Retrieving Spatial Pattern of Urban Using Spectral Ratios for Major Features of an Urban Ecosystem with Satellite Image Processing

Ekta Baranwal¹ and Shamshad Ahmad¹

¹Department of Civil Engineering, Jamia Millia Islamia, New Delhi, India
Email: ektabaranwal01@gmail.com

Abstract. Sustainability is not limited to one field or dimension; it is related to every aspect of humans' life, whatever surrounds us. The growing population always creates the need to expand urban areas, which affects all other natural resources. To fulfill human activities' needs, proper balancing and managing natural resources is essential and necessary. So, urban areas are the most sensitive for sustainability because they include natural resources like water and vegetation. Therefore, it becomes vital to plan, develop, and manage the existing and new urban areas sustainably and live by maintaining harmony among the ecosystem. Accordingly, this research shows one method to retrieve urban patterns through satellite images considering the significant components of the urban, i.e., built-ups, water, and vegetation. The study area's urban pattern is retrieved spatially through two spectral ratios based on three different spectral indices for three urban components with the LANDSAT-8 image.

Keywords. Remote sensing, spectral ratio, urban pattern, sustainable urban

1. Introduction
The entire urban system includes living and non-living features of the earth. Humans' life is impossible without greens and water; even apart from basic needs, every other essential that makes human life comfortable depends on various trees, soil, and water components. Therefore, sustainability has a huge role when considering the urban area, i.e., caring for our surroundings in a balanced way for all. So, when experts either plan to develop and manage the existing urban areas or plan to design a new urban area, there is the consideration of sustainability standards. Although sustainability has its history, it has become a necessity nowadays and has risen in the last few years. With advancements in technology, it became more convenient to measure the earth’s surface changes to track our entire ecosystem's balance. To achieve sustainability, monitoring and to assess the changes in the earth's surface features is necessary, whether evaluating some features creates degradation of others.

Remote sensing is a promising field to monitor the earth’s surface from space and air. Remote sensing provides various data types to observe the earth and evaluate the information about the several features present on it [1] [2]. Also, the geographical information system (GIS) is used to store various geographical data. It allows the facility to assess them to support the experts' decision-making by generating maps of the desired area's desired objects. Together remote sensing and GIS have the power to monitor, store, and assess the spatiotemporal data of the earth’s surface. Therefore, this field provides the essential and advanced tools to monitor the ecosystem's balance in the current era, whether it is about urban areas, forests, various water bodies, wildlife, weather monitoring, snow monitoring, pollution monitoring, crop yield, or disaster management. Remote sensing and GIS work in all these applications.
Some studies in the literature show the role of GIS and remote sensing in sustainability [3] - [5]. Still, this research focuses on the extraction of urban pattern, which is very complicated because urban has vegetation, water, built-ups all in one place. Retrieving the urban pattern is essential in urban planning, whether in the development phase or maintenance. It helps in mapping the area and evaluating the changes taken in time. For this research, a computational model known as the spectral ratio is used to get the urban pattern. The interesting point is that two spectral ratios are taken for the purpose, which considers vegetation and water features in the urban. The spectral ratio is the computing model for multispectral images. In spectral ratio, the electromagnetic (EM) bands are algebraically arranged in such a way that it helps to extract or retrieve the particular feature from the image. Since each EM bands are the image representation of a specific range of the electromagnetic spectrum. Each of them is sensitive to some particular features, like the near-infrared (NIR) band is sensitive to vegetation. In the literature, there are several spectral ratios for various features due to this sensitivity [1] [2] [6] - [8]. These spectral ratios help in retrieving the particular feature or object from the satellite images to keep tracking its pattern changes. This ultimately helps to measure the up-gradation and degradation of the features to understand and make a sustainable relation between them. The details of the spectral ratios taken for the research are in the next section.

2. Literature Background of the spectral ratios used
Since the urban ecosystem involves three significant elements: built-ups, vegetation, and water in various forms, this makes the urban a tricky feature to deal with in remote sensing and evaluate its information through satellite images. We have taken two spectral ratios that comprise of these three major components of urban to retrieve the pattern of urban impervious surfaces. The spectral ratios are index-based built-up index (IBI) [9] and new built-up index (NBUI) [10] that uses three other indices for built-up, vegetation, and water features to finally obtain the urban pattern through medium resolution satellite imageries. Both the indices, IBI and NBUI, are similar as both are dependent on other indices. They both use soil adjusted vegetation index (SAVI) [11] and different version of water index, i.e., normalized difference water index (NDWI) [12], and modified normalized difference water index (MNDWI) [13] for vegetation and water features, respectively but differ in the index used for the built-up part and the algebraic arrangement of IBI and NBUI. SAVI is the index which not only covers the vegetation present in the scene but also considers the soil components for less dense vegetation. IBI uses normalized difference built-up index (NDBI) [14] while NBUI uses enhanced built-up and bareness index (EBBI) [15] for the built-up feature. NDBI and EBBI differ in the number of electromagnetic (EM) bands and types of electromagnetic (EM) bands they use in their formulation. NDBI has only two EM bands, one short wave infrared (SWIR) and one near-infrared (NIR), while EBBI has four EM bands, two short wave infrared (SWIR) bands, one near-infrared (NIR), and one thermal infrared (TIR). Due to the EM band combination, the performance of NDBI and EBBI also differs as EBBI has the advantage of the thermal infrared band, which is sensitive to impervious surfaces. The thermal energy of impervious surfaces is a little higher than that of vegetation and water. That's why using the TIR band in the spectral ratio enhances its performance and retrieve urban pattern much better than the spectral ratio without TIR band. This comparison of IBI and NBUI is visible in their algebraic formula, and from there, it can be easily understandable.

\[ IBI = \frac{NDBI - \frac{SAVI + MNDWI}{2}}{NDBI + \frac{SAVI + MNDWI}{2}} \]

and

\[ NBUI = EBBI - SAVI - NDWI \]

Where,

\[ NDBI = \frac{SWIR_1 - NIR}{SWIR_1 + NIR} \]
\[
E_{\text{BBI}} = \frac{SWIR_1 - NIR}{10\sqrt{(SWIR_1 + TIR)}}
\]
\[
M_{\text{NDWI}} = \frac{\text{Green} - SWIR}{\text{Green} + SWIR}
\]
\[
S_{\text{AVI}} = \frac{NIR + \text{Red} + L}{\text{Green} - NIR} \times (1 + L)
\]
\[
N_{\text{DWI}} = \frac{\text{Green} - NIR}{\text{Green} + NIR}
\]

L is a correction factor for soil brightness, and its value varies from 0 (for high vegetation) to 1 (for low or no green vegetation), Red is the red EM band, and Green is the green EM band.

3. Selection of spectral ratios IBI and NBUI by comparing them with other similar built-up indices

Following are the steps and considerations are taken into account while selecting spectral ratios for this study.

i. In consideration of retrieving urban patterns through satellite imagery, the significant four features in an urban ecosystem that can be captured through space are built-ups, water or moisture contents, vegetation, and soil or bare land.

ii. Spectral indices are categorized into direct indices and indirect indices. Direct indices are those where spectral bands are directly used to formulate the index, while indirect indices use spectral bands indirectly like through other indices or other methods. There is no built-up index from the first category, which considers all the four major features of an urban area. So, it is decided to opt for the index-based spectral indices from the second category. Index-based spectral indices use other indices for various components to retrieve the urban pattern.

iii. Following are the built-up indices that are based on other indices with their consideration of major urban features.

| Other index-based built-up indices                  | Urban features it considers                      |
|----------------------------------------------------|-------------------------------------------------|
| Fractional impervious surface area (FIS) [16]      | Vegetation and soil                             |
| Index-based built-up index (IBI) [9]               | Vegetation, soil, water, and built-ups           |
| Vegetation index built-up index (VIBI) [17]        | Vegetation and built-ups                        |
| Enhancement Built-up Index (ENBI) [18]             | Water and vegetation                            |
| Modified Built-up Index (MBI) [19]                 | Built-ups, water, and bare land                 |
| New Built-up Index (NBUI) [10]                     | Built-ups, vegetation, soil, and water           |
| Modified Built-up Index (MBUI) [20]                | Vegetation, built-ups, and water                 |

iv. Comparing the built-up indices above for the urban features they cover for extracting urban pattern only two indices IBI and NBUI, are found that considers all of the four major urban features.

4. Methodology Followed

Methodology for any research starts with creating the knowledge of the literature after that experiments took place. Here the investigation has begun with obtaining relevant data for the study. After downloading the satellite images, they are pre-processed to make them error-free. Methods under this step vary according to the need of the research and the utilization of EM bands. The TIR band's pre-
processing is different from the pre-processing of other bands in the multispectral imagery. After this, every individual index has been calculated for both the spectral ratios, IBI and NBUI. Following the EM bands’ algebraic arrangement, all indices shown in figure 1 were evaluated, as mentioned in the literature section. Final images of IBI and NBUI were then recoded to classify the pixels as urban and non-urban or impervious and non-impervious surfaces. This recoding is either based on the threshold method or can be a quick two-class classification. The obtained image is an urban pattern of the study area, but it needs to be statistically assessed. Therefore, accuracy assessment is the next step in the procedure, and here, the error matrix method was used to do so where two classes were cross-checked in a matrix. After having the satisfactory result of visual interpretation and statistical assessment, the urban pattern is retrieved for the particular study area.

5. Study area & Data sets
One of the Agro-climatic regions of India is chosen as the area of interest for this research. Three districts from Haryana state are taken to extract the pattern of urban in there. Kurukshetra, Kaithal, and Karnal are the three districts that were once only Karnal before 1973. The place is significant for farming and has religious significance in the Hindu mythology ‘Mahabharat.’ Kurukshetra is the place where the largest war Mahabharat was fought, and Lord Krishna has given the ‘Geeta Updesh.’ Since Haryana is an agricultural state in India, all urban areas are surrounded by agricultural land, which is visible as several clusters of impervious surfaces in between the greenness of farming lands, as shown in figure 2.
Figure 2. Study area

The dataset used here to obtain the urban pattern is the image of satellite LANDSAT-8 having sensors operational land imager (OLI) and thermal infrared sensor (TIRS). This multispectral image has eleven EM bands, including two SWIR and two TIR bands. Sensor OLI has a spatial resolution of 30m with a panchromatic image of 15m resolution, and TIRS has a 100m spatial resolution. Combining all the images of each sensor, we can get the image of fine resolution. Data from the LANDSAT series are available free of cost or at a low cost, so most studies are based on these images. Our study area's LANDSAT image is shown in figure 3 with false composite color (FCC) of SWIR1, NIR, and Red bands.

Figure 3. LANDSAT-8 image of the study area
6. Result Discussion

From figure 3, it can be seen that the study area has urban in several clusters with many roads connecting them. Obtaining the perfect pattern of impervious surfaces is a challenging task. Still, assessing the result of IBI and NBUI visually, we can see from figure 4 that NBUI successfully extracted the road network pattern better than IBI. Still, it also has many misclassified pixels at the top right and around many small clusters. IBI has highlighted the impervious surface pattern much better in terms of misclassification, although it does not include the TIR band. TIR band has the sensitivity for all features' thermal energy, but impervious surfaces have more thermal energy than vegetation and water. This advantage of NBUI does not affect much in enhancing its performance for our study area. Another observation is that IBI and NBUI both use SAVI and water index that got subtracted from the built-up index but in a distinct manner. In NBUI, the whole SAVI and NDWI images are deducted, while IBI utilizes the average of SAVI and MNDWI to subtract from the built-up index. This algebraic arrangement may also affect the result of the index.

Also, the statistical assessment of the images has a similar result to visual evaluation. That means the overall accuracy calculated through the error matrix is higher for IBI than NBUI. IBI resulted in 83% of overall accuracy, while NBUI has 72% of overall accuracy. In this research, IBI has given satisfactory results as the urban pattern for the area better than NBUI.

7. Conclusion

A sustainable ecosystem means a balance between natural beings on the earth involving humans, animals, water, trees, sun energy, land, etc. To do so during developing and managing urban, it is necessary to track all-natural beings' relations. So, monitoring and assessing the features in an urban becomes a big task. Satellite data helps in doing so, and in this paper, it is shown with an experiment. The two spectral ratios worked well to get the urban pattern for our study area, but IBI gave a most satisfactory result than NBUI. Although NBUI has the TIR band's advantage, it performed less than IBI visually and statistically for this study area. Also, it may be possible that the algebraic arrangement of indices in NBUI has affected its performance because in IBI average of water and vegetation indices is removed from built-up to enhance the built-up pattern. But, in NBUI, the entire vegetation and water indices result has been subtracted. It may be one of the reasons for misclassification in NBUI for this study area.
study area. But in the end, these two spectral ratios are satisfactorily enough to recognize and extract impervious surfaces’ pattern of an urban area with vegetation and water inclusion in that urban area.

References

[1] Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2008). Remote Sensing and Image Interpretation. U.S.A.: John Wiley & Sons, Inc.
[2] Jensen, J. R. (2016). Introductory Digital Image Processing-A Remote Sensing Perspective. U.S.A.: Pearson Education, Inc.
[3] Xie, Y., Sha, Z., & Mesev, V. (2018). Remote Sensing of Sustainable Ecosystems. Hindawi Journal of Sensors.
[4] Babatunde, A. A., Martins, O. A., & Adewuyi, G. K. (2019). Relevance of Remote Sensing And GIS In Sustainability of the Built Up Environment. 6th National conference of Environmental Studies on The Nigeria economy and sustainable built environment,2017. Ogun State, Southwest Nigeria.
[5] Goyal, M. K., Sharma, A., & Surampalli, R. Y. (2020). Remote Sensing and GIS Applications in Sustainability. In Sustainability: Fundamentals and Applications, First Edition (pp. 605-626). John Wiley & Sons Ltd.
[6] Alphabetical list of spectral indices. (2020, 17 06). Retrieved from L3HARRIS GEOSPATIAL SOLUTIONS: https://www.harrisgeospatial.com/docs/AlphabeticalListSpectralIndices.html
[7] Indices gallery. (2020, 06 17). Retrieved from ESRI: https://pro.arcgis.com/en/proapp/help/data/imagery/indices-gallery.htm
[8] Spectral Indices with multispectral satellite data. (2020, 05 11). Retrieved from GEO UNIVERSITY: https://www.geo.university/pages/spectral-indices-with-multispectral-satellite-data
[9] Xu, H. (2008). A new index for delineating built-up land features in satellite imagery. International Journal of Remote Sensing, 4269-4276.
[10] Sinha, P., Verma, N. K., & Ayele, E. (2016). Urban Built-up Area Extraction and Change Detection of Adama Municipal Area using Time-Series Landsat Images. International Journal of Advanced Remote Sensing and GIS, 1886-1895.
[11] Huete, A. R. (1988). A Soil-Adjusted Vegetation Index (SAVI) . Remote Sensing of Environment, 295-309.
[12] McFeeters, S. K. (1996). The use of normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17, 1425-1432.
[13] Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing, 3025-3033.
[14] Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. International Journal of Remote Sensing, 583-594.
[15] As-syakur, A. R., Adhynana, I. S., Arthana, I. W., & Nuarsa, I. W. (2012). Enhanced Built-Up and Barenness Index (EBBI) for Mapping Built-Up and Bare Land in an Urban Area. Remote Sensing, MDPI, 2957-2970.
[16] Ridd, M. K. (1995). Exploring a V-I-S (vegetation- impervious surface-soil) model for urban ecosystem analysis through remote sensing: comparative anatomy for cities. International Journal of Remote Sensing, 2165-2185.
[17] Stathakis, D., Perakis, K., & Savin, I. (2012). Efficient segmentation of urban areas by the VIBI. International Journal of Remote Sensing, 6361-6377.
[18] Basarudin, Z., & Adnan, N. A. (2014). Impervious surface detection and mapping via digital remotely sensed techniques. International conference on Civil, Biological and Environmental Engineering (CBEE-2014). Istanbul, Turkey.
[19] Bhattacharjee, D., & Hazra, S. (2014). Fractional impervious surface detection of urban built-up area- A case study in Barasat town, West Bengal, India. Indian Cartographer.

[20] Prasomsup, W., Piyatadsananon, P., Aumphoklang, W., & Boonrang, A. (2020). Extraction technique for built-up area classification in Landsat 8 imagery. International Journal of Environmental Science and Development, 15-20.