JOURNAL OF EARTH SCIENCE AND GEOMATICS INDONESIA

Volume 1 (2026), Page 12-19

Monitoring the Growth of Built-up Areas in Bandar Lampung City (2020-2024) Based on Sentinel-2 Data

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Received: December 9, 2025
Revised: February 10, 2026
Accepted: February 25, 2026
Published: June 10, 2026

Citation: Al Attar S, M. N., & Tabitha, A. K. (2026). Monitoring the Growth of Built-up Areas in Bandar Lampung City (2020-2024) Based on Sentinel-2 Data. Journal of Earth Science and Geomatics Indonesia, 1, 12–19.

Abstract

The rapid urbanization in Bandar Lampung City has driven significant land cover changes, necessitating continuous monitoring to support sustainable planning. This study aims to analyze the spatio-temporal changes of built-up areas in Bandar Lampung City during the 2020-2024 period. Utilizing Sentinel-2 satellite imagery and the Normalized Difference Built-up Index (NDBI), classification and analysis of built-up area growth were conducted across all districts. The results indicate a substantial increase in built-up area by 13,603 km², from 49,412 km² in 2020 to 63,016 km² in 2024. The highest growth was concentrated in suburban areas, indicating an urban sprawl phenomenon, with Sukabumi District experiencing the most rapid increase (54,63%). Conversely, the densely populated city center exhibited limited growth. These findings highlight a shift in development dynamics toward suburban areas, implying increasing environmental pressure. The results of this study can serve as essential information for local governments to strengthen spatial utilization control and formulate strategies for urban disaster risk mitigation.

Keywords: Built-up Area, Urbanization, Sentinel-2, NDBI

1. Introduction

Urbanization is one of the key factors driving land cover change. The rapid expansion of built-up areas often occurs at the expense of agricultural land and vegetation (Gandharum et al., 2022). This transformation brings various environmental consequences, such as the reduction of green open spaces (Purnayudhanto et al., 2023), the intensification of the urban heat island phenomenon (Prasasti et al., 2015), increased flood risk (Handayani et al., 2020), and growing pressure on urban infrastructure (Pravitasari et al., 2018). Therefore, monitoring built-up area growth is essential for understanding urban dynamics and supporting sustainable urban planning. In Indonesia, the expansion of built-up areas in urban regions has been accelerating (Olivia et al., 2018). Several major cities such as Jakarta-Bandung (Rustiadi et al., 2021), Surabaya (Purwono et al., 2024), and Makassar (Sukri et al., 2025) have experienced significant increases in built-up land.

Bandar Lampung City, as the capital of Lampung Province, has experienced significant population growth. According to the Badan Pusat Statistik Kota Bandar Lampung (2025), the city's population increased from 1.015.910 in 2017 to 1.209.937 in 2022. Thus, within five years, the population grew by 194.027 people, equivalent to 19.09%. This substantial population growth indicates that the demand for new land for built-up area development in Bandar Lampung City will continue to rise in the coming years.

To comprehensively understand the dynamics of built-up area growth, spatial data capable of capturing changes over time are required. Remote sensing offers an effective solution, providing continuous temporal information and extensive spatial coverage. Among various satellite data sources, Sentinel-2 offers advantages in terms of adequate spatial resolution and multispectral capabilities suitable for urban area analysis (Xu et al., 2022). Through the application of spectral indices such as the Normalized Difference Built-up Index (NDBI), this imagery can be utilized to detect and quantify built-up areas more accurately, while providing continuous insights into urban land use dynamics (Zha et al., 2003). Moreover, the open access nature of Sentinel-2 data makes it an easily accessible information source, especially where field data are often limited.

Several studies have examined the dynamics of built-up area changes in major Indonesian cities; however, similar research in Bandar Lampung City remains limited, particularly in the context of temporal analysis using Sentinel-2 imagery. Some previous studies have attempted to investigate the spatial changes in settlements and the development of built-up areas in the city. Wulansari et al (2023) analyzed the relationship between settlement growth and population increase, while Sari (2017) examined the general dynamics of built-up area development in earlier periods without utilizing high resolution satellite data. A recent study by Darmawan and Trio (2024) applied the Random Forest algorithm to map land use transformations; however, their research focused more on overall land cover classification rather than quantitative analysis of built-up area growth at the sub district level.

Based on these considerations, this study aims to provide an updated analysis of temporal built-up area changes in Bandar Lampung City during the 2020-2024 period by utilizing Sentinel-2 imagery and applying the NDBI index. This approach enables a more specific and quantitative observation of built-up area changes across districts. Furthermore, the study highlights the spatial growth patterns and their implications for the city's development direction. The findings are expected to provide up to date baseline information for spatial planning and land use management, while supporting sustainable urban development efforts in Bandar Lampung City.

2. Materials and Methods

The study area is Bandar Lampung City, the capital of Lampung Province. The city covers an area of 183,75 km² and is located between 5°20' to 5°30' South Latitude and 105°28' to 105° East Longitude, bordering South Lampung and Pesawaran Regencies. The city's position is considered strategic due to its proximity to the toll road network that connects Sumatra and Java

Islands, providing significant advantages for regional economic growth and development (Lubis and Silviana, 2023)

In this study, the primary data used were Sentinel-2 satellite images for the years 2020 and 2024, which were accessed and processed using the Google Earth Engine platform (Gorelick et al., 2017). The imagery was composited into annual mosaics to represent land conditions for each respective year. To detect built-up areas, the Normalized Difference Built-up Index (NDBI) method was applied. This index identifies built-up areas by utilizing the spectral difference between the Near Infrared (NIR) and Short Wave Infrared (SWIR) bands, using the following formula:

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

The data collection and analysis process began with retrieving Sentinel-2 imagery. The imagery used was based on the World Geodetic System (WGS) 84 coordinate reference system and had been radiometrically and atmospherically corrected, thus eliminating the need for further correction to avoid reflectance bias. Subsequently, the imagery was processed using the NDBI algorithm to classify built-up areas. In this study, an NDBI threshold value of ≥ 0.1 was set to classify built-up land (Kumar & Gupta, 2023). The classification results were then analyzed spatially to identify patterns and trends of change. The spatial analysis included overlap analysis to visualize the distribution of built-up areas during the 2020-2024 period.

To validate the NDBI analysis results, a confusion matrix was employed to assess the classification accuracy by comparing the classified results with reference (ground truth) data (Banko, 1998). This matrix provides information on the number of correctly and incorrectly classified pixels for each land cover class. Based on the matrix, several parameters were calculated, including Overall Accuracy (OA), which represents the overall classification accuracy; Producer's Accuracy (PA), which reflects the accuracy from the reference data perspective; User's Accuracy (UA), which indicates the reliability of the classification results from the user's perspective; and the Kappa coefficient ($\varkappa$), which accounts for the level of agreement that may occur by chance.

The determination of the sample size for the confusion matrix in this study refers to the guidelines proposed by Congalton and Green (2009), which state that for areas smaller than one million acres (approximately 4.047 km²) and with fewer than twelve map classes, it is recommended to collect at least 50 samples per class. Considering that the study area Bandar Lampung City covers approximately 183,75 km² and consists of only two land cover classes (built-up and non built-up areas), this guideline is deemed relevant and appropriate for application. Therefore, a minimum of 50 sample points was considered sufficient to validate the classification accuracy of the satellite imagery in this study.

3. Results

3.1 Changes in Built-up Land Area

Based on the classification results using NDBI derived from Sentinel-2 satellite imagery, a significant increase in built-up land cover was identified in Bandar Lampung City during the 2020-2024 period. The classification process produced two land cover categories built-up and non built-up areas. The results of the built-up land growth analysis are presented in the form of maps, as shown in Figure 1.

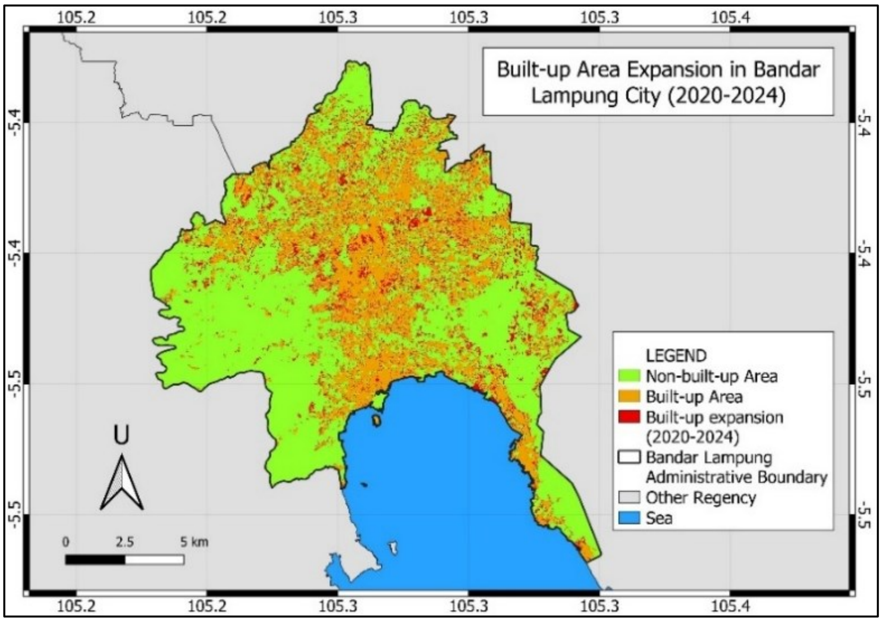

Figure 1. Growth of built-up Areas in Bandar Lampung City during the 2020-2024 Period

The NDBI analysis for the 2020-2024 period revealed a substantial change in the extent of built-up land in Bandar Lampung City. In 2020, the built-up area was recorded at 49,412 km², which increased to 63,016 km² by the end of 2024. Thus, within approximately five years, the built-up area expanded by 13.603 km², equivalent to 7,4% of the city's total area. The NDBI analysis also identified the direction of built-up land growth toward the north, northeast, east, southeast, south, and northwest, which aligns with the findings of Sari (2017), with additional minor growth detected in the central part of the city.

Table 1. Annual NDVI, rainfall, and burned area in Pelalawan Regency (2015 to 2022) based on MODIS and CHIRPS datasets.

District	Built-up Area 2020 (km²)	Built-up Area 2024 (km²)	Built-up Area Growth 2020–2024 (km²)	Growth (%)
Bumi Waras	2,022	2,240	0,218	10,759
Enggal	1,686	1,891	0,205	12,171
Kedamaian	2,868	3,680	0,812	28,312
Kedaton	2,232	2,612	0,380	17,043
Kemiling	3,074	4,203	1,129	36,716
Labuhan Ratu	2,775	3,436	0,661	23,811
Langkapura	1,918	2,562	0,643	33,528
Panjang	3,746	4,942	1,196	31,931
Rajabasa	3,014	4,084	1,069	35,470
Sukabumi	4,300	6,649	2,349	54,633
Sukarame	4,184	5,213	1,029	24,589
Tanjung Senang	2,872	3,786	0,914	31,820
Tanjungkarang Barat	2,284	3,112	0,827	36,211
Tanjungkarang Pusat	1,776	2,196	0,420	23,621
Tanjungkarang Timur	1,365	1,545	0,180	13,185
Telukbetung Barat	1,103	1,229	0,126	11,421

Telukbetung Selatan	1,652	1,791	0,139	8,402
Telukbetung Timur	1,392	1,611	0,219	15,752
Telukbetung Utara	2,092	2,324	0,231	11,050
Way Halim	3,050	3,906	0,856	28,052

During the 2020-2024 period, all districts in Bandar Lampung City experienced an increase in built-up area with varying magnitudes. As shown in Table 1, the growth of built-up land ranged from 0,126 km² to 2,349 km². Sukabumi District recorded the highest increase in built-up land, followed by Panjang, Kemiling, Rajabasa, and Sukarame. Meanwhile, the areas with the smallest increases were Telukbetung Barat, Telukbetung Selatan, and Tanjungkarang Timur. This condition indicates that the already densely developed city center has reached a saturation point in development, while the suburban areas are becoming new zones for residential and infrastructural expansion.

In terms of growth rate, the highest percentage increase occurred in Sukabumi District (54,63%), followed by Kemiling (36,72%), Tanjungkarang Barat (36,21%), Rajabasa (35,47%), Langkapura (33,53%), and Tanjung Senang (31,82%). Conversely, districts with relatively low growth rates include Telukbetung Selatan (8,40%), Telukbetung Utara (11,05%), and Telukbetung Barat (11,42%). These differences in growth rates indicate a tendency toward urban sprawl, characterized by the outward expansion of built-up areas from the city center to the suburbs particularly toward the north, east, southeast, and west. This pattern of expansion aligns with the spatial plan of Bandar Lampung City, which designates Sukabumi, Rajabasa, Sukarame, and Tanjung Senang as zones for new residential and educational area development.

The rapid growth of built-up land in areas such as Sukabumi and Kemiling is influenced by large scale housing development, the availability of open and vegetated land, and improved transportation connectivity to the city center. Specifically, in Sukabumi and Sukarame Districts, this development is further driven by the presence of the Trans Sumatra Toll Road (Jalan Tol Trans Sumatera; JTTS), which plays a crucial role in enhancing mobility and goods distribution, reducing travel times, and improving economic efficiency in surrounding areas (Fakhurozi et al., 2020). In addition to strengthening access to the city's core activity centers, the JTTS corridor also opens opportunities for new regional development along the toll route. In the context of Bandar Lampung City, the direct access provided by JTTS in Sukabumi and Sukarame serves as a key driver of accelerated urbanization and built-up area expansion. Conversely, coastal and central economic zones such as Telukbetung exhibit limited growth due to spatial constraints. This phenomenon reflects a significant spatial transformation in Bandar Lampung City over the past four years, in which development dynamics have increasingly shifted toward peripheral areas.

3.2 Validation Using Confusion Matrix

The classified land cover results obtained through the application of the NDBI index for the years 2020 and 2024 were evaluated using a confusion matrix to assess the classification accuracy and reliability. The detailed evaluation results are presented in Tables 2 and 3.

Table 2. Annual NDVI, rainfall, and burned area in Pelalawan Regency (2015 to 2022) based on MODIS and CHIRPS datasets.

Classification Result	Reference Data			Result					
	Built-up Area	Non Built-up Area	Total	Commission	Omission	Map accuracy	Producer accuracy	User accuracy	Kappa
Built-up Area	38	0	38	0%	24%	76%	76%	100%	76%
Non-Built-up Area	12	50	62	19%	0%	81%	100%	81%	
Total	50	50	100		Overall Accuracy			88%	

Table 3. Confusion matrix and accuracy parameters of built-up and non built-up land cover classification in 2024

Classification Result	Reference Data			Result					
	Built-up Area	Non Built-up Area	Total	Commission	Omission	Map accuracy	Producer accuracy	User accuracy	Kappa
Built-up Area	40	2	42	5%	20%	77%	80%	95%	76%
Non-Built-up Area	10	48	58	17%	4%	80%	96%	83%	
Total	50	50	100		Overall Accuracy			88%	

Based on the confusion matrix and accuracy parameters for the land cover classifications in 2020 (Table 2) and 2024 (Table 3), the NDBI based classification using Sentinel-2 imagery demonstrated a high and consistent level of reliability in distinguishing between built-up and non built-up areas in Bandar Lampung City. In 2020, the OA reached 88%, with a Kappa coefficient of 0.76 indicating a strong agreement between the classification results and reference data. Similarly in 2024, the OA remained at 88% with the same Kappa value, showing consistency in classification performance. These results suggest that the NDBI effectively detected built-up areas in 2024 despite a slight increase in commission errors due to spectral similarities between newly developed areas and bare land. Overall, the NDBI classification method using Sentinel-2 imagery proved effective for monitoring built-up land cover changes in urban areas such as Bandar Lampung, demonstrating stable accuracy and strong detection capability for built-up area expansion over the 2020-2024 period.

4. Conclusions

Based on the analysis of Sentinel-2 imagery using the NDBI index, a significant increase in built-up land area was observed in Bandar Lampung City during the 2020-2024 period, with a total expansion of 13,603 km². The rapid growth observed in several districts reflects accelerated urban development that may exert pressure on the environment, particularly due to the reduction of vegetated areas and water infiltration zones. These findings are crucial for local governments to strengthen spatial utilization control, guide development in accordance with environmental carrying capacity, and integrate land cover change monitoring results into urban disaster risk mitigation strategies.

5. Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Acknowledgement

This study made use of Copernicus Sentinel-2 data (European Space Agency) obtained through the Copernicus Open Access Hub and processed using Google Earth Engine. The authors gratefully acknowledge the ESA and Google for providing open-access satellite data and cloud-based processing resources.

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