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Original Article

The Creeping City: Spatial Analysis Of Built-Up Land Expansion and Coastal Settlement Conversion in Central Kendari

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Abstract

Urban expansion is one of the key indicators of spatial change in coastal urban settings. Kendari City, especially the coastal area of Kendari Bay, has undergone swift urban growth due to a rise in population, infrastructure advancements, and economic concentration. This research seeks to examine the spatial dynamics of urban land growth and coastal land-use change in Central Kendari from 2019 to 2024. The study utilizes Sentinel-2 satellite images analyzed via Google Earth Engine (GEE) by integrating the Normalized Difference Built-up Index (NDBI), Normalized Difference Vegetation Index (NDVI), and land mask classification. The approach involves image preprocessing, calculating spectral indices, classifying land, and performing spatial overlay analysis to identify temporal variations in land cover. Quantitative analysis indicates that developed regions grew from 1,391.99 hectares in 2019 to 1,437.25 hectares in 2024, reflecting an overall increase of 45.25 hectares. The geographic distribution of urban expansion is focused on coastal areas and key transit routes, demonstrating a significant impact of accessibility and economic factors. The findings also show a negative relationship between NDBI and NDVI values, suggesting that vegetation cover has increasingly been substituted by developed land. The change is mainly fueled by infrastructure expansion, coastal economic initiatives, and urban connectivity. This research emphasizes the efficacy of combining remote sensing metrics with cloud-based geospatial analysis to track urban growth, underscoring the necessity for sustainable spatial planning in coastal urban areas.

Keywords: Coastal, Developed Area, Google Earth Engine, LULC

INTRODUCTION

Land-use change represents one of the most visible manifestations of socioeconomic transformation and is widely recognized as an important indicator of urban development. The expansion of cities is rarely a purely spatial process; rather, it reflects the interaction between demographic growth, economic activity, infrastructure development, housing demand, and changing patterns of human mobility. As urban populations increase and economic functions become increasingly concentrated in strategic locations, land that was previously occupied by vegetation, agricultural areas, wetlands, or other forms of open space is progressively transformed into residential, commercial, institutional, transportation, and industrial uses. Such transformation is particularly pronounced in rapidly developing cities where the demand for land frequently exceeds the capacity of existing urban areas to accommodate new activities. Consequently, monitoring changes in land use and land cover is essential not only for understanding the physical growth of cities but also for evaluating the environmental implications of urbanization and informing sustainable spatial planning.

Remote sensing has become an important methodological approach for examining these dynamics because it provides repeated, spatially continuous, and relatively objective observations of the Earth's surface. Unlike conventional field-based surveys, which may require considerable time and resources to collect information across extensive areas, satellite observations enable researchers to investigate

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land-cover conditions over large spatial and temporal scales. This capability is particularly relevant to urban environments because land-cover transformation may occur rapidly and in spatially fragmented patterns. Remote sensing imagery allows these transformations to be identified by examining differences in the spectral characteristics of vegetation, soil, water, and built-up surfaces. Consequently, the integration of satellite imagery with geographic information system (GIS) techniques has increasingly become a fundamental approach for detecting, quantifying, and interpreting urban expansion (Drusch et al., 2012).

The relationship between urban development and land-cover transformation is particularly important because the conversion of natural or semi-natural surfaces into built-up environments changes the physical characteristics of the urban landscape. The replacement of vegetated and permeable surfaces by buildings, roads, parking areas, and other impervious structures can alter the balance between infiltration, evapotranspiration, and surface runoff. Urbanization can therefore generate consequences that extend beyond the simple increase in the spatial extent of buildings. Changes in surface permeability may influence drainage systems, flood generation, groundwater recharge, surface temperature, ecological conditions, and the availability of urban green spaces. Pasquier et al. (2022), for example, demonstrated that impervious surfaces associated with urban development can substantially modify the partitioning of rainfall between infiltration and surface runoff, thereby influencing groundwater recharge and urban hydrology. Their findings reinforce the importance of considering land-cover change not merely as a spatial phenomenon but also as a process with direct environmental consequences. These issues become increasingly relevant in coastal cities, where urban expansion is frequently concentrated along relatively accessible and economically valuable areas. Coastal urban zones generally accommodate a combination of residential settlements, commercial activities, transportation infrastructure, public facilities, and other economic functions because of their strategic location and accessibility. At the same time, these areas may contain environmentally sensitive ecosystems and drainage pathways that are important for maintaining ecological and hydrological functions. The expansion of built-up areas into coastal and low-lying landscapes may consequently generate multiple forms of environmental pressure. Changes in vegetation cover, for instance, can reduce the capacity of urban landscapes to provide ecological services, while increasing impervious surfaces can modify the movement and accumulation of stormwater. The spatial identification of these changes is therefore an important prerequisite for understanding the direction and intensity of urban development.

Kendari City, the capital of Southeast Sulawesi Province, provides an important context for examining these processes. As a provincial capital and an important urban center in eastern Indonesia, Kendari functions as a concentration of administrative, economic, educational, commercial, and service activities. Its development has progressively increased the demand for land and infrastructure, particularly in areas with high accessibility and strategic connections to major urban functions. Central Kendari District represents one of the areas that deserves particular attention because of its location along Kendari Bay and its relationship with the broader development of the urban area. The combination of coastal accessibility, settlement growth, commercial activity, public services, and transportation infrastructure creates conditions in which land-use transformation can occur intensively within a relatively limited spatial area. The development of Central Kendari should consequently be understood as part of a broader process of urban restructuring. Increasing demand for residential and commercial land may encourage the conversion of vegetated surfaces and other open areas into built-up land. At the same time, infrastructure development can strengthen the accessibility of previously less-developed areas, creating additional incentives for subsequent settlement expansion. This process may generate a cumulative spatial effect in which the expansion of individual buildings, roads, and supporting facilities gradually produces a more continuous built-up landscape. Identifying the spatial distribution of these changes is important because the physical pattern of urban expansion may provide information about the direction, concentration, and intensity of development.

The environmental significance of such transformation is equally important. Vegetated and open surfaces perform several ecological functions within urban landscapes, including supporting evapotranspiration, intercepting rainfall, reducing surface runoff, facilitating infiltration, moderating local microclimates, and providing habitat for urban biodiversity. When these surfaces are replaced by impervious structures, their ecological functions may be reduced. Urban hydrological studies have

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consistently emphasized that the expansion of impervious surfaces can alter the relationship between rainfall, infiltration, and runoff. Pasquier et al. (2022) found that extensive impervious development can redirect a substantial proportion of water away from infiltration and toward surface runoff. Similarly, research on urbanization and groundwater systems has shown that changes in land cover can influence groundwater recharge and the urban water balance, although the magnitude and direction of these effects vary according to local environmental and infrastructural conditions (Kumar et al., 2018).

This consideration is particularly significant for Central Kendari because the district is spatially connected with Kendari Bay. Urban expansion in coastal environments needs to be considered in relation to both terrestrial and coastal processes. Increased surface runoff from developed areas may transport sediments, nutrients, and other pollutants toward drainage channels and receiving waters. Meanwhile, the reduction of vegetation and open areas can diminish the landscape's capacity to regulate water flows. Although remote sensing analysis alone cannot directly quantify all of these hydrological and ecological processes, mapping the spatial transformation of built-up and vegetated areas provides an essential first step for identifying locations where environmental pressure may be increasing.

The development of remote sensing technology has substantially enhanced the capacity to conduct such analyses. Among the satellite missions currently available for land-cover monitoring, Sentinel-2 provides particularly useful characteristics for urban and environmental studies. The Sentinel-2 mission is equipped with the Multispectral Instrument (MSI), which records 13 spectral bands across the visible, near-infrared, red-edge, and shortwave-infrared portions of the electromagnetic spectrum. Four of its bands have a spatial resolution of 10 m, six bands have a resolution of 20 m, and three atmospheric bands have a resolution of 60 m. The two-satellite constellation also provides a nominal five-day revisit interval at the equator. These characteristics make Sentinel-2 suitable for monitoring land-use and land-cover changes at relatively detailed spatial and temporal scales. The European Space Agency identifies land-use and land-cover monitoring, vegetation assessment, and coastal observation among the major applications of the Sentinel-2 mission.

The spectral characteristics of Sentinel-2 are particularly valuable for differentiating built-up surfaces from vegetation. Vegetation exhibits a strong spectral response in the near-infrared region and relatively strong absorption in the red portion of the electromagnetic spectrum. This spectral contrast forms the basis of the Normalized Difference Vegetation Index (NDVI), which has become one of the most widely used indicators for estimating vegetation conditions from remotely sensed imagery. The foundations of vegetation monitoring using spectral ratios can be traced to the work of Rouse et al. (1974), who demonstrated the potential of multispectral satellite observations to quantitatively assess vegetation conditions over broad areas. Subsequent developments have established NDVI as an important tool for characterizing vegetation distribution, density, and temporal changes. In an urban context, NDVI can therefore be used not only to identify vegetation but also to complement built-up area detection by distinguishing areas characterized by strong vegetation responses from surfaces dominated by buildings and other artificial structures.

In parallel with vegetation indices, the Normalized Difference Built-up Index (NDBI) has been widely applied to identify and map built-up surfaces. Zha et al. (2003) introduced NDBI as an approach for automatically mapping urban areas based on the distinctive spectral characteristics of built-up land. The method was developed to facilitate the extraction of urban land from remotely sensed imagery and demonstrated its applicability in mapping built-up areas in Nanjing, China. Their study reported an overall mapping accuracy of 92.6%, highlighting the potential of NDBI as a relatively simple and efficient method for identifying urban surfaces. The original formulation of NDBI is based on the contrast between shortwave-infrared and near-infrared reflectance, allowing built-up surfaces to be emphasized relative to other land-cover types.

Nevertheless, the use of NDBI should not be interpreted as an independent or universally definitive representation of built-up land. Spectral similarity among urban surfaces, bare soil, exposed sediment, and certain other land-cover types can generate classification ambiguities. Consequently, combining NDBI with NDVI provides a more informative framework for urban land-cover extraction. Areas with high NDBI and relatively low NDVI may indicate surfaces dominated by buildings or other impervious structures, whereas areas characterized by stronger vegetation responses can be distinguished through higher NDVI values. This combined interpretation is particularly useful in heterogeneous urban environments, where buildings, vegetation, bare land, roads, and water bodies may occur within close spatial proximity.

The use of a water or land mask can further improve the interpretation of built-up areas. Water bodies have distinct spectral characteristics that may interfere with the identification of built-up surfaces if they are not excluded from the analysis. This consideration is particularly important for Central Kendari because the study area is associated with Kendari Bay. By incorporating a land mask, water surfaces can be excluded before the analysis of built-up and vegetated land, thereby reducing the possibility that coastal and aquatic features will be incorrectly interpreted as terrestrial land-cover classes. The resulting analytical framework can provide a more spatially coherent representation of the relationship between built-up expansion and changes in vegetation or open land.

The methodological advantages of Sentinel-2 become even more significant when combined with Google Earth Engine (GEE). Conventional remote sensing workflows often require researchers to download, store, preprocess, and analyze large volumes of satellite imagery locally. These procedures can become increasingly demanding when the research involves multiple observation years or repeated analyses. Google Earth Engine addresses this limitation by providing a cloud-based platform that combines a large geospatial data catalogue with high-performance computational infrastructure. Gorelick et al. (2017) described GEE as a planetary-scale geospatial analysis platform designed to facilitate large-scale processing of remotely sensed and other geospatial datasets. Its architecture enables users to access and process extensive satellite archives without having to manage the entire computational burden locally.

The application of GEE is particularly appropriate for multitemporal urban analysis because the platform contains extensive satellite imagery archives and allows researchers to filter imagery according to spatial boundaries, acquisition dates, and cloud conditions before performing spectral calculations. Sentinel-2 imagery can therefore be processed consistently for different observation years, allowing changes in NDBI and NDVI to be examined using comparable procedures. This approach is advantageous for the 2019–2024 observation period because it enables the identification of changes occurring over a five-year interval while maintaining a consistent analytical framework. Rather than relying solely on visual interpretation of individual satellite images, the integration of spectral indices and temporal image processing provides a more systematic basis for identifying the spatial expansion of built-up areas.

Despite the increasing application of remote sensing for urban studies, spatially explicit analyses of urban expansion remain important at the local scale because the patterns and environmental consequences of urbanization are highly context dependent. A general increase in built-up area at the city scale does not necessarily reveal where development is concentrated, which land-cover types are being converted, or how expansion relates to specific environmental settings. In a coastal district such as Central Kendari, these questions become particularly relevant because urban development occurs within a landscape where terrestrial settlement patterns intersect with coastal environmental systems. Therefore, examining changes in built-up areas together with vegetation conditions and the spatial configuration of land surfaces can provide a more meaningful understanding of urban development than simply measuring total urban area.

Against this background, the present study focuses on the spatial dynamics of built-up area expansion in Central Kendari District during the 2019–2024 period. Sentinel-2 imagery is utilized as the principal source of multitemporal remote sensing data, while Google Earth Engine provides the computational environment for image processing and spatial analysis. NDBI is employed to identify the spectral characteristics of built-up surfaces, NDVI is used to characterize vegetation conditions, and a land mask is incorporated to minimize interference from water bodies associated with Kendari Bay. The integration of these approaches is expected to provide a consistent spatial representation of changes in built-up areas and their relationship with the transformation of vegetated and open surfaces.

Accordingly, this study aims to analyze the spatial expansion of built-up areas and the conversion of coastal settlement landscapes in Central Kendari District between 2019 and 2024 using Sentinel-2 imagery processed through Google Earth Engine. More specifically, the analysis is intended to identify the spatial distribution of built-up areas, examine changes in their extent between the two observation periods, and interpret the direction and pattern of urban expansion in relation to vegetation and land-cover conditions. The resulting information is expected to contribute to a more comprehensive

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understanding of urban development in Central Kendari and provide spatial evidence that can support environmentally sensitive urban and regional planning. In this context, remote sensing is not positioned merely as a technical instrument for producing land-cover maps, but as an analytical means of understanding how urban growth reshapes the relationship between human activities, land resources, and environmental sustainability.

MATERIALS AND METHODS

This study was conducted in Central Kendari District, Kendari City, Southeast Sulawesi Province, Indonesia. The study area is situated along Kendari Bay and represents an urban coastal environment characterized by residential development, commercial activities, public facilities, transportation infrastructure, and other supporting urban functions. The spatial setting of the district provides an appropriate context for examining urban land transformation because increasing development pressure may result in the conversion of vegetated and open surfaces into built-up areas. The analysis was designed to examine the dynamics of built-up area expansion during the 2019–2024 period by comparing the spatial distribution of built-up surfaces between the two observation years. The methodological framework combined multitemporal satellite imagery, spectral indices, spatial masking, and overlay analysis to identify and quantify changes in the built-up landscape. The primary data used in this study were Sentinel-2 Surface Reflectance imagery accessed and processed through the Google Earth Engine (GEE) cloud computing platform. Sentinel-2 imagery was selected because of its multispectral characteristics and spatial resolution, which are appropriate for detailed land-cover analysis in urban environments. The use of Surface Reflectance products also provides an important advantage for multitemporal analysis because the imagery has undergone atmospheric correction, resulting in surface reflectance values that are more appropriate for comparisons across different observation dates. The use of a consistent satellite data product for the two observation years was intended to reduce potential differences arising from variations in data processing. Google Earth Engine was utilized as the computational environment because it provides access to extensive satellite image collections and facilitates large-scale geospatial processing without requiring all imagery to be downloaded and processed locally. The platform has been widely recognized as an effective environment for planetary-scale analysis of remotely sensed and geospatial data (Gorelick et al., 2017). This capability is particularly useful for multitemporal urban analysis because image filtering, spectral-index calculation, masking, compositing, and spatial analysis can be implemented within a consistent computational workflow.

The image preprocessing stage was undertaken before the spectral indices and built-up area maps were generated. Sentinel-2 imagery corresponding to the 2019 and 2024 observation periods was first filtered according to the spatial extent of Central Kendari District and the availability of imagery with relatively low cloud contamination. The selection of images with minimal cloud cover was important because clouds and their associated shadows can substantially influence spectral reflectance and consequently affect the calculation of spectral indices. Following image selection, the imagery was clipped to the administrative boundary of Central Kendari District so that subsequent calculations were restricted to the study area. The use of Sentinel-2 Surface Reflectance imagery further reduced the influence of atmospheric scattering and absorption, thereby improving the consistency of spectral information used for the comparison between 2019 and 2024. These preprocessing procedures established a standardized dataset before the calculation of NDBI, NDVI, and NDWI. Built-up areas were subsequently extracted using the Normalized Difference Built-up Index (NDBI). NDBI is a spectral index developed to emphasize built-up surfaces based on their different reflectance characteristics in the short-wave infrared (SWIR) and near-infrared (NIR) portions of the electromagnetic spectrum. Zha et al. (2003) demonstrated the usefulness of NDBI for automatically mapping urban areas and showed that the index could provide an efficient approach for distinguishing built-up land from other land-cover types. In this study, NDBI was calculated using Sentinel-2 Band 11, representing SWIR at approximately 1,610 nm, and Band 8, representing NIR at approximately 842 nm. The NDBI calculation follows the general formulation:

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

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The resulting NDBI values were interpreted according to the relative spectral response of the land surface. Higher positive values generally indicate a stronger spectral response associated with built-up or impervious surfaces, whereas lower or negative values are more commonly associated with vegetation and water. Nevertheless, NDBI values should be interpreted as an indicator of built-up characteristics rather than as an absolute classification of urban land because exposed soil and other spectrally similar surfaces may also generate relatively high NDBI responses. For this reason, the NDBI analysis was integrated with vegetation and water indices to improve the separation of built-up surfaces from other land-cover types.

Vegetation conditions were characterized using the Normalized Difference Vegetation Index (NDVI). NDVI exploits the contrast between the strong absorption of red wavelengths by chlorophyll and the relatively high reflectance of healthy vegetation in the near-infrared region. In this study, Sentinel-2 Band 8 was used as the NIR band and Band 4 as the red band. The NDVI was calculated using the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Higher NDVI values generally represent surfaces with greater vegetation density and stronger vegetation activity, whereas lower values may correspond to built-up surfaces, bare land, exposed soil, or water. The inclusion of NDVI in the analytical workflow was important because vegetation represents one of the major land-cover components that may be affected by urban expansion. Areas exhibiting high NDBI values but relatively low NDVI values can therefore provide stronger indications of built-up surfaces than NDBI alone. Conversely, areas characterized by high NDVI values can be distinguished as vegetation-dominated surfaces and subsequently examined in relation to changes in the built-up landscape.

Because Central Kendari is located along Kendari Bay, water bodies were explicitly excluded from the built-up area analysis. This step was necessary because water surfaces may produce spectral responses that overlap with other low-reflectance land-cover types and may potentially interfere with the interpretation of urban land. Open water was identified using the Normalized Difference Water Index (NDWI), which in this study was calculated using the Green and NIR bands following the formulation proposed by McFeeters (1996). The NDWI developed by McFeeters was specifically designed to enhance open-water features in remotely sensed imagery by exploiting the contrast between green and near-infrared reflectance. The formulation applied in this study was:

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

Pixels exhibiting positive NDWI values were interpreted as potential water surfaces and were subsequently used as a water mask. The application of this mask allowed the analysis to exclude the waters of Kendari Bay and other water features from the terrestrial built-up area extraction. This procedure was particularly important for a coastal study area because it reduced the possibility of water pixels being incorrectly incorporated into the built-up classification. It should be noted that the NDWI formulation used here differs from the vegetation-water-content index proposed by Gao (1996); the present study adopts the McFeeters formulation because the analytical objective is the delineation of open water features. The integration of NDBI, NDVI, and NDWI was then used to establish a more robust representation of built-up surfaces. NDBI served as the primary indicator of built-up spectral characteristics, NDVI provided information on vegetation distribution, and NDWI was applied to exclude water surfaces from the analysis. This integrated approach was intended to minimize potential confusion among built-up areas, vegetation, bare land, and water. Rather than interpreting a single spectral index independently, the spatial relationship among the three indices was considered in identifying terrestrial surfaces with characteristics consistent with built-up land. This approach is particularly relevant in heterogeneous coastal urban environments such as Central Kendari, where buildings and infrastructure may occur in close proximity to vegetation, exposed land, drainage channels, and coastal water bodies.

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After the built-up area maps for 2019 and 2024 were generated, spatial overlay analysis was conducted to identify changes in the distribution of built-up surfaces. The built-up maps from the two observation years were spatially compared to determine areas that remained continuously built-up, areas that emerged as new built-up surfaces, and areas that did not exhibit built-up characteristics during the respective observation periods. The overlay process also facilitated the examination of the spatial direction and pattern of urban expansion. In this context, urban expansion was interpreted not simply as an increase in the total amount of built-up land but as a spatial process involving the emergence and distribution of newly developed areas throughout Central Kendari District. This distinction is important because two areas may experience similar increases in built-up area but exhibit substantially different spatial patterns of development.

The percentage change in built-up area between 2019 and 2024 was calculated using the difference between the built-up area in the two observation years relative to the 2019 baseline. The calculation was expressed as:

$$Percentage\ Change = \frac{A_{2024} - A_{2019}}{A_{2019}} \times 100\%$$

This formulation provides a standardized measure of the relative increase or decrease in built-up land during the observation period and enables the magnitude of urban expansion to be expressed independently of the absolute size of the study area.

RESULTS AND DISCUSSION

The analysis of land use dynamics in Central Kendari District between 2019 and 2024 demonstrates a gradual but spatially meaningful expansion of built-up areas. The results derived from Sentinel-2 imagery, NDBI analysis, NDVI interpretation, water masking, and spatial overlay provide evidence that urban development in the study area was not evenly distributed but followed particular spatial patterns associated with existing urban structures, transportation accessibility, and activity centers. This finding reinforces the importance of satellite-based observation for understanding urban growth because remotely sensed imagery enables changes in land cover to be observed consistently across space and over different periods. Remote sensing has long been recognized as an effective approach for monitoring urban land transformation because urban surfaces possess distinctive spectral characteristics that can be extracted and compared through multitemporal imagery (Zha et al., 2003).

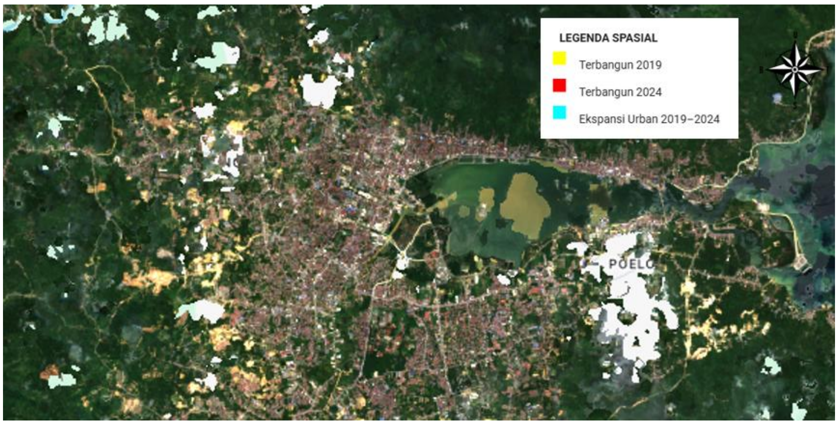

Figure 1. Sentinel-2 Imagery of Kendari City in 2024

The 2024 natural color composite presented in Figure 1 provides an initial visual representation of the physical landscape of Kendari City. The built-up environment is generally represented by grayish to brownish tones, vegetation by green tones, and Kendari Bay by dark blue to black tones. The visual differentiation between these land-cover components provides an important basis for interpreting the subsequent spectral-index results. In an urban environment, however, visual interpretation alone is insufficient because buildings, bare soil, roads, vegetation, and water can occur in highly fragmented patterns. Sentinel-2 is particularly useful in this context because its combination of relatively fine spatial

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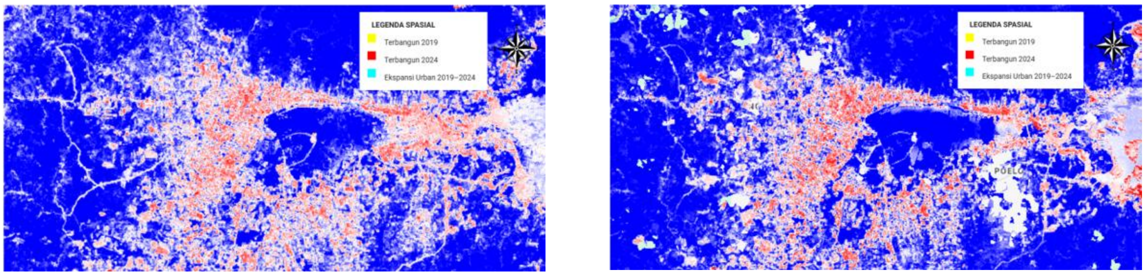
resolution, multispectral information, and frequent revisit capability provides opportunities for detailed urban land-cover analysis (Xu et al., 2022). Nevertheless, Sentinel-2 imagery also has limitations in highly heterogeneous urban environments because individual pixels may contain mixtures of several land-cover types. This mixed-pixel problem can influence the separation of buildings, roads, bare land, and vegetation, meaning that spectral indices should ideally be interpreted together rather than independently (Xu et al., 2022).



(a) (b)

Figure 2. NDBI Map: (a) 2019; (b) 2024

The NDBI results in Figure 2(a) indicate that built-up surfaces in 2019 were concentrated mainly within the established urban area. Positive NDBI values were predominantly distributed around the urban core and along major transportation corridors. This pattern is consistent with the fundamental characteristics of the NDBI, which was originally developed to distinguish built-up surfaces based on the spectral contrast between near-infrared and short-wave infrared wavelengths. Zha et al. (2003) demonstrated that NDBI can provide an efficient means of automatically extracting urban land from satellite imagery and can serve as an alternative to more complex conventional classification approaches. The concentration of positive NDBI values in the central part of Kendari therefore provides a reasonable spectral indication of the established urban structure at the beginning of the observation period. The 2024 NDBI map in Figure 2(b) shows a broader distribution of positive values compared with the 2019 condition. The expansion of high NDBI values toward peripheral residential areas and along transportation networks indicates that urban development continued to extend beyond the previously established urban core. The pattern suggests that the transformation was not merely an increase in building density within existing settlements but also involved the spatial extension of built-up land into previously non-built-up areas. Similar patterns have been documented in studies using multitemporal remote sensing, where urban expansion is reflected by the outward extension of built-up surfaces and the progressive transformation of surrounding land-cover classes (Varshney, 2013). In this regard, the difference between the 2019 and 2024 NDBI distributions provides important evidence that Central Kendari experienced a continuing process of urban spatial expansion.

(a) (b)

Figure 3. Built Up Area: (a) 2019; (b) 2024

At the quantitative level, the classified built-up area increased from 1,391.99 ha in 2019 to 1,437.25 ha in 2024. This represents a net increase of 45.25 ha, equivalent to approximately 3.25% over the five-year observation period. Although the magnitude of change appears moderate when expressed as a percentage, its spatial distribution is important because land conversion does not occur uniformly throughout the study area. A relatively small net increase can nevertheless generate substantial spatial consequences when concentrated in environmentally sensitive or strategically important locations. Studies of urban land change have similarly emphasized that the interpretation of urban expansion

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should consider not only the total amount of land converted but also its spatial configuration, location, and relationship with existing urban infrastructure (Lin et al., 2020).

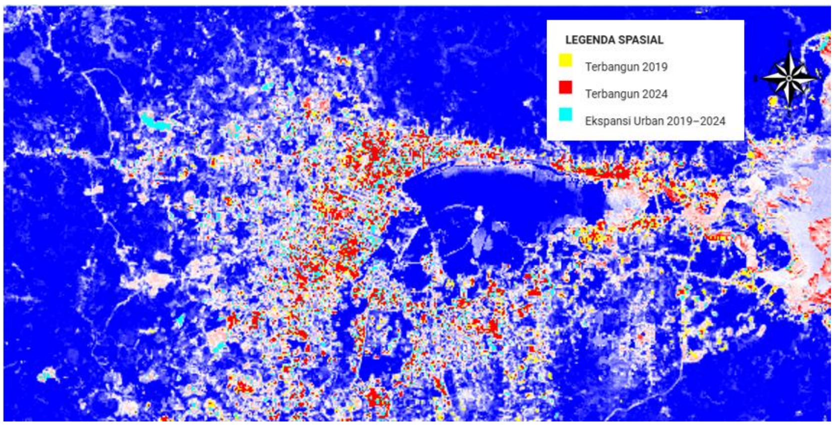

Figure 4. Urban Expansion Map (2019–2024)

The spatial overlay presented in Figure 4 provides a more detailed interpretation of this expansion. Newly developed built-up areas were particularly visible in the eastern and southern parts of the study area and in several locations surrounding Kendari Bay. The concentration of expansion around transportation corridors suggests that accessibility has played an important role in determining the direction of urban growth. Areas connected to established roads and urban activity centers generally offer better access to employment, commerce, public services, and transportation, thereby increasing their attractiveness for residential and commercial development. This interpretation is consistent with contemporary urban land-change studies, which identify accessibility and infrastructure as important spatial factors in determining patterns of urban expansion. The integration of geospatial analysis and cloud-based processing has increasingly been used to identify these spatial trajectories and provide evidence for urban planning (Zhang et al., 2025). The observed pattern also indicates that Central Kendari does not exhibit a purely random form of urban expansion. Instead, development appears to follow existing spatial structures and transportation networks, producing a form of corridor-oriented or accessibility-driven expansion. This is important because transportation infrastructure can act not only as a response to urban growth but also as a factor that stimulates further land development. Once an area obtains improved accessibility, the surrounding land tends to become more attractive for residential, commercial, and service functions. Consequently, road development and urban expansion can create a mutually reinforcing process in which infrastructure facilitates land conversion, while increasing settlement density subsequently generates additional infrastructure demand. The spatial identification of these processes through satellite imagery is consistent with the growing use of geospatial approaches to investigate urban growth trajectories and land-use transformation (Yang, 2021).

The NDBI findings become more meaningful when interpreted together with NDVI. Several locations showing an increase in NDBI values were accompanied by reductions in NDVI values. This spatial relationship indicates that part of the increase in built-up surfaces was associated with the transformation of vegetated land. NDVI has long been used to represent vegetation density and condition because healthy vegetation strongly reflects near-infrared radiation while absorbing red wavelengths. In the context of urban land-change analysis, the simultaneous use of NDBI and NDVI allows built-up expansion to be interpreted not simply as the appearance of buildings but as a process involving changes in the balance between constructed and vegetated surfaces. Xu et al. (2008), for example, demonstrated the value of combining built-up, vegetation, and water-related indices to improve the discrimination of urban land from other surface components. The observed inverse tendency between NDBI and NDVI is particularly relevant in areas where residential development and urban facilities are expanding. As vegetation is removed and replaced by buildings, roads, parking areas, and other impervious surfaces, the spectral response of the landscape shifts toward characteristics associated with built-up land. Similar relationships between urban land expansion and vegetation reduction have been documented in numerous remote-sensing studies. Jiang et al. (2015), for instance, found that urbanization-associated land-cover change modifies vegetation cover, surface moisture, and other biophysical characteristics. Thus, the changes observed in Central Kendari can be understood as part of a broader urban transformation process in which the expansion of impervious surfaces occurs simultaneously with the modification of vegetated land. The use of NDWI as a water mask further improves the interpretation of the NDBI results. Kendari Bay occupies an important portion of the landscape surrounding the study area, and water surfaces may produce spectral responses that interfere with built-up land extraction. The application of NDWI makes it possible to identify and exclude water pixels before interpreting built-up surfaces. This is particularly important because water bodies, shadows, and some dark urban materials can exhibit similar spectral characteristics in optical satellite imagery. Research using Sentinel-2 has shown that NDWI-based water extraction can improve the separation of water bodies from other low-reflectance surfaces, although additional classification or object-based procedures may sometimes be necessary in complex urban environments (Koutsias et al., 2017). Therefore, the combination of NDBI, NDVI, and NDWI in the present study provides a more coherent framework for interpreting urban land transformation than reliance on a single index.

Table 1. Built-up Area in Central Kendari District in 2019 and 2024

No.	Category	Area (ha)
1	Built-up area (2019)	1,391.99
2	Built-up area (2024)	1,437.25
3	Net increase in built-up area	45.25
4	Percentage increase	3.25%

The findings also have important implications for the environmental condition of Central Kendari. The increase of 45.25 ha in built-up land indicates that urban development has resulted in the occupation of additional land surfaces that were previously classified as non-built-up. Where this expansion occurs at the expense of vegetation, the transformation can alter the hydrological characteristics of the urban landscape. Built surfaces such as roofs, roads, and paved areas generally have lower infiltration capacity than vegetated or permeable surfaces. Consequently, the conversion of vegetated land into impervious surfaces can increase surface runoff and reduce infiltration. Shrestha et al. (2021), in their study of Xiamen, demonstrated that urbanization and the associated increase in impervious surfaces significantly influenced surface runoff and altered urban hydrological processes. Similar findings have been reported in Khulna, where increases in impervious urban areas were associated with higher surface runoff, while vegetation cover declined during the same period (Das et al., 2022). This relationship is particularly relevant to Central Kendari because the study area is directly connected to Kendari Bay. Urban expansion in coastal or bay-side environments requires greater attention than expansion in less environmentally sensitive areas because changes in land cover can influence runoff pathways, sediment transport, drainage systems, and the quality of water entering coastal environments. The spatial proximity between newly developed built-up areas and Kendari Bay therefore deserves particular attention in future planning. The present study does not directly measure runoff, sedimentation, or water quality, and consequently it would be inappropriate to conclude that the observed 45.25 ha increase has already produced a measurable deterioration of the bay ecosystem. Nevertheless, the spatial pattern provides an early indication of areas where land conversion could potentially generate environmental pressure.

The ecological implications become clearer when the findings are considered in relation to previous research on urbanization and hydrological change. Carlson and Arthur (2000) demonstrated that urbanization modifies vegetation cover, surface moisture, imperviousness, and runoff characteristics, illustrating the capacity of remote sensing to reveal these interconnected processes. More recent research has similarly shown that the replacement of natural or vegetated surfaces by impervious urban land can modify infiltration and increase runoff responses. Ongaga et al. (2024), for example, found that urbanization alters natural landscapes through the replacement of vegetated surfaces with impervious areas, thereby reducing infiltration and increasing runoff. These studies strengthen the interpretation that the observed NDBI increase and NDVI reduction in Central Kendari should be viewed not merely as cartographic changes but as indicators of a broader transformation of urban environmental processes. The relatively moderate 3.25% increase in built-up area should therefore not be interpreted as evidence that urban pressure is insignificant. The spatial arrangement of the 45.25 ha increase is more important from a planning perspective than the percentage alone. If expansion occurs through compact development within already urbanized areas, the environmental consequences may differ from those generated by dispersed expansion into vegetated or environmentally sensitive land. Conversely, peripheral development that fragments remaining vegetation may create a cumulative ecological impact even when the total converted area is relatively small. Research on urban land-cover mapping emphasizes the importance of spatial resolution and spatial configuration because urban environments are characterized by fragmented land-cover patterns and mixed pixels (Xu et al., 2022).

The findings also demonstrate the usefulness of Google Earth Engine for monitoring urban development. Processing Sentinel-2 imagery through GEE enables multitemporal analysis to be conducted without requiring extensive local data storage or conventional image-processing infrastructure. This advantage is particularly relevant for studies that need to compare multiple observation periods and spatial indices. Lin et al. (2020) demonstrated the usefulness of GEE for monitoring land-cover change in rapidly urbanizing environments, while Yang (2021) emphasized that cloud-based remote sensing platforms have expanded the capacity to investigate urban extent, urbanization, ecosystem characteristics, and accessibility at large spatial and temporal scales. Recent studies have further demonstrated that GEE can support large-scale spatiotemporal urban analysis and the integration of multiple remote-sensing datasets for urban growth assessment (Zhang et al., 2025). The methodological combination used in this study is also supported by research demonstrating that NDBI should not be interpreted as an independent and universally definitive indicator of built-up land. He et al. (2010) noted that conventional NDBI can have limitations, particularly because bare soil and some non-built surfaces may generate spectral responses similar to urban surfaces. Their improved approach demonstrated that additional segmentation and contextual information can reduce classification errors. Bhatti and Tripathi (2014) similarly confirmed the usefulness of NDBI for built-up area extraction while demonstrating the importance of appropriate image processing and classification strategies. These observations are important for the interpretation of the present results because the 1,391.99 ha and 1,437.25 ha estimates should be understood as results of spectral-based extraction rather than absolute representations of every individual building footprint.

Accordingly, the observed expansion should be interpreted primarily as a change in the spectral and spatial extent of built-up land. The method is highly effective for identifying broad patterns of urban transformation, but it may be less capable of distinguishing specific urban land uses such as residential, commercial, industrial, and institutional areas without additional classification procedures. This limitation is consistent with findings from Sentinel-2 urban mapping studies, which show that although the sensor provides valuable spatial and spectral information, heterogeneous urban landscapes can still generate classification ambiguity because different materials may share similar spectral characteristics (Xu et al., 2022). Future research could therefore integrate supervised classification, object-based analysis, building-footprint data, or very-high-resolution imagery to distinguish the functional characteristics of newly developed areas. From a planning perspective, the results provide an important spatial basis for controlling the future direction of urban expansion in Central Kendari. The concentration of new development around transportation corridors and the areas surrounding Kendari Bay suggests that these locations should receive particular attention in spatial planning. Urban development should not only consider the availability of land for construction but also the ecological functions of remaining vegetation and open spaces. Maintaining vegetation patches and integrating green infrastructure into expanding urban areas can help reduce some of the hydrological consequences associated with increasing impervious surfaces. Shrestha et al. (2021) specifically identified green infrastructure and nature-based approaches as potential strategies for mitigating runoff associated with rapid urbanization.

Overall, the results demonstrate that Central Kendari experienced continuous and spatially structured urban expansion between 2019 and 2024. The increase from 1,391.99 ha to 1,437.25 ha, or 45.25 ha (3.25%), indicates a measurable growth of built-up land. More importantly, the overlay analysis shows that the expansion was concentrated in areas with strong accessibility and around existing urban activity centers, including locations adjacent to Kendari Bay. The corresponding increase in NDBI and reduction in NDVI in several locations indicate that part of the expansion involved the conversion of vegetated surfaces into built-up land. These findings are consistent with broader evidence that urbanization transforms land-cover composition and can subsequently influence hydrological and

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ecological processes (Carlson & Arthur, 2000; Shrestha et al., 2021; Ongaga et al., 2024). Therefore, the spatial expansion identified in this study should be considered not merely as an indicator of physical urban growth but also as an important signal for sustainable land management in a coastal urban environment.

CONCLUSION

Urban development in Central Kendari District during 2019–2024 was characterized by a gradual expansion of built-up areas. The analysis using Sentinel-2 imagery, NDBI, NDVI, NDWI, and spatial overlay showed that built-up land increased from 1,391.99 ha in 2019 to 1,437.25 ha in 2024, representing a net increase of 45.25 ha (3.25%). The expansion was mainly concentrated along major transportation corridors, urban activity centers, and areas surrounding Kendari Bay. The increase in NDBI accompanied by declining NDVI in several locations indicates the conversion of vegetated land into built-up surfaces. These changes may contribute to reduced vegetation cover and increased environmental pressure, particularly in coastal areas. The findings demonstrate that Sentinel-2 and Google Earth Engine provide an effective approach for monitoring urban land-use dynamics and can support sustainable spatial planning in Central Kendari.

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