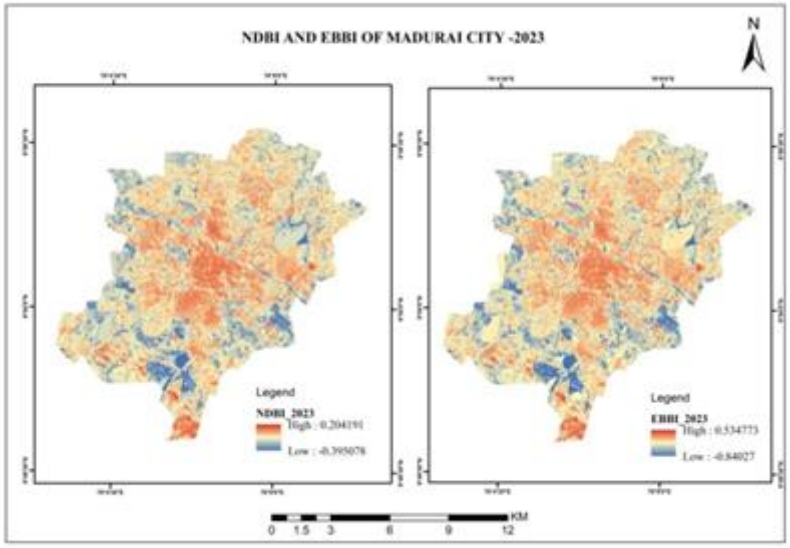

Fig. 5 NDBI and EBBI of Madurai City.

Table 2 Zone wise distribution of NDBI and EBBI for 2023.

Zones	North		South		West		East		Central		City	
LU	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**	**NDBI**	**EBBI**
BU	26.13	24.13	18.72	17.42	20.78	18.78	21.79	20.34	22.46	22.1	84.56	85.10
NB	5.51	7.87	7.07	17.52	12.37	14.26	11.38	12.61	2.205	3.42	62.7	62.13
BL	0.43	.77	.001	.882	.103	.21	.063	.28	.65	.13	.19	.16
Total	**32.2**		**25.791**		**33.25**		**33.23**		**25.63**		**147.48**	

LU: Land Use, BU: Built Up, NB: Non-Built up, BL: Barren land

Considering the distribution zone wise as seen in table 2, in 2023, a similar pattern is observed where the North and Central zones continue to dominate in terms of built – up areas, encompassing 26.13 sq.km and 22.46 sq.km respectively according to NDBI. Conversely, non-built-up activities occupy a larger portion of the South and Western zones, although the area has decreased to 17.52 sq.km and 14.26 sq.km, respectively, compared to previous years. Notably, the southern zone has the highest extent of barren land, covering 0.882 sq.km. Figure 6 gives the zonal distribution of built up, non-built up as well as barren land for 2023 in both the indices. The northern zone comprises 26.13 sq.km of built-up area, closely followed by the central zone. Conversely, the southern zone boasts the largest expansion of non-built-up land, with the western zone coming in second. Barren land is evident in the southern zone occupying .88 sq.km, followed by .77 sq.km in the northern zone and .65 sq.km in the central zone, primarily attributed to the dried up river channel.

Comparison of Zone wise BU, NB and BL for 2015 and 2023 in Madurai City: The northern zone consistently exhibits a larger area under built up land in both time periods, while the western zone had relatively less built-up area in 2015 and the southern zone in 2023. Figure

7 shows that non built is having highest area in 2015, and in 2023, built occupies maximum area. Barren land remains almost same during both the periods. The western zone, an area newly incorporated into the city limits, was predominantly occupied by croplands and barren land, and with a few residential and educational structures situated around Thirupparankundram and near airport. The extent of barren land within the entire city was minimal in both the time periods, decreasing from 0.26 sq.km in 2015 to 0.16 sq.km in 2023. It is worth noting that in the 2023 analysis, the satellite image used was captured in June, which is typically a dry period in Madurai. Consequently, the barren land observed within the city corresponds to the dried river channel. Additionally, there are numerous water tanks within the city limits, which remain non perennial, but appears as barren land in terms of spectral reflectance due to their dry state.

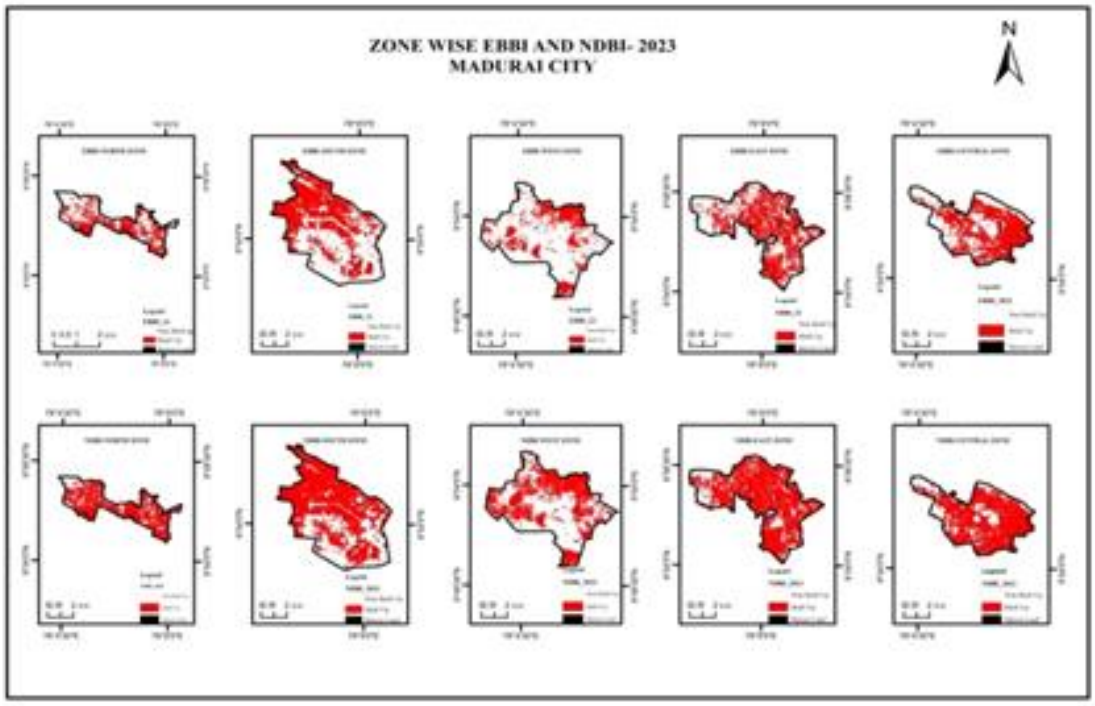

Fig. 6 Zone Wise NDBI and EBBI -2023.

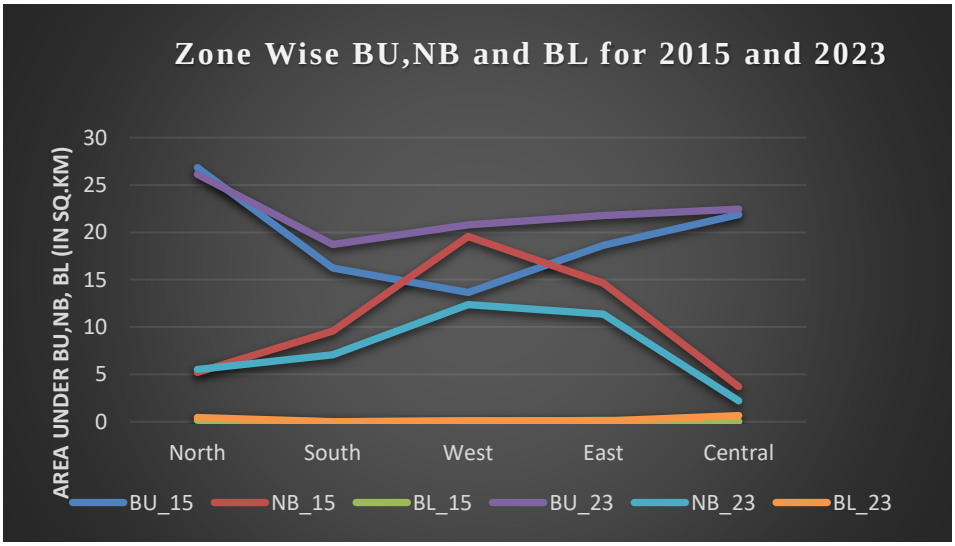

Fig. 7 Comparison of BU, NB and BL in 2015 & 2023.

Accuracy Assessment for NDBI and EBBI: Kappa is a valuable metric used to assess the accuracy of different indices in distinguishing between built up and bare land. It provides a quantitative comparison between EBBI and NDBI, with the calculation of both producer's and user's accuracy, along with overall accuracy and kappa coefficients. In the context of land related studies, a kappa statistic exceeding 80% is considered substantial, and anything above 80 % is deemed almost perfect (Islami, 2022). Some sources even suggest that a kappa value higher than 0.5 can be considered satisfactory (Pontius, 2000). Specifically, when examining the NDBI index for 2015 and 2023, the Kappa and overall accuracy were found to be (84.4%, 89.65%) and (80.39%, 86.95%) respectively. As for the EBBI index, the Kappa statistic and over all accuracy were (81.2%, 90%) in 2015 and (90.24%, 93.61%) in 2023.

Table 3 Accuracy assessment of NDBI and EBBI.

Indices	**NDBI_2015**			**EBBI_2015**			**NDBI_2023**			**EBBI_2023**		
Accuracy	BU	BL	NB	BU	BL	NB	BU	BL	NB	BU	BL	NB
User Accuracy	90.9	80	100	80	91.66	100	85.7	75	100	90	90.9	100
Producer Accuracy	90.9	88.8	88.8	85.7	91.66	92.85	85.7	85.7	88.8	100	83.3	94.1
Overall Accuracy		89.65			90			86.95			93.61	
Kappa Coefficient		84.4			81.2			80.39			90.24	

LU: Land Use, BU: Built Up, NB: Non-Built up, BL: Barren land

Conclusions

Since the inception of Smart City Program in the city, a consistent increase in built up areas and decrease in non-built up and barren land is witnessed. In 2015, the city had minimal barren land, mainly concentrated in the western zone. However recent years have seen a notable rise in built up activities, particularly in the North West. The eastern zone has also experienced significant growth in built up areas due to high residential demand. The city is now predominantly covered by built up areas, with very little land remaining as barren. Consequently, city planners must prioritize the enhancement of existing facilities and infrastructure instead of creating new ones. With no available space for further construction, we may need to explore the possibility of repurposing cropland and scrubland to meet the demand for land, which could impact the city's suitability. This approach may lead to the city expanding horizontally. Areas recently merged into the city, such as west and east zones, have already seen a substantial reduction in non-built-up land. Therefore, it makes more sense to focus on extending existing infrastructure and amenities rather than planning entirely new ones. It's important to note that NDBI provides a more accurate representation of built-up areas, while EBBI is better suited for identifying barren land.

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