

Evaluating Urban Green Space Dynamics in Makassar City Through NDVI-Based Analysis of Sentinel-2 Imagery

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Abstract

Urban expansion in rapidly growing cities like Makassar has considerable implications for vegetation loss and ecosystem degradation. This study investigates vegetation cover changes in Makassar City by analyzing the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2 imagery for the years 2020 and 2024. A threshold of $NDVI > 0.5$ was applied to identify areas classified as dense vegetation. Image pre-processing, NDVI computation, and binary classification were performed to quantify and map vegetation extent. The analysis reveals a noticeable reduction in densely vegetated areas. This study analyzes the changes in vegetation health in Makassar City using the Normalized Difference Vegetation Index (NDVI) for the years 2020 and 2024. The NDVI threshold of >0.5 was used to identify areas of healthy vegetation. The spatial analysis and classification maps reveal a significant decline in vegetated areas, with a decrease from 4,792.93 hectares in 2020 to 1,157.23 hectares in 2024. This trend highlights a substantial reduction in healthy vegetation cover, potentially caused by urban development, land-use changes, and environmental pressures. The findings underscore the need for sustainable land management and green infrastructure policies to mitigate the adverse effects of vegetation loss and promote ecological balance in urban areas.

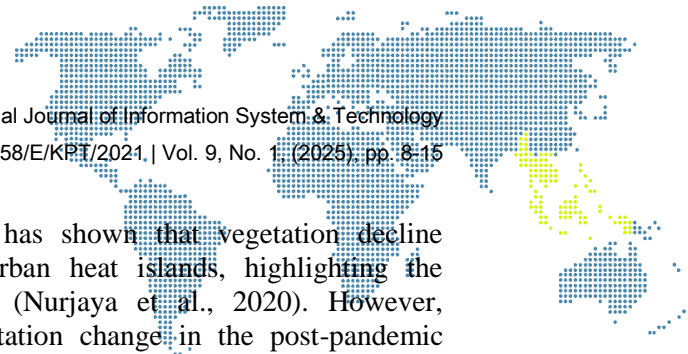
Keywords: NDVI, Sentinel-2, Vegetation Cover, Urban Expansion, Land Cover Change, Makassar City, Remote Sensing

1. Introduction

Urban development is a leading contributor to environmental change, especially in developing nations where rapid expansion frequently leads to substantial alterations in land cover and the progressive loss of urban green areas (Seto et al., 2012). Makassar City, as one of the fastest-growing metropolitan centers in eastern Indonesia, faces significant challenges in maintaining ecological balance amid intensive infrastructure and housing development. Therefore, timely and accurate monitoring of vegetation dynamics is essential for supporting sustainable urban planning and enhancing the city's environmental resilience.

Remote sensing technologies, particularly those involving the Normalized Difference Vegetation Index (NDVI), have become crucial for tracking vegetation health and spatial distribution over time (Xue & Su, 2017). NDVI values, which typically range from -1 to +1, serve as an effective indicator of vegetation vigor, with values above 0.5 commonly representing dense and healthy plant cover. Sentinel-2 satellite imagery, due to its high spatial and temporal resolution, is especially effective for monitoring changes in urban vegetation (Drusch et al., 2012).

Applying NDVI thresholding—especially using a threshold of >0.5 —enables the clear classification of dense vegetative areas and facilitates the comparison of land cover changes across different time periods (Forkuor et al., 2018). This approach is not only efficient but also reproducible, making it a valuable tool for environmental monitoring in rapidly urbanizing regions.



In the context of Makassar, recent research has shown that vegetation decline correlates strongly with the intensification of urban heat islands, highlighting the ecological cost of unregulated urban expansion (Nurjaya et al., 2020). However, comprehensive and updated assessments of vegetation change in the post-pandemic development era (2020–2024) are still limited.

Given the increasing demand for land conversion in Makassar and the growing environmental pressures associated with urbanization, this study is urgently needed. It provides empirical evidence to assess the spatial and temporal dynamics of vegetation cover over a four-year period using NDVI thresholding from Sentinel-2 data. The research specifically aims to (1) quantify the extent of dense vegetation areas in 2020 and 2024, (2) identify spatial trends and hotspots of change, and (3) offer science-based recommendations for enhancing urban green space protection and sustainable land use strategies in Makassar.

2. Research Methodology

2.1. NDVI and Remote Sensing

The Normalized Difference Vegetation Index (NDVI) is among the most commonly employed indices in the field of remote sensing for assessing vegetation. First introduced by Rouse et al. (1974), NDVI is calculated based on the contrast between near-infrared (NIR) and red light reflectance, which makes it effective for evaluating the condition and density of vegetation. NDVI values range between -1 and +1, where figures above 0.5 typically signify areas with healthy and dense plant coverage.

The Sentinel-2 satellite, launched by the European Space Agency (ESA), delivers high-resolution optical data that is particularly suited for monitoring vegetation. With spatial resolutions ranging from 10 to 20 meters and revisit intervals of five days, Sentinel-2 allows for frequent and detailed observation of vegetative changes across various landscapes, including urban environments (Drusch et al., 2012).

2.2. Applications of NDVI in Urban Vegetation Monitoring

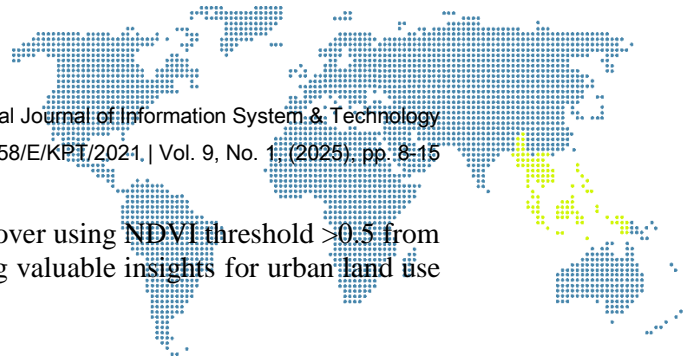
NDVI is widely recognized as a useful tool in evaluating how urban growth affects vegetation. For instance, research by Zhou et al. (2014) utilized NDVI to assess green cover reduction in large Chinese cities, demonstrating the utility of time-series NDVI data in long-term spatial planning. Additionally, Forkuor et al. (2018) showed that applying NDVI thresholds particularly values exceeding 0.5 enables accurate differentiation between vegetated zones and built-up areas, especially when incorporating Sentinel-2's red-edge spectral bands.

The index is also instrumental in exploring the Urban Heat Island (UHI) phenomenon. Studies indicate that vegetation plays a vital role in lowering surface temperatures, and its loss can intensify heat concentrations in city cores (Zhou et al., 2014; Imhoff et al., 2010). Consequently, NDVI has become a key metric in assessing urban ecology and supporting sustainable urban development initiatives.

2.3. Vegetation Monitoring in Indonesia and Makassar Context

In Indonesia, the use of NDVI for monitoring urban environmental degradation has grown considerably. For example, Handayani et al. (2021) investigated vegetation cover change in Yogyakarta, showing that rapid urban development significantly reduced green spaces. In a similar vein, Nurjaya et al. (2020) identified a strong correlation between vegetation loss and increasing urban temperatures in Makassar, underlining the ecological importance of preserving green zones.

Nonetheless, studies focused on analyzing vegetation changes in the post-pandemic period are still lacking. Since 2020, land conversion in Makassar has continued at a fast pace, leading to further decline in urban greenery. However, these developments have yet to be fully documented and quantified. Therefore, this research seeks to fill that gap by



providing an updated spatial analysis of vegetative cover using NDVI threshold >0.5 from Sentinel-2 data for the years 2020 and 2024, offering valuable insights for urban land use planning and environmental policy.

2.4. Study Area

This study was carried out in Makassar, the capital city of South Sulawesi Province, Indonesia. Recognized as a prominent metropolitan hub in eastern Indonesia, Makassar has undergone significant urban growth over the past ten years. The delineated research area corresponds to the official city boundaries, encompassing both highly urbanized regions and existing vegetated land.

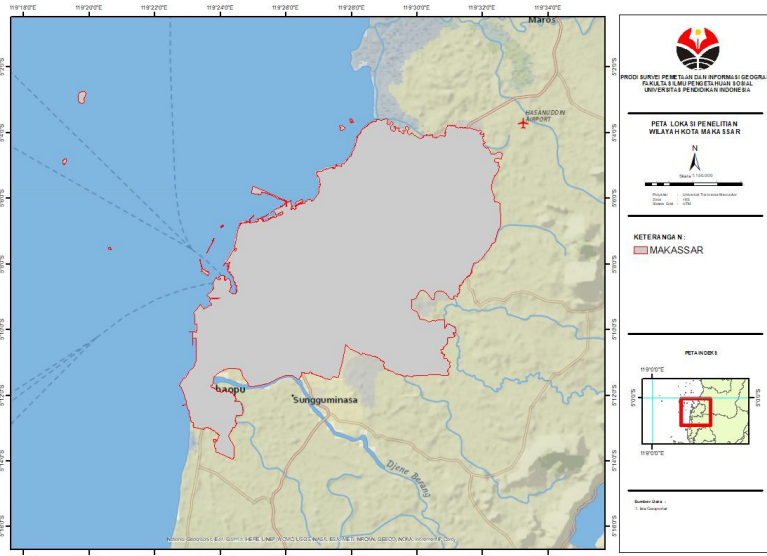


Figure 1. Map of Research Location

2.5. Data Collection

The analysis relied on Sentinel-2 Level-1C satellite images, retrieved from the Copernicus Open Access Hub, covering two key observation periods: 2020 and 2024. Image selection followed specific criteria:

- (a) Cloud cover below 10%.
- (b) Acquisition within the dry season months (June to August) to ensure consistency and minimize seasonal influence.
- (c) High spatial resolution of 10 meters for Bands 4 (Red) and 8 (NIR).

2.6. Preprocessing

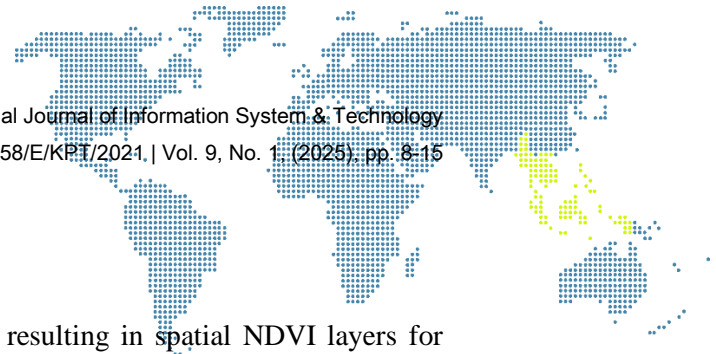
Preprocessing of imagery was conducted using the cloud-based platform Google Earth Engine (GEE). The following procedures were applied:

- (a) Atmospheric correction using the Sentinel-2 Surface Reflectance (S2 SR) dataset.
- (b) Removal of cloud-contaminated pixels using the QA60 quality band and cloud probability filtering.
- (c) Creation of annual image composites for both 2020 and 2024 through mosaicking.

2.7. NDVI Calculation

The Normalized Difference Vegetation Index (NDVI) was derived using the classical equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$



Where:

NIR corresponds to Band 8 (842 nm).

Red corresponds to Band 4 (665 nm).

NDVI values were computed on a per-pixel basis, resulting in spatial NDVI layers for each year of analysis.

2.8. Vegetation Classification Using Threshold

A binary classification scheme was applied based on a threshold value of $NDVI > 0.5$ to identify areas with dense vegetation. Pixels surpassing this threshold were designated as “dense vegetation,” while those below were grouped under “non-dense vegetation,” which includes urban infrastructure, bare surfaces, and sparsely vegetated areas.

2.9. Change Detection Analysis

To evaluate changes in vegetative cover between the two years, a post-classification comparison was employed. This approach enabled the identification of zones where vegetation had either increased, decreased, or remained unchanged. The magnitude of these changes was quantified in terms of area (hectares), and spatial patterns were examined using zonal statistical methods.

3. Results and Discussion

3.1 NDVI of Makassar 2020

The NDVI map of Makassar City for the year 2020 provides a detailed visualization of vegetation density within the city’s administrative boundaries. With NDVI values ranging from -0.673905 to 0.913492, the map highlights areas with varying levels of vegetation health. Higher NDVI values, approaching 0.91 and represented by darker green shades, indicate dense and healthy vegetation cover, predominantly found in the northern and peripheral regions of the city. Conversely, areas with lower NDVI values are concentrated in the central and southern parts of Makassar, which are typically more urbanized and built-up. This spatial distribution reflects the ongoing urban expansion and its impact on green space availability. As a baseline dataset, this NDVI map is essential for assessing vegetation conditions in 2020 and serves as a reference for future change detection analysis, especially in evaluating the effectiveness of urban green space management and sustainable land use planning efforts.

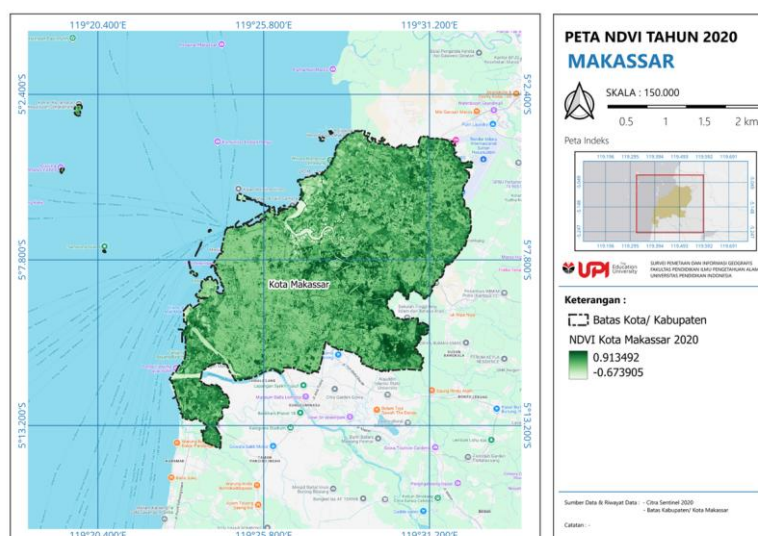
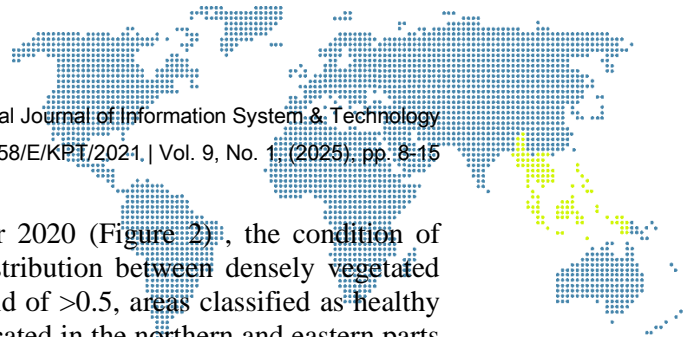


Figure 2. NDVI Map of Makassar City in 2020 Based on Sentinel-2 Imagery



Based on the NDVI threshold map for the year 2020 (Figure 2), the condition of vegetation in Makassar City reveals an uneven distribution between densely vegetated areas and urbanized zones. Using an NDVI threshold of >0.5 , areas classified as healthy vegetation (indicated in green) are predominantly located in the northern and eastern parts of the city, which generally represent the outskirts or less developed regions. In contrast, areas with NDVI values below 0.5 (shown in red), encompassing dense settlements, industrial zones, and open lands, are concentrated in the central and southern parts of Makassar. The NDVI values range from -0.673905 to 0.913492, where higher values indicate dense, healthy vegetation, and lower or negative values represent non-vegetated surfaces such as buildings, roads, or bare land. This spatial pattern reflects the significant pressure of urban development on green spaces, particularly in the urban core.

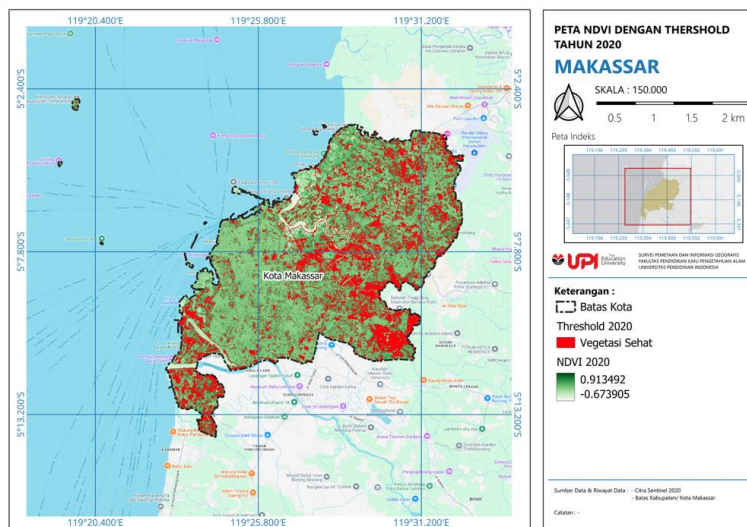


Figure 3. NDVI Map with Threshold for the Year 2020 – Makassar

3.2. NDVI of Makassar 2024

The 2024 NDVI map of Makassar City illustrates the spatial distribution of vegetation density using Sentinel-2 satellite imagery. The NDVI values range from -0.30098 to 0.683171, reflecting diverse vegetation conditions throughout the city. Areas with darker green shades represent higher NDVI values, indicating regions with denser and healthier vegetation, predominantly located in the northern and peripheral zones. In contrast, the central and southern parts of the city display lighter green hues, suggesting lower vegetation density likely due to ongoing urbanization. When compared to the NDVI data from 2020, the 2024 map indicates a potential decline in overall vegetation cover, especially in areas affected by construction and land-use changes. This map plays an essential role in evaluating urban ecological shifts and supporting sustainable land management initiatives in Makassar.

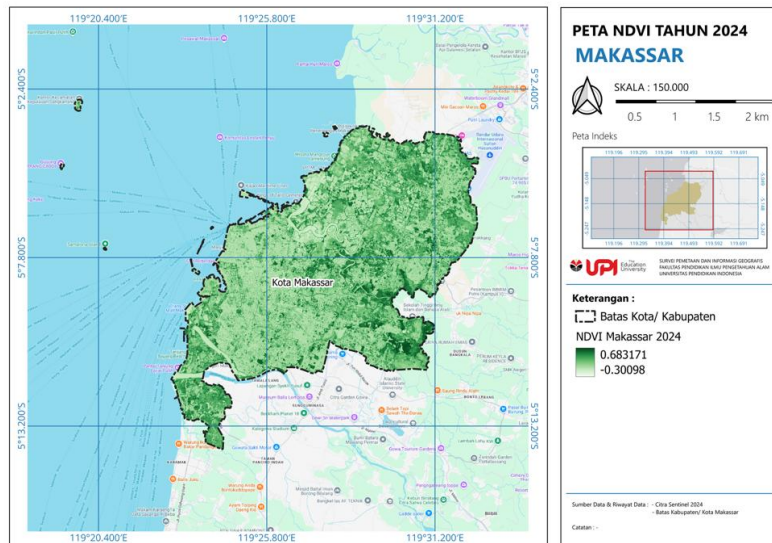
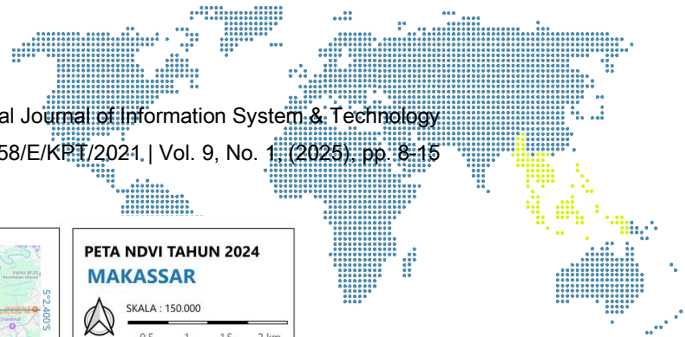


Figure 4. NDVI Map of Makassar City in 2020 Based on Sentinel-2 Imagery

The 2024 NDVI Threshold Map of Makassar provides a focused representation of areas with healthy vegetation based on a specific NDVI value threshold. In this map, regions marked in red indicate zones with healthy vegetation—those that exceed the defined NDVI threshold value. These red-highlighted areas are predominantly scattered throughout the city, with a higher concentration observed in the eastern and southern parts of Makassar. This suggests that despite urban expansion, pockets of vegetation with strong vitality are still present, particularly in less urbanized zones. Meanwhile, the green areas represent the full NDVI range from -0.30098 to 0.683171, covering various degrees of vegetation density. This threshold-based visualization allows for clearer identification and monitoring of ecologically significant zones, serving as an essential tool for urban planning, green space conservation, and sustainable development efforts in Makassar.

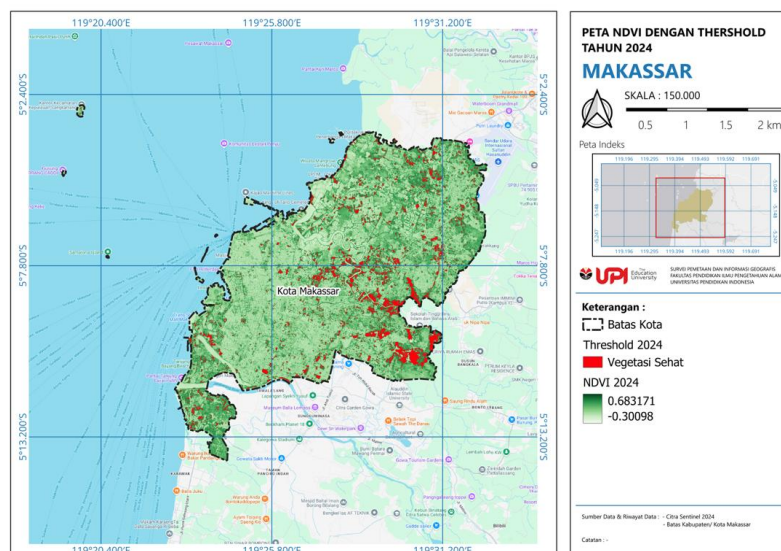
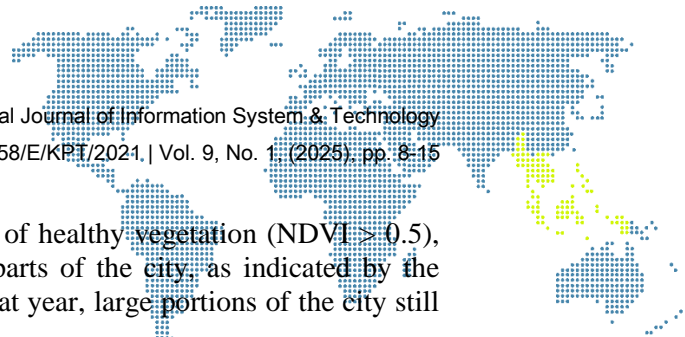


Figure 5. NDVI Map with Threshold for the Year 2024 – Makassar

3.3. Temporal Comparison of Vegetation Health in Makassar

Based on the comparison of the NDVI threshold maps for the years 2020 and 2024 in Makassar City, there is a clear trend of declining vegetation health over the four-year



period. In 2020, the map shows a wide distribution of healthy vegetation (NDVI > 0.5), particularly in the central, northern, and southern parts of the city, as indicated by the dominance of red areas. This suggests that during that year, large portions of the city still maintained relatively healthy vegetation cover.

By 2024, however, there is a noticeable reduction in healthy vegetation areas. The 2024 map displays significantly fewer red zones, especially in the central and southern urban areas, which are now dominated by pale zones representing less healthy or sparse vegetation. This indicates an expansion of built-up areas and a decline in natural vegetative cover, likely driven by urban development and land-use change.

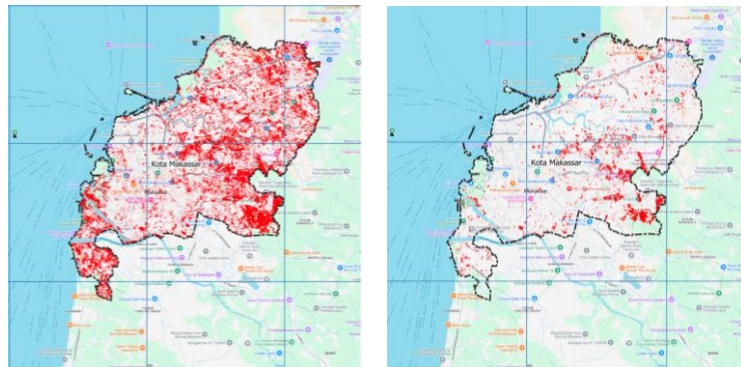


Figure 6. Temporal Ciomparison 2020-2024

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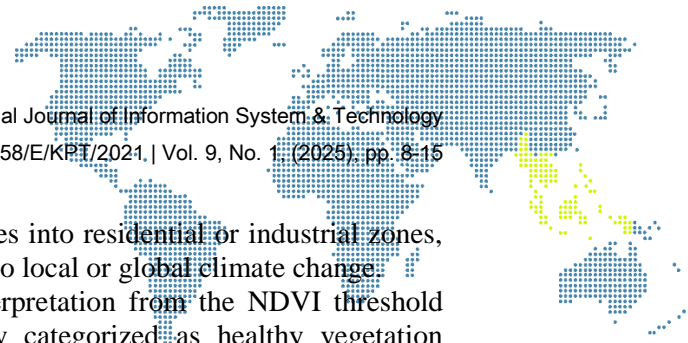
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Table 1. The area with NDVI values

No	Year	Area (Ha)
1	2020	4,792.93
2	2024	1,157.23

Based on the chart and table showing the area with NDVI values > 0.5 in Makassar City for the years 2020 and 2024, there is a significant decline in the extent of healthy vegetation. In 2020, the total area with NDVI > 0.5 reached approximately 4,792.93 hectares, while in 2024 it decreased drastically to only 1,157.23 hectares. This indicates a reduction of about 3,635.70 hectares, or around 76% of the healthy vegetation area recorded in 2020.

This sharp decline highlights a concerning trend of vegetation degradation over the four-year period. Potential contributing factors may include the expansion of built-up



areas due to urbanization, conversion of green spaces into residential or industrial zones, and a possible decline in environmental quality due to local or global climate change. These quantitative findings support the visual interpretation from the NDVI threshold maps of 2020 and 2024, where areas previously categorized as healthy vegetation (marked in red) have become significantly reduced in 2024. Therefore, these results underscore the urgent need for greater environmental awareness and the development of sustainable land-use policies in Makassar City.

4. Conclusion

The comparison of NDVI values between 2020 and 2024 in Makassar City reveals a significant decline in vegetative health, as indicated by the reduction of areas with NDVI > 0.5 from 4,792.93 hectares to 1,157.23 hectares. This trend suggests ongoing environmental degradation likely driven by urban expansion, land-use change, and possible climate-related stressors. If this decline continues, it could lead to further ecological imbalance and reduced green space in the city. Therefore, immediate efforts are needed to implement sustainable development strategies, protect remaining vegetation, and restore degraded areas to ensure long-term environmental resilience in Makassar.

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