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Original Article

Spatio-Temporal Analysis of Built-Up Land Expansion in Central Kotamobagu Using NDBI and Google Earth Engine

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Abstract

This study examines the spatial and temporal dynamics of built-up land expansion in Central Kotamobagu using Google Earth Engine and the Normalized Difference Built-up Index (NDBI). The study aims to identify changes in land cover, particularly the transformation of vegetated areas into built-up surfaces, and to examine the spatial distribution and temporal development of urban expansion. NDBI was applied to satellite imagery processed through the Google Earth Engine platform to extract built-up land information and quantify changes over the study period. The results indicate a continuous increase in built-up areas, reflecting the ongoing process of urban growth in Central Kotamobagu. The expansion is closely associated with population growth, increasing economic activities, and the development of urban infrastructure. Spatially, built-up land expansion is initially concentrated in the urban core and areas with relatively high accessibility, particularly along established transportation networks. Over time, these developed areas have progressively extended toward surrounding locations, indicating a pattern of outward urban expansion. This spatial development suggests that accessibility and existing urban structures play important roles in shaping the direction and intensity of land transformation. The findings highlight the importance of systematic monitoring of built-up land dynamics to support environmentally sustainable urban and regional planning. The integration of NDBI and Google Earth Engine provides an efficient and reproducible approach for identifying, mapping, and monitoring urban land development, offering valuable spatial information for managing future urban growth and minimizing potential environmental impacts in Central Kotamobagu.

Keywords: Built-Up Land, Google Earth Engine, Land Expansion, NDBI

INTRODUCTION

Urban development is an inseparable part of population growth and expanding economic activities. The increasing extent of built-up areas replacing natural landscapes, such as vegetation and agricultural land, is one of the primary indicators of urbanization. While this transformation reflects progress in urban development, it also generates a range of environmental consequences, including ecosystem degradation, altered hydrological systems, rising land surface temperatures that contribute to the urban heat island effect, and a reduced capacity of the environment to sustain ecological functions (Muryanti, 2022). Therefore, continuous monitoring and a comprehensive understanding of built-up area expansion are essential, particularly in emerging urban centers such as Central Kotamobagu. From an urban geographical perspective, the development of small cities differs from that of large metropolitan areas. Small cities generally expand in a dispersed pattern, with urban growth influenced by road networks, proximity to activity centers, and the availability of developable land. The concentration of economic and social activities within the urban core, accompanied by the outward expansion of residential areas, represents a common pattern of urban growth. This process illustrates how development gradually

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extends from the city center toward surrounding areas (Surya & Taibe, 2022). Without effective planning and management, such expansion may eventually lead to an unstructured urban spatial pattern.

Central Kotamobagu exhibits a dynamic growth pattern characteristic of an emerging small city. Rapid urban development and the expansion of residential areas into the surrounding landscape have driven substantial land use change. The conversion of vegetated land into residential areas and supporting infrastructure has become one of the most prominent forms of transformation. Beyond altering the physical environment, these changes also affect socio-economic conditions, including shifts in local livelihoods, increasing land values, and widening disparities in access to urban facilities (Makalalag, Rondonuwu, & Siregar, 2024). Consequently, a more comprehensive investigation of small-scale urbanization in Central Kotamobagu is needed to better understand its spatial patterns and broader implications. Moreover, the expansion of built-up areas in small cities generally occurs gradually yet continuously, making long-term changes difficult to detect without multi-temporal analysis. In this context, a spatio-temporal approach plays a crucial role by revealing both the spatial distribution of built-up land at a given time and the temporal dynamics of its expansion. Such analysis provides valuable insights into the direction of urban growth, the magnitude of land transformation, and the areas most affected by development activities. Advances in remote sensing technology have enabled the development of various methods for monitoring changes in the Earth's surface. One of the most widely applied approaches is the Normalized Difference Built-up Index (NDBI), which effectively extracts information on built-up areas from satellite imagery. In addition, change detection techniques are commonly employed to compare land cover conditions across two or more observation periods, enabling the identification of changes in both their magnitude and spatial distribution. Integrating these methods within the Google Earth Engine (GEE) platform offers significant advantages, including faster data processing, large-scale analytical capabilities, and access to continuously updated satellite imagery. Despite the widespread application of NDBI and change detection techniques, most previous studies have concentrated on large metropolitan areas characterized by high levels of urbanization. As a result, limited attention has been given to understanding how these methods perform in the context of small cities, where urban growth follows different spatial dynamics. To address this research gap, the present study employs a Google Earth Engine-based NDBI approach to examine built-up land expansion in Central Kotamobagu, which serves as a representative example of a rapidly developing small city.

The growing demand for accurate spatial information to support sustainable regional planning further underscores the importance of this study. Without a clear understanding of how built-up land expands, spatial planning policies may become less effective and fail to accommodate ongoing urban development. This study also contributes to the existing literature by integrating spatio-temporal analysis using NDBI and change detection within the context of small-scale urbanization, an area that remains relatively underexplored. Furthermore, the application of Google Earth Engine demonstrates an innovative approach to utilizing contemporary geospatial technologies for urban analysis. This study investigates changes in built-up land across Central Kotamobagu from 2019 to 2024 through both spatial and temporal perspectives. The analysis aims to identify the distribution of built-up land, examine the conversion of vegetated areas into residential land, and evaluate the direction and pattern of urban expansion over time. This approach is expected to provide a comprehensive understanding of urban growth dynamics in a developing small city. The objectives of this study are to examine the spatial distribution of built-up land expansion in Central Kotamobagu, analyze temporal changes in built-up land using the NDBI-based change detection method, and understand the characteristics of small-city development as reflected by urban core growth and residential expansion. The findings are expected to contribute to the advancement of geographical science, particularly in the fields of remote sensing and spatial analysis, while also providing a scientific basis for developing more effective, targeted, and adaptive spatial planning policies.

MATERIALS AND METHODS

This study employed a quantitative approach using spatio-temporal analysis based on remote sensing data to examine built-up land expansion in Central Kotamobagu. This approach was selected because it effectively captures land cover changes across both spatial and temporal dimensions while enabling the analysis of relationships among variables influencing small-scale urbanization. The study aimed to generate comprehensive, accurate, and reliable data to support regional planning using multi-

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temporal satellite imagery and cloud-based geospatial analysis. The identification of built-up areas was carried out using the Normalized Difference Built-up Index (NDBI). This index is calculated by comparing the reflectance values of the Shortwave Infrared (SWIR) and Near Infrared (NIR) bands derived from Landsat satellite imagery. Mathematically, the NDBI is expressed as:

$$\mathrm{NDBI} = \frac{\mathrm{SWIR}_1 - \mathrm{NIR}}{\mathrm{SWIR}_1 + \mathrm{NIR}}$$

The resulting NDBI values were then used to distinguish built-up from non-built-up areas. Positive NDBI values generally indicate built-up surfaces, whereas negative values typically represent vegetation or non-built-up land. In this study, Landsat 8/9 imagery was utilized, with Band 6 representing the SWIR band and Band 5 representing the NIR band. These bands were selected based on their spectral characteristics, as built-up surfaces generally exhibit higher reflectance in the SWIR band than in the NIR band, resulting in relatively higher NDBI values. The research workflow followed a sequential procedure beginning with the acquisition of multi-temporal satellite imagery. The imagery then underwent preprocessing, including cloud masking, image correction, and clipping to the study area. These preprocessing steps were essential to ensure the quality and reliability of the data used in subsequent analyses. The Normalized Difference Built-up Index (NDBI) was subsequently calculated to identify built-up land. NDBI was selected because of its ability to effectively distinguish built-up surfaces from vegetation based on their contrasting spectral responses, particularly within the SWIR and NIR wavelength regions. Based on the calculated NDBI values, land cover was classified into two primary categories: built-up and non-built-up areas. Classification was performed using a threshold value adjusted to the characteristics of the study area. The threshold-based approach was considered appropriate because it could be adapted to local environmental conditions while remaining straightforward to implement. Nevertheless, potential classification errors should be acknowledged, particularly in open land areas whose spectral characteristics closely resemble those of built-up surfaces.

Change detection analysis was conducted by comparing classification results from two different observation periods to identify land cover changes over time. This approach enabled the detection of both the spatial distribution and magnitude of change, particularly the conversion of non-built-up land into built-up land. Furthermore, the analysis provided insights into the rate of land transformation and the pattern of urban development. Multi-temporal analysis was especially important for understanding gradual urban expansion in small cities, where development typically occurs incrementally over extended periods. This study examined not only the spatial distribution of built-up land but also the characteristics and direction of urban expansion. The analysis assessed whether built-up development tended to occur in highly accessible locations before expanding toward surrounding areas by considering proximity to the urban center and the road network. Such a development pattern reflects the typical urban expansion process observed in growing small cities. In addition to spatial analysis, statistical methods consisting of correlation and linear regression analyses were employed. Correlation analysis was conducted to evaluate the strength of the relationship between population growth and the extent of built-up land, while linear regression analysis was used to examine the influence of population growth on built-up land expansion.

The linear regression model applied in this study is expressed as follows:

$$\mathrm{Y} = a + bX$$

Y = built-up land area
X = population size or population growth

The regression model can be further expanded by incorporating accessibility as an additional explanatory variable influencing land use change. This approach facilitates the interpretation of causal relationships and provides a more comprehensive understanding of the observed phenomenon (Hidayati). To visually verify the classification results, the classified maps were compared with high-resolution imagery and actual field conditions. However, several limitations should be acknowledged. The spatial resolution of Landsat imagery may limit the level of detail captured in the analysis. In

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addition, the limited integration of spatially referenced socio-economic data constrained the development of more comprehensive analyses (Prasetyo, 2023).

The research hypothesis proposes that a significant relationship exists between population growth and the expansion of built-up land in Central Kotamobagu. Spatially, it is further hypothesized that built-up land expansion follows a diffusion pattern extending outward from the urban core toward more accessible surrounding areas. Accordingly, this study aims not only to identify patterns of land cover change but also to understand the underlying processes driving small-scale urbanization. Overall, the research methodology integrates remote sensing techniques, spatial analysis, and statistical analysis to provide a comprehensive understanding of the processes and patterns of built-up land expansion. This integrated approach is particularly well suited for small cities, where urban growth often occurs gradually and may appear insignificant over short periods, yet can substantially reshape urban spatial structure and the surrounding environment over the long term (Jarir, 2026).

RESULTS AND DISCUSSION

The spatio-temporal analysis revealed a substantial increase in the extent of built-up land in Central Kotamobagu during the observation period. In 2019, the built-up area covered 359.33 hectares, increasing to 439.07 hectares by 2024. These values were derived from satellite imagery analysis using the Normalized Difference Built-up Index (NDBI) implemented through Google Earth Engine. Overall, the built-up area expanded by 79.74 hectares over the five-year period. The built-up area grew by approximately 22.2% relative to its extent in 2019. This finding indicates that although Central Kotamobagu is classified as a small city, it has experienced considerable urban expansion that should not be overlooked. The observed growth reflects increasing pressure on land resources, primarily driven by the rising demand for residential areas and urban infrastructure. Furthermore, the change detection analysis identified 166.58 hectares of newly developed built-up land. This represents an increase of approximately 46.35% compared with the built-up area recorded in 2019, indicating that nearly half of the initial built-up extent experienced expansion during the study period. When compared with the total built-up area in 2024, the newly developed land accounts for approximately 37.9% of the total built-up extent. These findings suggest that the conversion of previously non-built-up land into built-up land has been one of the primary drivers of urban growth in Central Kotamobagu.

The spatial pattern of built-up land expansion was concentrated around the urban core and along the major road network. This pattern highlights the important role of accessibility in shaping urban development, as land use conversion occurred more rapidly in areas with better transportation access. Such a pattern is characteristic of small-city development, where urban expansion typically spreads outward from the city center as development pressure increases (Navastara, 2025). Land cover change was primarily characterized by the conversion of vegetated land into residential areas and supporting infrastructure. This transformation reflects a shift in land function from natural ecosystems to urban economic and social activities. Over the long term, such changes may disrupt environmental balance if they are not accompanied by effective and sustainable land use planning. The magnitude of this increase indicates that urban development in Central Kotamobagu was not limited to the gradual intensification of existing built-up areas. The relatively large extent of newly developed land suggests that urban growth also involved the conversion of previously non-built-up surfaces. This finding is important because the increase in total built-up area and the extent of newly developed land represent two related but distinct dimensions of urban expansion. While the former describes the net change in developed land between the two observation years, the latter illustrates the spatial process through which new areas were incorporated into the urban landscape. The comparison between these indicators therefore provides a more comprehensive picture of the urbanization process occurring in Central Kotamobagu.

Table 1. Changes in Built-Up Area in Central Kotamobagu

Description	Area (ha)	Percentage
Built-up Area (2019)	359.33	100%
Built-up Area (2024)	439.07	122.2%
Increase (2019–2024)	79.74	22.2%
New Urban Physical Expansion	166.58	46.35%

Source: Author Analysis, 2026

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The results demonstrate a consistent and significant increase in the built-up area of Central Kotamobagu throughout the study period. These findings are consistent with the typical pattern of small-city development, characterized by the expansion of the urban core and the outward growth of residential areas toward the urban fringe. Consequently, this study not only documents the magnitude of built-up land expansion but also provides valuable insights into the processes of urban development and the key factors influencing its spatial growth. The quantitative results presented in Table 1 provide a basis for examining how the increase in built-up land was spatially distributed. The change in area alone does not fully explain the nature of urban expansion, because similar increases in built-up land can produce different spatial configurations. Therefore, the spatial distribution of NDBI values for 2019 and 2024 was further examined to identify the location, direction, and pattern of development. This spatial comparison is particularly important for understanding whether urban growth remained concentrated within the existing urban core or increasingly extended toward peripheral areas.

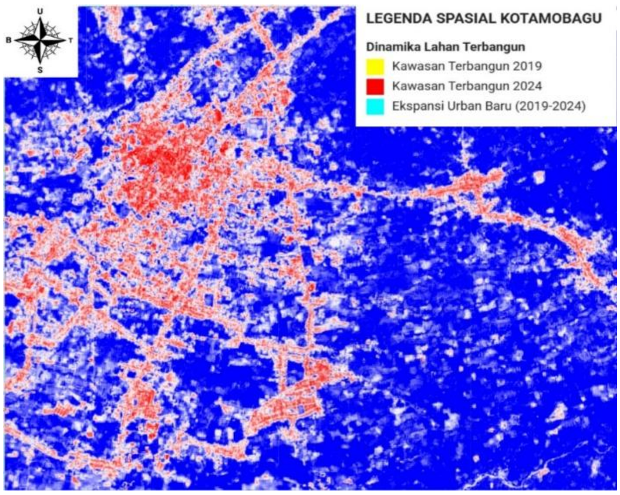

Figure 1. NDBI Map of Central Kotamobagu, 2019

The 2019 Normalized Difference Built-up Index (NDBI) analysis indicates that the distribution of built-up land in Central Kotamobagu remained highly concentrated within the urban core. Areas with positive NDBI values represent built-up land, while the surrounding areas were predominantly characterized by lower values, indicating vegetation cover or undeveloped land. This spatial pattern reflects the typical structure of a small city, where urban development is largely concentrated within a single primary activity center. The 2019 spatial pattern further shows that built-up land expansion was concentrated toward the city center while beginning to extend linearly along the main road network. This finding suggests that, in addition to the influence of the urban core, accessibility had already become an important factor shaping urban growth. Such a pattern is consistent with the relationship between location theory and transportation network theory in urban geography, which proposes that development tends to occur in areas with high accessibility and strong connectivity (Tama, Rilansari, Hermawan, Prakasa, & Rahmah, 2026). The urban core identified through the 2019 NDBI analysis also reflects a clear spatial hierarchy. The highest concentration of built-up land occurred within the city center, while the surrounding areas functioned as transitional zones that had begun to experience development pressure (Abduh, 2023). This condition suggests that Central Kotamobagu was entering the early stages of transformation from a relatively simple urban structure toward a more complex urban system. Residential areas had begun to expand in response to increasing activities within the city center and the growing demand for urban space. Moreover, the emergence of built-up land in several peripheral areas indicates the initial stage of gradual urban expansion. Although this expansion remained relatively limited, it represents an important early signal of future urban growth that warrants attention. In the context of small-scale urbanization, such changes generally occur gradually and are not immediately apparent, yet they progressively reshape spatial structure and land use over time (Dharma, 2026). The occurrence of positive NDBI values in areas previously dominated by vegetation highlights one of the major findings of the 2019 analysis, namely the conversion of vegetated land into residential areas.

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From an ecological perspective, this land transformation may reduce important environmental functions, including water infiltration capacity and local temperature regulation (Hasyim & Pamungkas, 2023). If left unmanaged, this trend could gradually degrade the urban environment over the long term.

Methodologically, the application of NDBI demonstrated its effectiveness in identifying the spatial distribution of built-up land. However, NDBI has limitations, particularly its inability to consistently distinguish built-up surfaces from dry bare land with similar spectral characteristics. Therefore, the results should always be interpreted within their surrounding spatial context. For this reason, NDBI was not used as a standalone analytical tool but was integrated with change detection techniques to improve the accuracy of identifying land cover changes across different observation periods. Overall, the 2019 NDBI results indicate that Central Kotamobagu remained in the early stage of urbanization, as reflected by the dominance of development within the urban core and the relatively limited extent of residential expansion. Nevertheless, the emerging development pattern, characterized by growth along transportation corridors and the appearance of new residential areas in the urban fringe, suggests that the urbanization process was already underway and had the potential to continue expanding. Consequently, the 2019 NDBI analysis provides not only a representation of existing built-up conditions but also an important baseline for understanding subsequent urban development. These findings reinforce the value of NDBI as an effective preliminary tool for analyzing urbanization processes, particularly in small cities whose development patterns differ from those observed in large metropolitan areas.

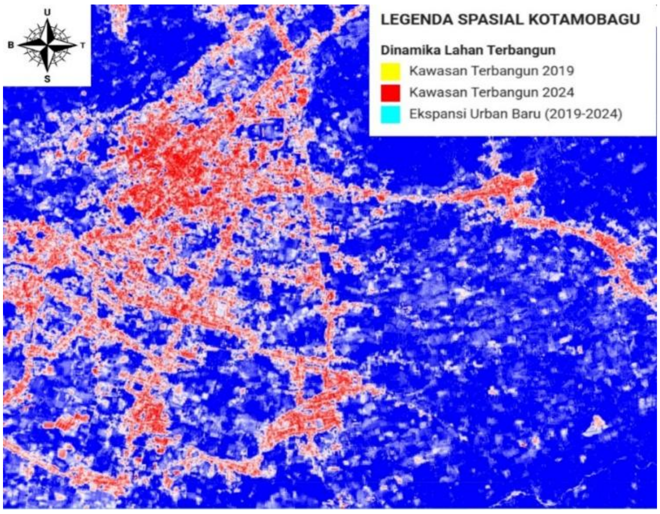

Figure 2. NDBI Map of Central Kotamobagu, 2024

The 2024 NDBI analysis reveals a substantial increase in both the extent and density of built-up land in Central Kotamobagu compared with 2019. Urban development was no longer confined to the city center but had expanded outward in multiple directions, following the main road network and major activity corridors. This spatial pattern indicates that urbanization during the study period contributed to the formation of a broader and increasingly complex urban structure. Based on the NDBI analysis, the built-up area reached 439.07 hectares in 2024, compared with 359.33 hectares in 2019. The increase of 79.74 hectares, equivalent to 22.2%, demonstrates that urban development in Central Kotamobagu progressed considerably over the five-year period. The growing demand for residential land, public facilities, commercial activities, and supporting infrastructure reflects an ongoing transformation in urban land use throughout the study area.

Compared with the 2019 distribution, the 2024 NDBI map illustrates a much broader spatial extent of built-up land. Although the urban core remained the dominant concentration of development, built-up areas had increasingly expanded toward the urban fringe through elongated patterns aligned with the transportation network. This condition suggests that while the city center continued to function as the primary growth pole, urban development had progressively spread into surrounding areas. Such a pattern is characteristic of urbanization in small cities, where development generally occurs gradually but continuously, in contrast to the more rapid expansion observed in large metropolitan areas. Despite

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its gradual nature, this process can substantially reshape the urban spatial structure over time. One of the most significant findings of this study is the expansion of residential areas. The spatial pattern observed in the 2024 NDBI map indicates that urban growth occurred through both the infilling of existing developed areas and the outward expansion into surrounding land. This pattern suggests that increasing demand for housing and urban activities has encouraged the conversion of previously undeveloped land, consistent with the findings of Huda, Hasyim, and Parlindungan (2022). Furthermore, development corridors following the major road network confirm that accessibility remains a key determinant in the selection of locations for residential development. From a methodological perspective, integrating NDBI with change detection analysis proved effective in providing a comprehensive understanding of land use dynamics. While NDBI identified the spatial distribution of built-up land for each observation year, change detection enabled direct comparisons between different periods, allowing changes to be quantified and spatially identified. The integration of these two methods therefore provides a more comprehensive assessment of the magnitude, location, and spatial pattern of land use change (Siregar, 2025).

Overall, the 2024 NDBI analysis and change detection results indicate that urban development in Central Kotamobagu has accelerated, as reflected by the continued expansion of the urban core and the increasing spread of residential development toward peripheral areas. This process illustrates the characteristics of urbanization in a growing small city, where gradual yet persistent changes substantially influence spatial organization and land use patterns over time. Consequently, this study not only documents the extent of built-up land expansion but also provides a deeper understanding of the processes and driving factors underlying urban development within the study area. The NDBI results provide an index-based representation of built-up land, while the built-up area maps offer a more direct spatial interpretation of the areas identified as developed surfaces. Comparing the two observation years therefore allows the temporal changes detected by NDBI to be interpreted in terms of the actual spatial configuration of urban development. This comparison is useful for identifying whether the observed increase resulted mainly from the intensification of existing urban areas, outward expansion, or a combination of both processes.

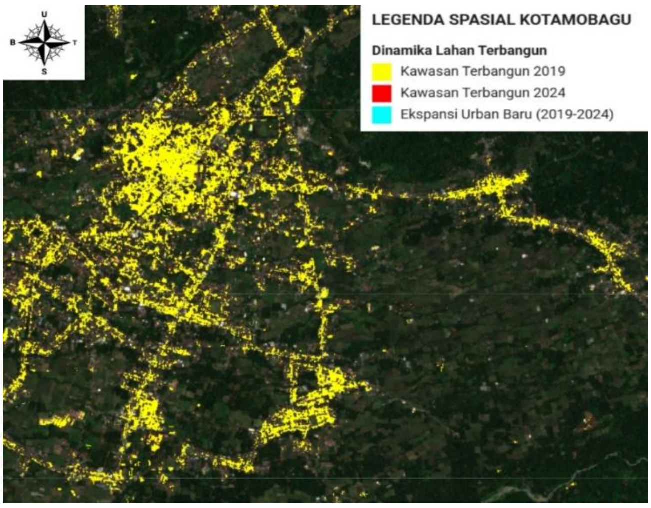

Figure 3. Built-Up Area Map of Central Kotamobagu, 2019

The built-up area map for 2019 indicates that most developed land was concentrated within the urban core of Central Kotamobagu. Areas highlighted in yellow represent built-up land, which was predominantly clustered in the city center, while the surrounding landscape remained largely characterized by vegetation and open land. This pattern reflects the early stage of development typically observed in emerging small cities, where economic, social, and governmental activities are concentrated within a single urban center. The urban core functioned as the primary center of activity and exhibited the highest concentration of development in 2019. Although urban growth remained centralized, the spatial analysis also revealed early indications of residential expansion toward peripheral areas. This trend is evident from the emergence of newly developed areas beyond the city center, generally

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following the existing road network. Such a pattern suggests that accessibility had begun to play a significant role in shaping urban growth, with areas offering better access experiencing more rapid development. Although still limited in extent, this directed pattern of expansion represents the initial stage of small-scale urbanization.

Despite its relatively modest scale, the conversion of vegetated land into residential areas had already become evident by 2019. Areas previously dominated by vegetation began to be transformed into built-up land, as indicated by elevated NDBI values in several locations surrounding the urban center. This phenomenon reflects the environmental consequences of ongoing urban development and, if left unmanaged, may lead to more substantial environmental challenges in the future. From a methodological perspective, the application of NDBI proved effective in identifying built-up areas based on the spectral characteristics of satellite imagery. The index clearly distinguished built-up surfaces from vegetated areas, providing an accurate representation of the spatial distribution of urban development in 2019. Nevertheless, the results should be interpreted cautiously, particularly in locations where dry bare land exhibits spectral characteristics like those of built-up surfaces (Milasari, 2026). Therefore, the 2019 results also provide an essential baseline for evaluating subsequent land cover changes.

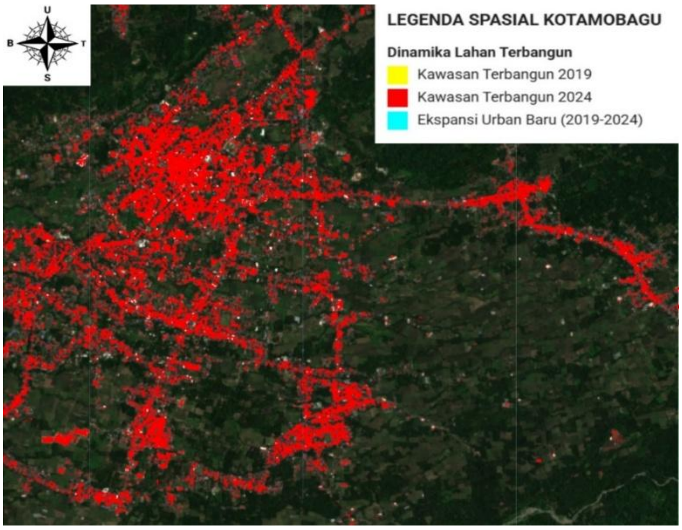

Figure 4. Built-Up Area Map of Central Kotamobagu, 2024

The 2024 built-up area map demonstrates a substantial increase in urban development compared with 2019. Areas displayed in red indicate that built-up land had expanded considerably, exhibiting a more complex spatial pattern that was no longer confined to the city center. Although the urban core remained the dominant activity center, development had increasingly spread toward the surrounding peripheral areas. While the city center continued to play a central role in the urban spatial structure, its function had evolved from merely accommodating urban activities to serving as the primary driver of regional growth. This is reflected in the increasing extent of built-up land connected to the urban core through the road network. From the perspective of urban growth theory, this pattern illustrates the outward diffusion of development from the growth center into surrounding areas, a characteristic process commonly observed in the evolution of small cities.

Residential expansion became increasingly evident in 2024, particularly in peripheral areas that had previously remained open or undeveloped. The predominance of linear expansion following major transportation corridors further emphasizes the importance of accessibility in directing urban growth. Areas with better transportation access generally experienced faster development than locations with lower accessibility. The 2024 conditions also indicate increasing pressure on the natural environment. The conversion of vegetated land into residential areas and supporting infrastructure became more extensive than in the previous observation period. Methodologically, the 2024 NDBI results demonstrate the effectiveness of the index in identifying the spatial distribution of built-up land. Higher

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NDBI values correspond to areas experiencing more intensive urban development, accurately reflecting the contemporary land use conditions across the study area.

Change detection analysis conducted between 2019 and 2024 revealed a substantial increase in the spatial extent of built-up land throughout Central Kotamobagu. During the five-year period, the built-up area expanded by 79.74 hectares, representing an increase of approximately 22.2%. In addition, newly developed urban expansion reached 166.58 hectares, indicating that urban growth occurred through both the densification of existing developed areas and the large-scale conversion of previously non-built-up land into built-up land. The observed expansion pattern demonstrates an outward diffusion of development from the urban core toward peripheral areas, generally following the major road network. This finding further emphasizes the critical role of accessibility in directing urban expansion. The gradual outward spread of development into previously vegetated areas reflects the typical characteristics of urban growth in small cities. Although this process occurs progressively, it increases environmental pressure and highlights the need for more sustainable and carefully planned land use management. o further clarifies the spatial process underlying the observed increase, a change detection analysis was conducted to identify areas that changed from non-built-up to built-up land between 2019 and 2024. Unlike the individual NDBI maps, which describe the condition of built-up land at a particular point in time, change detection directly identifies the locations where urban transformation occurred. The resulting map therefore provides an important basis for interpreting the direction and spatial characteristics of new urban expansion in Central Kotamobagu.

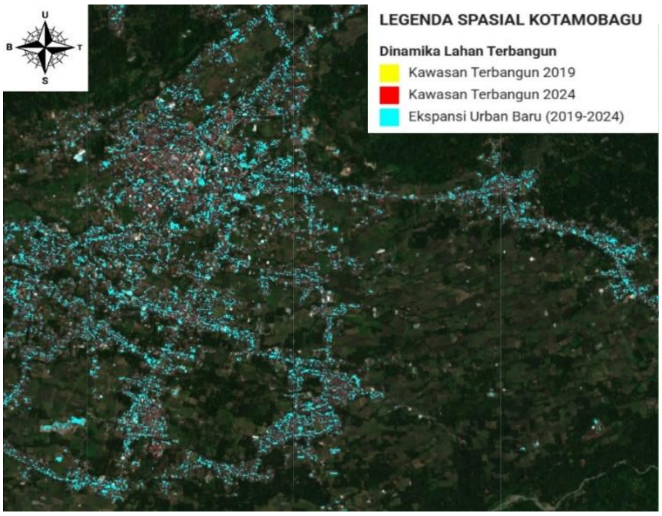

Figure 5. New Urban Expansion

The change detection analysis indicates substantial new urban expansion across Central Kotamobagu between 2019 and 2024. Areas that experienced conversion from non-built-up land to built-up land are represented by light blue polygons. These newly developed areas are widely distributed throughout the urban core and surrounding districts, with particularly high concentrations along the major road network. The pattern of new urban expansion exhibits both dispersed and linear characteristics, indicating that urbanization has shifted from a highly centralized form toward a broader pattern of spatial development. This phenomenon represents a more advanced stage of urban growth, in which development increasingly expands into peripheral areas where land remains available, while opportunities for further development within the urban core become more limited (Elsa, 2024). The spatial distribution also confirms that accessibility remains one of the primary factors influencing the selection of development locations, as expansion consistently follows well-connected transportation corridors.

The resulting expansion pattern can be interpreted through the concepts of spatial diffusion and urban sprawl. Spatial diffusion describes the outward spread of development from the urban center to surrounding areas, whereas urban sprawl refers to the emergence of newly developed areas that are not always directly connected to the existing urban core. This pattern suggests that Central Kotamobagu is gradually transitioning toward a more complex and fragmented urban spatial structure, despite its

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relatively small urban scale (Judijanto, Prabandari, Yuliani, Pahude, & Perkasa, 2026). The conversion of vegetated land into residential areas and supporting infrastructure represents one of the principal environmental consequences of this urban expansion. Areas that previously functioned as green open spaces have increasingly been transformed into built-up land, potentially contributing to the long-term decline of environmental quality (Fandeli, 2021). In small cities, this process often occurs gradually and irregularly, creating challenges in maintaining a balance between development needs and environmental sustainability. The findings of this study emphasize the importance of incorporating patterns of new urban expansion into future land use planning for Central Kotamobagu. The dispersed development pattern following major transportation corridors indicates the potential emergence of urban sprawl, which may reduce land use efficiency and intensify environmental pressures. Consequently, more strategic spatial planning and land management policies are required to guide residential growth while maintaining an appropriate balance between urban development and environmental conservation. Overall, urban expansion between 2019 and 2024 reflects the characteristic growth pattern of a developing small city. Development occurred not only within the urban core but also throughout surrounding areas, indicating the continuing urbanization process in Central Kotamobagu. These changes are expected to influence future spatial structure, land use dynamics, and environmental sustainability as the city continues to develop.

CONCLUSION

This study demonstrates that Central Kotamobagu experienced substantial spatial and temporal expansion of built-up land between 2019 and 2024. The built-up area increased from 359.33 hectares in 2019 to 439.07 hectares in 2024, representing a net increase of 79.74 hectares or approximately 22.2%. Change detection further identified 166.58 hectares of newly developed urban land, indicating that the transformation of previously non-built-up areas was an important component of urban growth during the study period. Spatially, urban expansion was initially concentrated within the urban core and subsequently extended toward peripheral areas, particularly along major transportation corridors. The persistence of linear development patterns demonstrates the important role of accessibility in directing the location and direction of urban growth. At the same time, the emergence of dispersed development beyond the existing urban core indicates an increasing tendency toward spatial diffusion and potential urban sprawl. The integration of NDBI, change detection, and Google Earth Engine proved effective for identifying, quantifying, and interpreting the spatial dynamics of built-up land in a small but developing urban area. Nevertheless, the potential spectral similarity between built-up surfaces and dry bare land indicates that NDBI results should be interpreted carefully within their spatial context. The findings emphasize the need for proactive spatial planning that accommodates urban development while protecting remaining vegetated areas and maintaining environmental functions. Sustainable land management and the strategic control of development along transportation corridors are therefore important for guiding the future growth of Central Kotamobagu.

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