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MODIFICATION OF NEW BUILT-UP INDEX TO PRECISELY EXTRACT AND IDENTIFY CHANGES IN THE BUILT-UP AREA: A CASE STUDY OF PUNJAB STATE OF INDIA

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Abstract. Remote sensing is very useful for mapping and managing earth resources. The application of this technique has been widely used and proven useful in assessing temporal changes. The indices are used to distinguish different complex land covers, but there are still difficulties with distinguishing specific land covers. Therefore, the prime aim of this present investigation is to identify the changes in the built-up area using a modified new built-up index (MNBUI). The MNBUI is developed using the reference of four earlier developed indices. The built-up area of Punjab state is extracted from 2013 and 2017 year remote sensing satellite data using MNBUI. The result shows MNBUI is more accurate in terms of built-up area extraction as compared to the other two indices – New Built-up Index and built-up index models. The accuracy assessment is carried out to evaluate the accuracy of MNBUI with a random sampling technique. The mapping accuracy reported is 95% and 0.9333 in terms of overall accuracy (OA) and kappa coefficient (π) respectively.

Keywords: MNBUI, built-up area, remote sensing, satellite data, Punjab State.

Introduction

Land use and land cover are an important component of understanding the relationships between human activity and the environment (Rajan & Shibasaki, 2001). In general, land use refers to human activities and different uses of land, whereas land cover refers to natural vegetation, water bodies, rock/soil, etc. Land use/land cover is the common terminology that can reflect the changes on the surface of the earth due to natural phenomena and various anthropogenic activities. Built-up land, farmland, forest, wasteland, water bodies and others comprise classes of land use/ land cover at first level. Built-up land is a human habitation area that has been created due to non-agricultural use and includes buildings, transport and communication, water, farmland and open land.

The remote sensing (RS) technique based index is a simple and effective way to highlight a specific land cover. Accessibility to high-resolution satellite images and advanced remote sensing technologies are developing since last decade. However, Manual mapping (on-screen digitization) was indeed found to be appropriate for the analysis of the built-up area afterward, and the remote sensing technique was used as tools for interpreting keys such as tonal value, texture, color and association and interpreting the built-up area. At present, built-up area extraction has been made possible due to the accessibility and variety of remote sensing data, thematic layers as causative factors and use of remote sensing and GIS techniques. Recent advancement of computer vision and machine intelligence results in the development of new techniques like index-based built-up area extraction. These techniques are used for the extraction of a built-up area.

In urban built-up area extraction studies, RS indices play an important role, which can be used to increase the accuracy of the built-up area mapping. For example, vegetation indices such as the normalized vegetation difference index (NDVI) (Jensen, 2005) and the enhanced vegetation index (EVI) (Jiang et al., 2008) are being developed to identify green vegetation, and water indices such as the normalized water difference index (NDWI) (Xu, 2005) and the modified NDWI (MNDWI) (Xu,

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2005) are used in many applications to extract different water bodies. An appropriate threshold is critical for extracting specific land cover from an index image because it has major effects on mapping accuracy (Hussain et al., 2013). However, due to their high complexity and correspondence of spectral response patterns, in general, in a mixture of pixels with heterogeneous objects (Zha et al., 2003), it is challenging to distinguish visually bare land and the built-up areas in one image. For example, the differences between bare land and built-up areas are minimal in the normalized difference built-up index (NDBI) (Zha et al., 2003), index-based built-up index (IBI) (Xu, 2008), and urban index (UI) (Kawamura et al., 1996) images. Therefore, when assigning the threshold to identify bare ground, these indices result in high uncertainties.

Several indices have recently been defined to better distinguish bare land, including the normalized differential bareness index (NDBaI) (Zhao & Chen, 2005) and the enhanced built-up and bareness index (EBBI) (As-syakur et al., 2012). A high threshold value also leads to the underestimation of bare land, whereas a low value leads to overestimation. There is always a need for repeated experiments and comparisons to define an appropriate threshold.

A new approach for identifying and changing the built-up area using Landsat remote sensing data is being applied in the present study. The approach involved creating a settlement mask with some buffer area based on settlement types viz.; village, historical data from the township. Extraction of the Built-up area and other spectrally mixed groups may have been a problem. A Modified New Built-up Index based on a literature survey is developed as the main purpose of the current research. The modified New Bult-up index is developed based on three indices; Enhanced Built-Up and Bareness Index (EBBI) (As-syakur et al., 2012), Modified Soil Adjusted Vegetation Index (MSAVI2) (Qi et al., 1994), and Modified Normalized Difference Water Index (MNDWI) (Xu, 2005). The prime objective of the present study is to develop a modified index for built-up area extraction and design methodology to identify the changes in the built-up area between two-time points of datasets of Punjab State of India.

1. Study area

The Punjab State of India is selected as case study. The Punjab state is situated in the North-Western part of the country (Figure 1). The state is surrounded by the Indian union territories of Jammu and Kashmir to the north, Chandigarh to the east, the Indian states of Himachal Pradesh to the north and northeast, Haryana to the south and southeast, and Rajasthan to the southwest. It is located between the northern latitudes of 29° 30' N to 32° 30' N and East longitudes 73° 30' to 77° 00' E. The state covers the area of 50,362 square kilometers (19,445 square miles), 1.53 percent of India's total geographical area. Punjab is the 16th-largest state by population, comprising 22 districts.

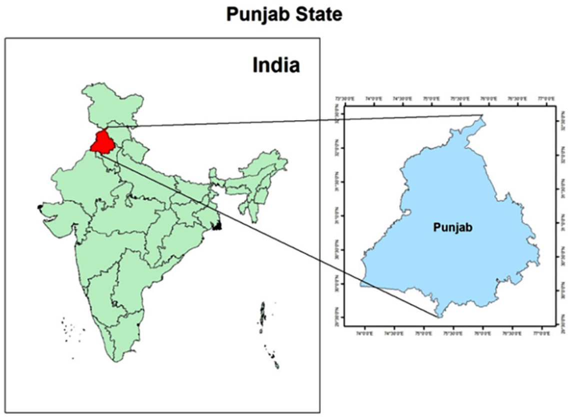

Figure 1. Location of the study area

2. Database and methodology

2.1. Database

Remote sensing Landsat satellite time series Enhanced Thematic Mapper plus (ETM+) data of 2013 year and 2017 year have been acquired for built-up area extraction and change detection analysis.

For current research purpose, the Space-Based Information Support for Decentralized Plan ing (SISDP) project's database (Bhuvan, 2018) for the built-up area identification has been used. Besides that, the Indian Remote Sensing Satellite (IRS) LISS-IV sensor data of Resourcesat-2 is also used for verification. The following Table 1 provides the details of the Landsat satellite data used for the analysis.

Table 1. Landsat satellite data

Satellite	Path/Row	Date	Spatial Resolution (Meters)
Landsat 8 – 2013	147/39	14-Dec-2013	30
	148/38	05-Dec-2013	30
	148/39	05-Dec-2013	30
	149/39	07-Sept-2013	30
Landsat 8 – 2017	147/39	24-Feb-2017	30
	148/38	19-Mar-2017	30
	148/39	19-Mar-2017	30
	149/39	22-Feb-2017	30

2.2. Research methodology

The graphical representation of the methodology for the extraction of built-up area for the year 2013 and 2017 using MNBUI is shown in Figure 2. The built-up areas are extracted using SISDP database and classified as per Census of India (2011) guildlines into village, town and city of Punjab State (India). A buffer area of 100 meter, 300 meter and 4 kilometer (km) have been considered for village,

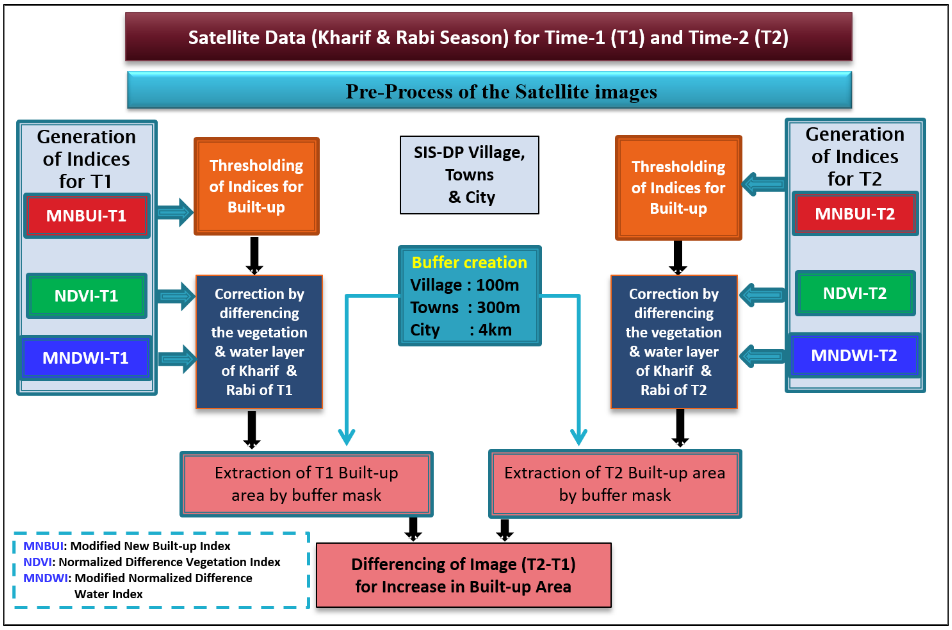

Figure 2. Research methodology

town and cities repetively for analysis purpose looking at settlement sprawl. These buffer areas later have been used for extraction of Time-1 (T1) & Time-2 (T2) built-up areas and further difference image (T2-T1) for total increase in built-up area.

2.2.1. Indices based on remote sensing satellite data and development of Modified New Built-Up Index (MNBUI)

As per the literature review on built-up area extraction using remote sensing techniques, many authors have developed various indices. Some are direct indices, whereas some are combinations of indices or modified indices. The following section describes these indices.

New Built-up Index (NBUI) (Sinha et al., 2016)

$$NBUI = \frac{SWIR\_1 - NIR}{10 \times \sqrt{SWIR\_1 + TIR}} - \left(\frac{(NIR - Red) \times (1 + L)}{NIR - Red + L} + \frac{Green - SWIR\_1}{Green + SWIR\_1} \right). \quad (1)$$

This formula of NBUI is a combination of three formula 1st part Enhanced Built-up and Bareness Index (EBBI) 2nd part Soil Adjusted Vegetation Index (SAVI) and 3rd part Modified Normalized Difference Water Index (NDWI).

2.2.2. Development of Modified New Built-up Index (MNBUI)

A Modified New Built-up Index (MNBUI) is developed, based on the above indices and literature review. The model and concept of MNBUI are based on the understanding that the built-up/urban area is a complex environment composed of few main heterogeneous components: impervious surface material, green vegetation, exposed soil or bare soil, fallow land and water-body. Therefore, MNBUI applied almost the entire wavelengths of Landsat images to represent these major built-up/urban land use classes and computed as:

$$MNBUI = \left\{ \frac{SWIR\_1 - NIR}{10 \times \sqrt{SWIR\_1 + TIR}} - \left(\frac{2 \times NIR + 1 - \sqrt{(2 \times NIR + 1)^2 - 8 \times (NIR - Red)}}{2} + \left(\frac{Green - SWIR\_1}{Green + SWIR\_1} \right) - \frac{NIR - Red}{NIR + Red} \right) \right\}, \quad (2)$$

where

NIR = B4 (ETM + TM) & B5 (OLI), Red = B3 (ETM + TM) & B4 (OLI),

SWIR = B5 (ETM + TM & B6 (OLI), Green = B2 (ETM + TM) & B3 (OLI),

TIR = B6 (ETM + TM) & B10 (OLI).

This formula is combination of four formula 1st part *Enhanced Built-up and Bareness Index (EBBI)* 2nd part *Normalized Difference Bare land Index (NBLI)* 3rd part *Modified Soil Adjusted Vegetation Index (MSAVI2)* and 4th part *Modified Normalized Difference Water Index MNDWI*.

The 1st part of Eq. (2) uses near-infrared (NIR) (0.83 μm), shortwave-infrared (SWIR) (1.65 μm), and thermal-infrared (TIR) (11.45 μm) of Landsat images to highlight the contrast reflection range and absorption in built-up and bare land areas (e.g., Chen et al., 2003; Zha et al., 2003).

Table 2. Punjab State area statistics for village, town and city – 2013 and 2017

Built-up land type	Area in 2013 Year (ha) (a)	Area in 2017 Year (ha) (b)	Diff. Area (2017–2013) (ha) (c) = (b) – (a)	Per year Increase in Area (ha) (d) = (c) / 4	Per year Percentage % (e)
Village	94 428.20	108 316.00	13 887.80	3471.95	14.70/4 = 3.67
Town	41873.90	47 864.30	5990.4	1497.60	14.30/4 = 3.57
City	65 591.20	74 386.00	8794.80	2198.7	13.41/4 = 3.35

The 2nd part of Eq. (2) of MNBUI uses NBLI to highlight bare land surface.

The 3rd and final expression of MNBUI (Eq. (2)) is used to map water, a major component in urban land-use, using a SWIR (B5) and green band (B2) as suggested by Xu (2005).

The 4th part of Eq. (2) of MNBUI uses MSAVI2 to highlight vegetation by taking ratio of NIR (B4) to a red (B3) band to take advantage of high vegetation reflectance in NIR and high pigment absorption of red light (Jensen, 2005).

The above equation has been processed to extract the built-up area for the study area.

2.2.3. Analysis of built-up sprawl for village, town and city

The spatial information/extent of the settlement in urban and rural areas can be easily seen on the satellite image. The settlement is characterized by local terrain conditions, natural resources availability, infrastructure and social and cultural conditions. The area of human habitation developed due to non-agricultural use and that has a cover of housing, transport and communication/utilities in association with water bodies, vegetation and vacant lands. Settlements vary in size and type depends on various factors linked to economic and social activities. They range from hamlets to Metropolitan cities.

Firstly, satellite imageries are pre-preprocessed in terms of enhancements, Top of the atmospheric (TOA) corrections and geo-referencing. After that index images are generated for Enhanced Built-up and Bareness Index (EBBI), Normalized Difference Bare land Index (NBLI), Modified Soil Adjusted Vegetation Index (MSAVI2), Modified Normalized Difference Water Index (MNDWI), and Modified New Built-up Index (MNBUI) using Eq. (2). These index images are generated for two time periods (T1 & T2) of data to extract the difference in the built-up area between two periods (from T1 to T2).

Further, to avoid a false class of built-up area and confined analysis for built-up area under buffer zones of 100 meters for villages, 300 meters for towns and 4 km for cities have been carried out.

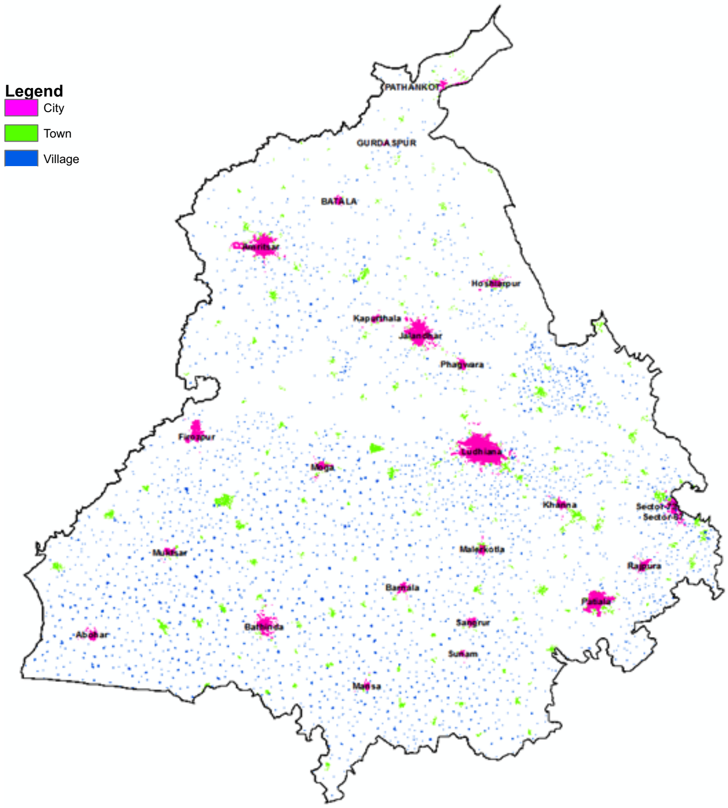

Figure 3. Locations of villages, towns and cities in Punjab State

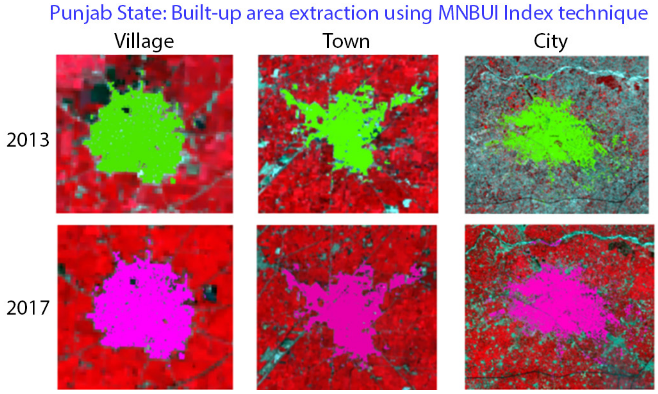

Figure 4. Extracted built-up area for village, town and city in Punjab State

3. Result and discussion

3.1. Modified New Built-up Index (MNBUI) using a spatial model

The developed Modified New Built-up Index (MNBUI) is more accurate in terms of built-up area extraction as compared to the other two indices (NBUI & BI) models. Hence this index is used for built-up area mapping for the years 2013 & 2017 for Punjab State. The locations of villages, towns and cities of Punjab state are shown in Figure 3.

In Punjab state, the increase in built-up area from 2013 to 2017 in the village category observed is 3.67% per year, in the town category, it is 3.57% per year and in the case of the city, it is 3.35% per year and shown in Table 2. In this study, the built-up area has been precisely extracted by the development of an approach of buffer zonation of 100 meter, 300 meter and 4 km of villages, towns and cities respectively based on SISDP project vector layer database and Modified New Built-up Index (MNBUI). The buit-up area extracted by explained approach is shown in Figure 4 for 1-village, 1-town and 1-city of Punjab State for 2013 and 2017 year with satellite image (False Color Compoiste-FCC) in background as illustration.

3.2. Accuracy assessment

High-resolution IRS LISS–IV image (5.8 m spatial resolution) of Punjab state was used to assess the accuracy of the extracted built-up area from MNBUI indices. The extracted built-up binary images have been overlaid on the LISS–IV image, and then visually inspected on a pixel basis. A random sampling technique was also applied to collect 80 samples to compare the accuracies of built-up extraction from MNBUI indices and to evaluate the difference between satellite image (LISS-IV) and classified image. The mapping accuracies have been reported in the form of overall accuracy (OA) and kappa coefficient (κ). The overall accuracy (OA) has been observed is 95.00% and kappa coefficient observed is 0.9333.

Conclusions

In the present case study, remote sensing technique based assessment of the increase in a built-up area is demonstrated using satellite data of two time periods. An approach of buffer zonation (100-meter for villages, 300-meter for towns and 4-km for cities) provided the active area for analysis i.e., actual settlement and surrounding probable built-up growth area. This has reduced the chances of false detection of the built-up area. Hence, the combination of buffer zonation approach and development of the Modified New Built-up Index (MNBUI) has assured precise extraction of built-up area for two time periods (it can be done for any year). This, in turn, provided an actual increase in built-up area. The remote sensing and geospatial technique based approach of estimation of built-up area sprawl is economically viable and could be achieved in a short duration of time.

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Author contributions

All authors have equally contributed.

Disclosure statement

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