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Identification of Settlement Growth and Density Using NDBI from Sentinel-2 Imagery: A Case Study of Sukarame District, South Lampung, Indonesia

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Abstract

Rapid urban expansion in peri-urban areas of Indonesia requires reliable and up-to-date spatial information to support sustainable planning. This study evaluates the use of the Normalized Difference Built-up Index (NDBI) derived from Sentinel-2 multispectral imagery to identify settlement growth and density in Sukarame District, South Lampung. Sentinel-2 Level-2A imagery acquired in 2018, 2021, and 2024 was processed using standardized atmospheric-corrected surface reflectance data. NDBI values were calculated from the shortwave infrared and near-infrared bands and classified into settlement density classes. The results show a consistent increase in built-up areas, particularly in zones adjacent to main transportation corridors and educational facilities. Temporal analysis indicates a clear spatial pattern of urban densification between 2018 and 2024, with medium- to high-density settlements expanding significantly. The findings demonstrate that Sentinel-2-based NDBI is effective for monitoring settlement dynamics at the district scale and can serve as a cost-efficient tool to support urban planning and land-use management.

Keywords: NDBI; sentinel-2; settlement density; urban growth; remote sensing.

1. Introduction

Urbanization is widely recognized as one of the most transformative land-change processes of the twenty-first century. Globally, more than half of the world's population resides in urban areas, and this proportion continues to increase, particularly in developing countries (Pflugmacher et al., 2019). Rapid demographic growth, economic development, and infrastructure expansion accelerate the conversion of agricultural and vegetated land into built-up surfaces. In Indonesia, urban growth is no longer concentrated solely in major metropolitan regions but increasingly affects peri- urban districts that function as transitional zones between rural and urban systems (Handayani et al., 2018; Gibson et al., 2023). Such areas frequently experience dispersed and unregulated settlement expansion, which may result in inefficient land use, environmental degradation, and increased pressure on transportation and public service networks (Ebraheem et al., 2024). Consequently, the provision of accurate, spatially explicit, and temporally consistent information on settlement distribution and density has become essential for evidence-based spatial planning and sustainable regional development.

Earth observation and geomatics technologies offer systematic and repeatable approaches for monitoring land-use and land-cover dynamics. Multispectral satellite imagery enables the identification of urban surfaces through analysis of spectral reflectance characteristics that distinguish impervious materials from vegetation and water bodies. Numerous spectral indices have been developed to enhance built-up features, including the Normalized Difference Built-up Index (NDBI), which exploits the contrast between shortwave infrared (SWIR) and near-infrared (NIR) reflectance to emphasize impervious surfaces (Kulkarni & Vijaya, 2021; Yasin et al., 2022). The NDBI has been widely applied in urban studies using medium-resolution imagery such as Landsat and Sentinel-2 due to its computational simplicity and interpretability (Zheng et al., 2021). Sentinel-2, in particular, provides 10–20 m spatial resolution and high revisit frequency, offering improved capability for district-scale monitoring compared with earlier satellite missions (Drusch et al., 2012).

Previous research has demonstrated the effectiveness of NDBI and related indices for mapping built-up areas and quantifying urban expansion across diverse geographic contexts (Guha et al., 2018; Alademomi et al., 2022; Hussain et al., 2023). However, several research gaps remain. First, many studies focus primarily on large metropolitan regions, while rapidly developing secondary districts receive comparatively limited attention. Second, numerous investigations adopt a binary classification scheme distinguishing built-up from non-built-up areas, with less emphasis on gradational settlement density that reflects stages of urban intensification. Third, the performance of threshold-based NDBI classification may vary according to local land-cover composition and atmospheric conditions, underscoring the need for context-specific evaluation and multi-temporal assessment. Sukarame District in South Lampung represents a peri-urban environment influenced by transportation corridors, educational facilities, and residential development. Despite observable growth in recent years, systematic analysis of settlement expansion and density dynamics using multi-temporal satellite imagery remains limited. The availability of freely accessible Sentinel-2 data provides an opportunity to conduct consistent temporal analysis; however, empirical evidence quantifying settlement densification at the district scale is still scarce. Therefore, this study aims to analyze spatial and temporal patterns of settlement growth and density in Sukarame District using multi-temporal Sentinel-2 imagery and NDBI for the years 2018, 2021, and 2024. Specifically, the research addresses the following questions: (1) How have built-up areas spatially expanded during the study period? (2) What changes have occurred in settlement density classes over time? and (3) To what extent can Sentinel-2-based NDBI support operational settlement monitoring at the district scale? By integrating multi-year analysis with density-based classification, this study contributes to advancing the application of remote sensing in geomatics for peri-urban monitoring. The findings are expected to provide scientific support for spatial planners and local governments in formulating sustainable land-use strategies grounded in quantitative geospatial evidence.

2. Materials and Methods

2.1 Preparation Stage

The preparation phase was conducted to ensure all research requirements were available and aligned with the analysis objectives. This included determining the topic, reviewing literature related to NDBI, selecting a study area, and gathering references on Sentinel-2 image processing. Furthermore, a research framework was developed, including the image data processing flow, masking techniques, and validation methods to be used. This phase also included setting up a Google Earth Engine (GEE) account and verifying the available datasets.

2.2 Research Location

The research location is in Sukarame District, Bandar Lampung , Lampung Province. This area was chosen because it has quite rapid residential development, making it relevant for analysis using the NDBI index. Sukarame District encompasses a variety of residential, educational, commercial, and open space areas, making it suitable for detecting built-up areas using Sentinel-2 multispectral imagery data.

2.3 Research Materials

The main materials used in this study include:

1. Sentinel-2 Level-2A imagery (Atmospherically corrected) from Earth Engine.
2. Sukarame District boundaries in shapefile or GeoJSON format for cropping the analysis area.
3. Supporting data such as land cover, administrative maps, and spectral index literature.
4. Image processing script using Google Earth Engine (GEE) JavaScript API.

2.4 Research Equipment

The research equipment used includes:

1. A laptop for programming and data visualization.
2. Internet access to use the Google Earth Engine platform.
3. Google Earth Engine Code Editor (cloud-based web-GIS).
4. Supporting software such as QGIS or ArcGIS for final map visualization.
5. Spreadsheets or statistical tools for validating results.

2.5 Research Implementation

The research was conducted through several systematic steps to produce an accurate analysis of built-up areas. The initial stage began with the collection of Sentinel-2 imagery from a predetermined observation period. Next, image preprocessing was performed, including cloud masking, image cropping based on the AOI (area-to-area) pattern, and composite creation. Once the imagery was ready for use, the NDBI index was calculated as a parameter for identifying built-up areas. The next step was to classify settlement density levels based on this index value. The analysis results were then validated and interpreted spatially, before being compiled into thematic maps and a research report.

2.6 Data Collection Stage

The data collection phase was conducted through the Google Earth Engine platform by accessing the Sentinel-2 archive dataset. The dataset used was derived from the COPERNICUS/S2_SR collection, which provides Level-2A imagery with atmospheric correction. Data collection was based on specific criteria, including the study period, cloud cover levels of less than 20%, and compliance with the Sukarame District boundaries. The spatial resolution used was 10 meters, allowing for detailed identification of built-up areas. All data was obtained directly through the GEE API, eliminating the for manual downloads.

2.7 Data Validation

Data validation was performed to ensure that the NDBI calculation results corresponded to spatial conditions in the field. The validation process was carried out by visually checking the classification results against true-color RGB images from Sentinel-2. Furthermore, residential and non-residential sample points were verified through visual inspection using Google Earth Pro to ensure consistency of index values. This validation also included checking whether areas with high NDBI values actually indicated the presence of buildings, infrastructure, or other built-up areas. This process is crucial to maintain the integrity of the analysis results before further interpretation.

2.8 Data Processing Stage

This research method was conducted through several systematic stages to produce an accurate settlement index map (Built-up Index Map). The process began with a literature review to obtain a theoretical basis for the NDBI index, image processing techniques, and relevant classification methods. Data collection then included downloading satellite imagery and other necessary supporting data. The data was then processed through a Research Area Clipping stage to focus the analysis on the study area. Following this, an NDBI Classification process was performed to extract built-up area information. The classification results were then reclassified to refine the class categories according to the analysis's needs. The next stage was map layouting to present spatial information in an informative visual format. The resulting map was then tested through a Map Accuracy Test to verify the quality of the interpretation. The verified data was used in the Area Calculation process to determine the distribution of built-up areas. The final result, the Built-up Index Map, served as the primary output of the research before the final stage.

1. Normalized Difference Built-up Index (NDBI)

   Built-up area extraction is performed using the Normalized Difference Built-up Index (NDBI), originally introduced by Xu Hanqiu (2008). The index enhances impervious surfaces by exploiting the contrast between shortwave infrared (SWIR) and near-infrared (NIR) reflectance. The NDBI is calculated as follows:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

   Where:
   NDBI represents the normalized difference built-up index value, SWIR denotes the reflectance of the shortwave infrared band (Sentinel-2 Band 11), and NIR denotes the reflectance of the near-infrared band (Sentinel-2 Band 8). The theoretical range of NDBI values extends from −1 to +1. Positive values generally indicate built-up surfaces, whereas negative values correspond to vegetation and water bodies (Xu, 2008). In this study, specific threshold values were applied

to classify settlement density levels. Areas with NDBI values below 0.0 were categorized as non-built-up areas, representing vegetation, open land, and water surfaces. NDBI values ranging from 0.0 to 0.2 were classified as low-density settlements, values between 0.2 and 0.4 were identified as medium-density settlements, and values greater than 0.4 were categorized as high-density settlements. These threshold values were determined through visual interpretation of Sentinel-2 imagery and comparison with actual land-cover conditions in the study area to ensure classification accuracy and consistency.

2. Percentage Change in Built-up Area

To quantify temporal changes in settlement extent between two observation years, percentage change is calculated using the standard change detection formulation (Singh, 1989):

$$Change\ (\%) = \frac{A_{t2} - A_{t1}}{A_{t1}}\ X\ 100$$

Where:
$At1At1At1$ represents the built-up area at the initial observation year, and $At2At2At2$ represents the built-up area at the subsequent observation year. This metric provides a normalized measure of spatial expansion or contraction over time.

3. Annual Growth Rate of Built-up Area

To evaluate the rate of urban expansion per year, the compound annual growth rate (CAGR) formulation is applied (Puyravaud, 2003):

$$Annual\ Growth\ Rate = \left(\frac{A_{t2}}{A_{t1}}\right)^{\frac{1}{n}} - 1$$

Where:

$At1At1At1andAt2At2At2$ represent built-up areas at the initial and final years, respectively, and denotes the number of years between observations. This formulation provides a consistent measure of annualized growth, independent of the length of the study period.

4. Overall Accuracy (OA)

Classification performance is evaluated using Overall Accuracy (OA), derived from the confusion matrix (Congalton, 1991):

$$OA = \frac{\sum_{i=1}^{k} x_i}{N}$$

Where:
xi represents correctly classified samples for class i, kkk is the total number of classes, and N is the total number of validation samples. OA indicates the proportion of correctly classified pixels relative to the total reference data.

3. Results

Various previous studies have examined land-use change dynamics settlement growth in urban areas, including in Lampung Province, by utilizing multispectral imagery and spectral indices such as the Normalized Difference Built-Up Index (NDBI) is shown in Tab 1. The study found that residential growth occurred progressively, particularly in areas located near major road access and regional activity centers. Furthermore, emphasized that NDBI is effective in identifying built-up areas in urban regions with relatively high accuracy, particularly in rapidly growing cities (Hussain et al., 2023). In general, previous literature indicates a consistent trend of increasing built-up areas and declining green open spaces in Bandar Lampung and its surrounding areas over time (Singh et al., 2024).

The findings of this study demonstrate patterns consistent with those reported in earlier research. NDBI analysis of Sentinel-2 imagery for 2018, 2021, and 2024 indicates a continuous increase in built-up areas over the six-year observation period. In 2018, the settlement area was recorded at 8.0315 km² and increased to 8.5318 km² in 2021 (Figure 1). The most significant growth occurred in 2024, reaching a total of 9.5154 km². Overall, this represents an expansion of 1.4839 km² within six years. These results support previous findings that identify Sukarame as one of the districts experiencing the highest development acceleration in Bandar Lampung, particularly in areas undergoing infrastructure expansion and new residential development. Moreover, the observed expansion pattern from the district center toward peripheral zones corresponds to the urban sprawl pattern.

Table 1. Built-up and Non-Built-up Area Changes in Sukarame District (2018–2024)

Description	2018 (km²)	2021 (km²)	2024 (km²)
Settlement Area	8.0315	8.5318	**9.5154**
Non-Settlement Area	**3.0819**	**2.5816**	**1.598**

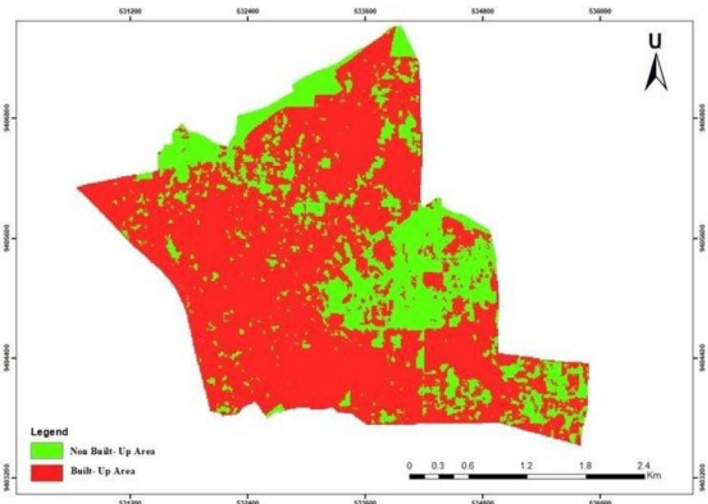

Figure 1. Normalized Difference Built-up Index (NDBI) Map of Sukarame District, 2024

Figure 2. Comparison of Settlement and Non-Settlement Areas in Sukarame District for 2018, 2021, and 2024

The spatial changes identified in this study further reinforce the assertion regarding the capability of NDBI to clearly delineate built-up areas. The 2024 map shows a more dominant and evenly distributed settlement pattern compared to the two previous periods. Meanwhile, non-built-up areas decreased substantially from 3.0819 km² in 2018 to 1.5980 km² in 2024, indicating intensive land-use conversion (Figure 2). This phenomenon, widely documented in previous studies, represents a characteristic feature of urban growth. The reduction of green spaces and the increasing density of settlements observed in this study not only confirm trends identified in earlier literature but also provide a more detailed and updated depiction of the current condition of Kecamatan Sukarame.

Therefore, this research not only corroborates previous findings but also updates the information on settlement growth dynamics in Sukarame up to 2024. Additionally, it offers a more comprehensive quantitative and visual representation of settlement density and spatial distribution patterns. Such information is essential to support spatial planning, land-use control, and sustainable regional development policies in Kota Bandar Lampung.

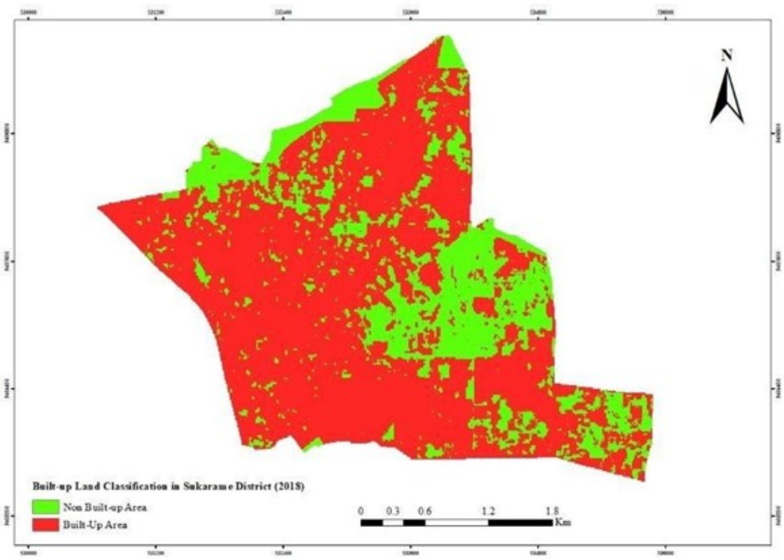

Figure 3. Normalized Difference Built-up Index (NDBI) Map of Sukarame District in 2018

Figure 3 presents the spatial condition of settlement density in Kecamatan Sukarame in 2018 based on the extraction results of the index. In this year, non-built-up areas, represented in green, still dominated most parts of the district, particularly in the northern, western, and several central areas. The predominance of vegetation indicates that development activities had not yet intensified, and a large proportion of the land remained in its natural state, such as mixed gardens, shrub vegetation, and undeveloped open land.

In contrast, built-up areas, shown in red, were primarily concentrated in the central and southeastern parts of the district. However, in peri-urban environments, NDBI may occasionally misclassify exposed bare soil or dry open land as built-up surfaces due to their similar spectral reflectance characteristics. To minimize this limitation, the classification results were visually validated using true- color Sentinel-2 imagery and cross-checked with high-resolution Google Earth imagery. This validation process ensured that areas identified as built-up land corresponded to actual settlements, infrastructure, and impervious surfaces rather than bare land or temporarily exposed soil. The distribution of settlements in these locations reflects the presence of established residential areas situated near community activity centers and major road access. The spatial pattern in 2018 suggests that Sukarame was at an early stage of urbanization, where development had begun to grow but was still concentrated in specific zones. The limited fragmentation of settlements and the extensive non-built-up areas indicate that the district's physical environment remained relatively stable, with development pressure not yet significant.

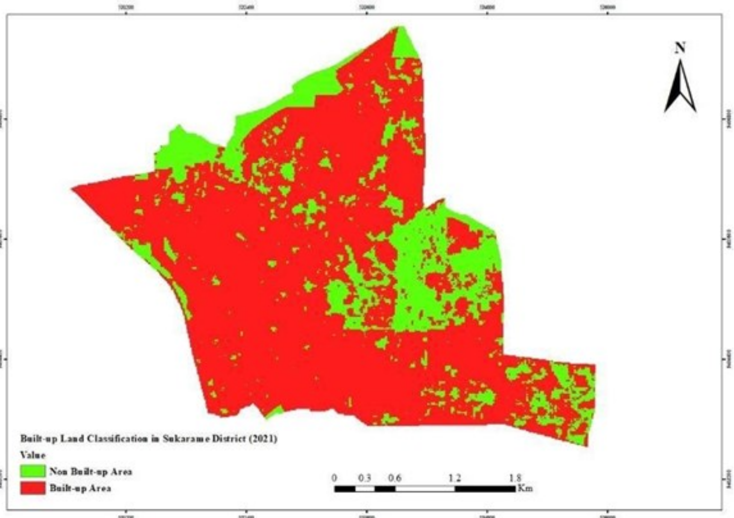

Figure 4. Normalized Difference Built-up Index (NDBI) Map of Sukarame District in 2021

Figure 4 illustrates significant spatial changes in 2021. Compared to 2018, built-up areas, represented in red, appear more extensive and have expanded toward the southern, central, and parts of the western sections of Kecamatan Sukarame. This development reflects an acceleration of construction activities over the past three years, including the establishment of new housing complexes, the expansion of medium-scale residential areas, and the improvement of urban infrastructure.

Non-built-up areas, shown in green, have begun to fragment into smaller patches, indicating an increasing rate of land-use conversion. This spatial pattern suggests that residential growth is no longer concentrated solely within the core area of the district but has gradually shifted toward peripheral zones due to rising housing demand and increasing socio-economic activities.

Furthermore, these changes reveal a relationship between settlement expansion and accessibility, as areas located near major transportation corridors tend to experience faster development. Overall, the 2021 condition represents a transitional phase of urbanization characterized by a more pronounced intensity of land conversion.

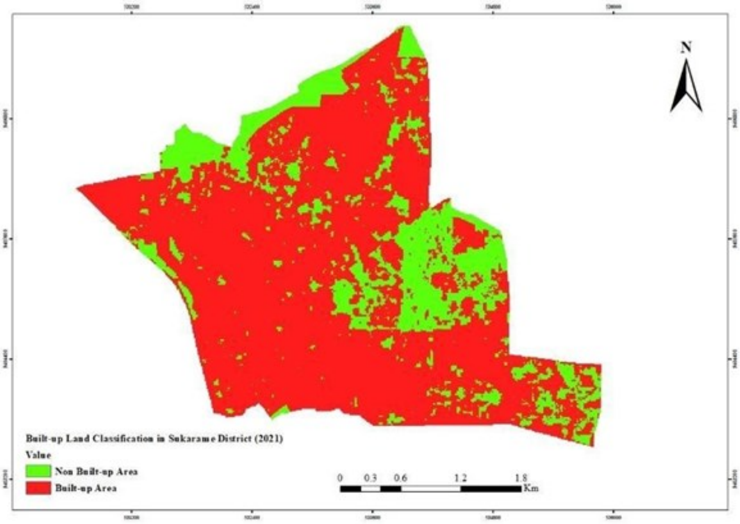

Figure 5. Normalized Difference Built-up Index (NDBI) Map of Sukarame District in 2024

Figure 5 presents the most recent condition in 2024, clearly illustrating the dominance of built-up areas. In this map, the red color occupies nearly the entire area of Kecamatan Sukarame, indicating that built-up land has expanded massively during the 2021 – 2024 period. Non-built-up areas, represented in green, have significantly decreased and remain only as small, isolated patches in several locations. This pattern confirms the occurrence of intensive land-use change, particularly the conversion of vegetation and open spaces that previously functioned as ecological buffers.

The substantial increase in built-up areas suggests that Sukarame has entered an advanced stage of urbanization, where population growth, rising housing demand, and economic development accelerate land conversion processes. Moreover, the spatial distribution of settlements in 2024 appears more homogeneous, indicating that development is no longer concentrated solely around activity centers but has spread radially across almost all parts of the district. The shrinking extent of green open spaces also signals growing environmental pressure, which may lead to declining urban ecosystem quality, increased surface temperatures, and reduced water infiltration capacity. Therefore, the 2024 map reflects the most pronounced spatial transformation and serves as clear evidence of the high intensity of development occurring in Kecamatan Sukarame.

4. Conclusions

This study demonstrates that the application of the Normalized Difference Built-Up Index (NDBI) derived from multispectral imagery of Sentinel-2 provides a reliable approach for detecting and quantifying built-up area dynamics in Kecamatan Sukarame during the 2018 – 2024 period. The results indicate a consistent increase in built-up land from 8.0315 km² in 2018 to 9.5154 km² in 2024, representing a total expansion of 1.4839 km² over six years. Concurrently, non-built-up areas decreased from 3.0819 km² to 1.5980 km², reflecting intensive land-use conversion. Spatially, the expansion pattern tends to spread outward from the activity center toward peripheral zones, indicating an urban sprawl phenomenon.

These findings confirm the ongoing acceleration of urban development in Kota Bandar Lampung, particularly within Kecamatan Sukarame, and are consistent with previous studies reporting continuous built-up expansion driven by population growth, infrastructure development, and public service facilities. The novelty of this study lies in providing updated spatial evidence up to 2024 and in demonstrating the applicability of NDBI-based remote sensing analysis to support quantitative urban growth assessment within the domains of geodesy, geomatics, and Earth sciences. From a practical perspective, the results offer relevant input for spatial planning, land-use control, and sustainable urban management. Nevertheless, this study is limited to a single spectral index and a specific temporal range. Future research is recommended to integrate additional spectral indices, higher-resolution datasets, and advanced spatial modeling approaches to enhance the robustness and comprehensiveness of urban growth analysis.

5. Declaration of Interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Acknowledgement

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