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# DYNAMICS OF URBAN GREEN SPACES IN DAVAO CITY: A SPATIOTEMPORAL ANALYSIS

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## Abstract

Urban green spaces (UGS) are critical to maintaining ecological balance and enhancing the quality of life in rapidly urbanizing cities. This study investigates the spatiotemporal dynamics of urban green spaces in Davao City, Philippines, from 2015 to 2024, using multispectral Landsat satellite imagery and the Normalized Difference Vegetation Index (NDVI) processed through QGIS. The analysis reveals a significant decline in dense and moderate vegetation across all three congressional districts, alongside a steady increase in non-vegetated land, indicating extensive urban expansion and land conversion. Notably, No Vegetation areas more than doubled city-wide, with District II experiencing the highest rate of green space loss. District III retained the most extensive green cover but displayed volatile NDVI trends due to alternating cycles of development and reforestation. The results underscore the fragmented and uneven development of green spaces, highlighting implications for biodiversity, climate resilience, and equitable access to ecological resources. The study draws on Marxist spatial theory to contextualize these patterns and emphasizes the urgency of integrating sustainable land-use planning into urban development strategies. Policy recommendations include long-term vegetation monitoring, ecological assessments, community involvement, and the prioritization of green infrastructure in city planning.

Keywords: urban green spaces, built-up, NDVI, spatiotemporal analysis, change, Davao City, Philippines.

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## INTRODUCTION

Green spaces are key components of green infrastructure, offering essential habitats for a wide range of plant and animal species (Pan et al. 2019). As such, they help mitigate the negative effects of urbanization on biodiversity (Hebblewhite 2022). Vegetation within these areas plays a vital role in managing atmospheric carbon dioxide levels, thereby helping to reduce the greenhouse effect (Zhang et al. 2022). The role of urban greenery, including forests and parks, in carbon storage and sequestration has increasingly drawn attention (Yao et al. 2018). Additionally, green spaces are recognized for their health benefits, primarily due to their ability to reduce exposure to air pollution and other harmful environmental factors (Dzhambov et al. 2020). Living near green spaces has been linked to several health benefits, including higher birth rates (Akaraci et al. 2020), better overall health (Krefis et al. 2018), and reduced mortality rates (Rojas-Rueda et al. 2019). Numerous studies have associated green environments with improved health outcomes (Mitchell & Popham 2007), such as lower rates of cardiovascular-related deaths, fewer respiratory conditions (Villeneuve et al. 2012), and enhanced mental well-being (Ward et al. 2012). However, with the accelerating pace of urbanization, it is projected that approximately 68% of the global population will reside in urban areas (United Nations 2018). This trend contributes to the loss and degradation of green spaces in cities (Collins 2014), a particularly pressing issue in developing nations (Baker et al. 2018). The fragmentation and decline of these areas can result in a range of social, economic, and environmental challenges (Li et al. 2019), including habitat destruction, disruption of urban ecological systems, and reduced biodiversity (Betts et al. 2019). The Philippines ranks among the most rapidly urbanizing nations in East Asia (Baker & Watanabe 2017). Davao City, recognized as one of the country's leading and most competitive industrial hubs (Palo 2022), holds the position of the third most populous city, with a population of 1.87 million as of 2021 (Philippine Statistics Authority 2022).

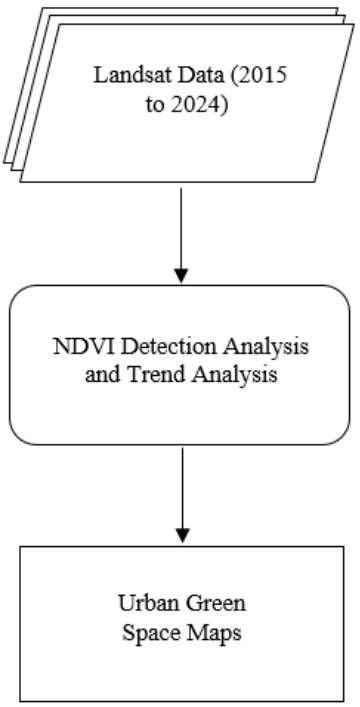


**Figure 1.** Conceptual framework of the study.

As investments and development projects continue to grow, the city is gradually emerging as a key economic center (Manila Standard 2021). However, ongoing expansion leads to the depletion of green spaces, which in turn diminishes the ecosystem services they provide, highlighting the environmental consequences of reduced green areas (Silva et al. 2023). This highlights the importance of conducting this research. At present, there is limited comparative analysis on the changes in urban green spaces across different congressional districts within a city. Therefore, the main objective of this study is to assess the spatial and temporal trends of urban green spaces in Davao City from 2015 to 2024. Specifically, this study aims to: (i) assess the dynamics of urban green spaces in the urban barangays of Davao City using the

Normalized Difference Vegetation Index (NDVI) and (ii) compare the changes in urban green spaces among the urban barangays across the three (3) Congressional Districts of Davao City. The conceptual basis of the study was the research of Wu et al. 2023, wherein they studied the spatiotemporal dynamics of urban green space in Changchun, China. Moreover, the study was anchored in the theory of Uneven Development by Marxist scholars (Smith & Harvey 1990).

## MATERIALS AND METHODS

This study employed a descriptive, quantitative, non-experimental research design. The research was conducted in Davao City, located at 7.207573°N latitude and 125.395874°E longitude (7° 12' 27.2628" North, 125° 23' 45.1464" East). Davao City, situated on the island of Mindanao, is classified as a first-class highly urbanized city (NEDA-Region XI 2022). The city is composed of three congressional districts, which are further subdivided into 11 administrative districts, encompassing a total of 182 barangays. This study concentrated on the urban barangays across the three districts. The 92 urban barangays, District 1 comprises 52, District 2 has 25, and District 3 includes 15 (City Planning and Development Office 2020). For data collection, the researchers used satellite imagery from Landsat 9 and processed it through Quantum Geographic Information System (QGIS) software to generate visual maps. The Normalized Difference Vegetation Index (NDVI) was applied using multispectral satellite data to detect and assess remaining green vegetation canopies. For data analysis, the researchers utilized mean values to quantify total green space and percentages to evaluate changes across various vegetation classifications. NDVI was calculated using the formula below:

$$NDVI = (NIR-Red)/(NIR+Red)$$

## RESULTS AND DISCUSSION

### Dynamics of urban green spaces in the urban Barangays of Davao City from 2015-2024

Table 1 presents the trends in urban green spaces across Davao City's urban barangays from 2015 to 2024, based on five land cover categories: No Vegetation, Minimal, Sparse, Moderate, and Dense Vegetation, within a constant area of 292.465 km². The proportion of areas categorized as No Vegetation more than doubled, reaching 18.8% in 2024, highlighting the increasing pressure of urban sprawl and the transformation of natural green spaces into built-up hardscapes (Masancay et al. 2025). This rise is strongly associated with rapid urbanization and extensive deforestation activities (Li et al. 2019), which in turn pose threats to local biodiversity and ecosystem services (Markevych et al. 2017). Sparse vegetation experienced a slight reduction from 20.8% to 18.6%, signaling a gradual degradation of low-density greenery (Patiño et al. 2019). Meanwhile, minimal vegetation increased marginally from 22.0% in 2015 and peaked in 2016, suggesting a temporary rise in transitional land covers like grasslands, cleared lots, or sites under development. However, this category experienced a mild decrease in 2024, possibly due to these transitional spaces being converted into permanent infrastructure over time.

The variability in moderate vegetation began at 35.7% in April 2014. It increased steadily and peaked in 2017 at over 40%, indicating a temporary expansion of green areas, possibly due to land rehabilitation or delayed construction projects. However, this was followed by fluctuating levels in the succeeding years, which could be attributed to changes in land use policies, urban development, and seasonal vegetation cycles. On the other hand, dense vegetation showed a more dynamic pattern of change. It dropped to 12.3% in 2016 and was slightly higher at 14.1% in 2015, reflecting ongoing land clearing activities during that period.

However, a significant increase was observed in 2022, reaching 34.5%, which may suggest reforestation efforts, tree planting initiatives, or the regeneration of vegetation in idle lands. Unfortunately, this trend did not continue, as dense vegetation declined to 26.6% in 2024, potentially driven by renewed urban expansion and infrastructure development, resulting in further land clearing and conversion (Silva et al. 2019). These trends highlight the ongoing tension between development and ecological preservation in Davao City.

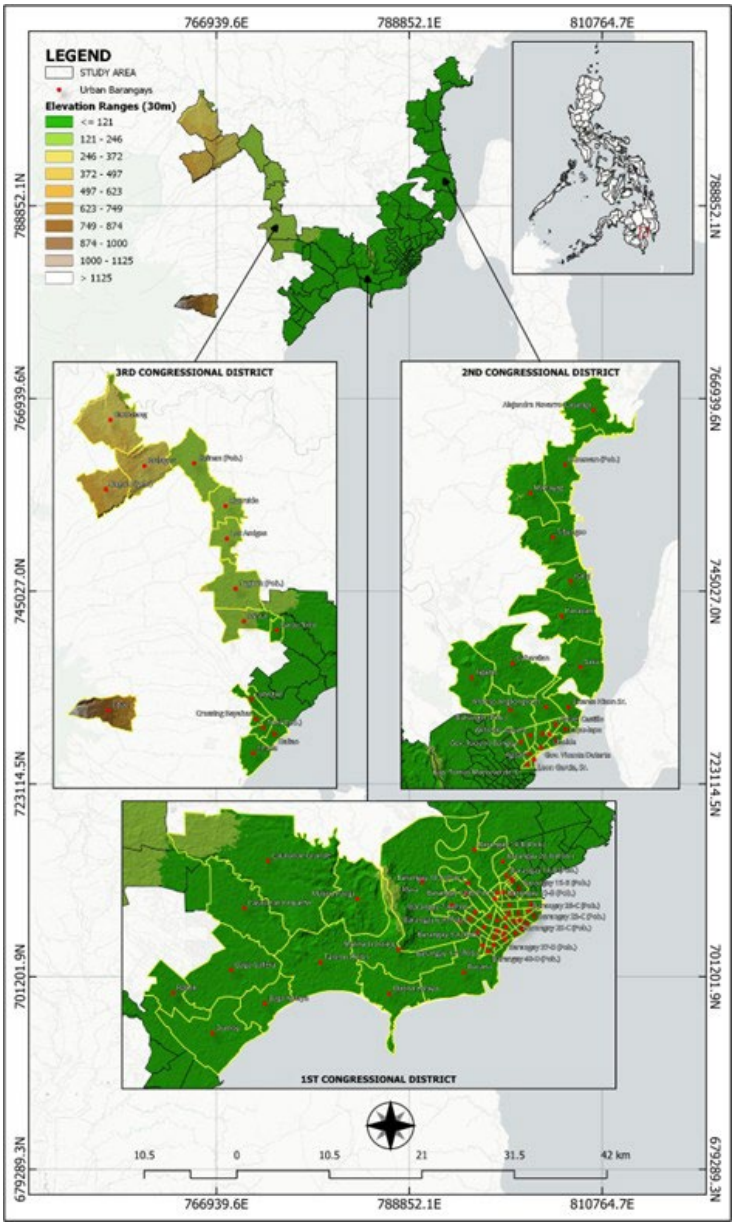


**Figure 2.** Map showing the location of the study.

**Table 1.** Dynamics of urban green spaces in the urban barangays of Davao City from 2015 to 2024.

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 21.8 | 7.4 | - | 27.2 | 9.3 | 24.7 | 35.1 | 11.9 | 29.1 | 36.7 | 12.5 | 4.6 | 38.7 | 13.2 | 5.6 |
| Minimal Vegetation | 64.6 | 22.0 | - | 72.5 | 24.7 | 12.2 | 51.8 | 17.6 | -28.5 | 70.1 | 23.9 | 35.3 | 48.3 | 16.4 | -31.1 |
| Sparce Vegetation | 61.1 | 20.8 | - | 74.3 | 25.3 | 21.7 | 51.5 | 17.5 | -30.7 | 61.7 | 21.0 | 19.7 | 49.2 | 16.7 | -20.3 |
| Moderate Vegetation | 104.9 | 35.7 | - | 83.7 | 28.5 | -20.2 | 117.5 | 40.0 | 40.5 | 76.8 | 26.2 | -34.6 | 88.1 | 30.0 | 14.7 |
| Dense Vegetation | 41.5 | 14.1 | - | 36.2 | 12.3 | -12.9 | 37.9 | 12.9 | 4.7 | 48.6 | 16.5 | 28.1 | 69.5 | 23.6 | 43.1 |
| TOTAL | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | |

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | 2021 | | | 2022 | | | 2023 | | | 2024 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 44.3 | 15.1 | 14.4 | 46.4 | 15.8 | 4.7 | 47.2 | 16.1 | 1.7 | 48.4 | 16.5 | 2.6 | 55.2 | 18.8 | 14.0 |
| Minimal Vegetation | 52.0 | 17.7 | 7.7 | 66.2 | 22.5 | 27.2 | 57.0 | 19.4 | -14.0 | 58.3 | 19.8 | 2.3 | 63.1 | 21.5 | 8.3 |
| Sparce Vegetation | 54.2 | 18.4 | 10.3 | 56.7 | 19.3 | 4.7 | 54.3 | 18.5 | -4.3 | 53.6 | 18.2 | -1.4 | 54.6 | 18.6 | 1.9 |
| Moderate Vegetation | 94.4 | 32.1 | 7.1 | 103.3 | 35.1 | 9.4 | 90.7 | 30.9 | -12.2 | 67.0 | 22.8 | -26.1 | 82.9 | 28.2 | 23.7 |
| Dense Vegetation | 48.8 | 16.6 | -29.7 | 21.2 | 7.2 | -56.6 | 44.7 | 15.2 | 110.7 | 66.6 | 22.7 | 48.9 | 38.1 | 13.0 | -42.8 |
| TOTAL | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | | 293.8 | 100 | |

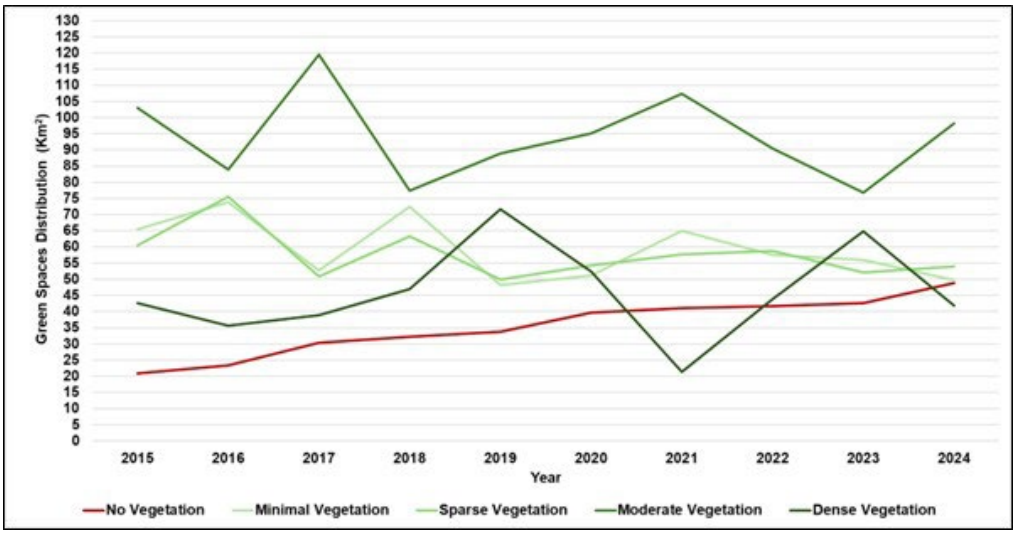


**Figure 3.** Trend graph showing the dynamics of urban green spaces indexes in Davao City from 2015 to 2024.

As shown in Figure 3, the variations of the vegetation cover of the years 2015-2024 indicate remarkable changes about urbanization. Considerable growth of the amount of land covered by No Vegetation (21.8 km² to 55.2 km²) is also a sign of land change, in which there is a probable urban sprawling and the development of infrastructure (Baker et al. 2018, Li et al. 2019). Dense Vegetation was also variable, reaching its highest point in 2017 and 2022, and dropping dramatically in 2024. Moderate vegetation grew and later decreased, meaning that previously whole green spaces were fragmented (Hebblewhite 2022). Minimal and Sparse Vegetation, on the other hand, did not change significantly, indicating that the rate of vegetation degradation was gradual. These trends indicate the conflict between growth and environmental conservation and

emphasize that sustainable urban planning is the only solution to stop biodiversity erosion and promote climate resilience (Pan et al. 2019, Zhang et al. 2022).

The maps below show a significant decline in vegetation cover in Davao City from 2015 to 2024, most severe in urbanized coastal and lowland barangays. This loss is linked to rapid population growth, infrastructure expansion, and increasing land demand (Palmeo et al. 2022, Salac et al. 2023). Between 2015 and 2019, non-vegetated zones expanded markedly due to the conversion of green spaces into built-up areas. After 2020, dense vegetation continued to decline, while medium vegetation fluctuated. By 2022–2024, green spaces became fragmented, forming smaller, isolated patches. These changes threaten biodiversity, weaken urban cooling functions, and reduce carbon storage and water regulation. Continuous vegetation loss undermines the city's climate resilience. Sustainable urban planning is essential to balance development with conservation by protecting vegetation and integrating green infrastructure to mitigate heat impacts and enhance ecological stability.

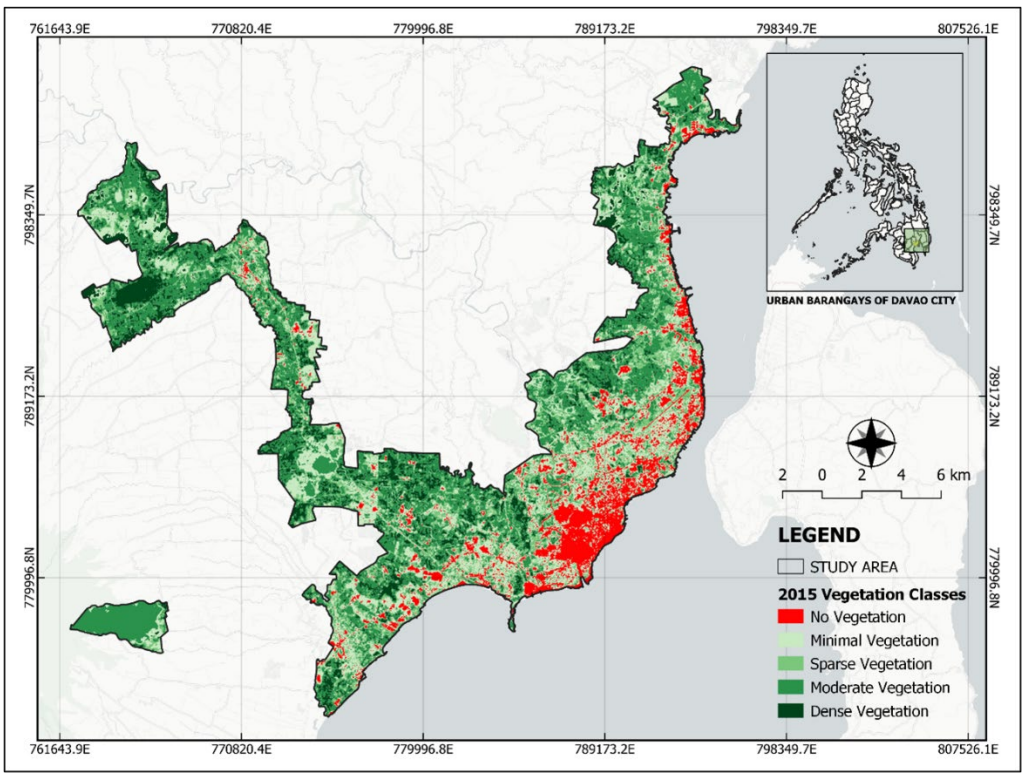


**Figure 4.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2015.

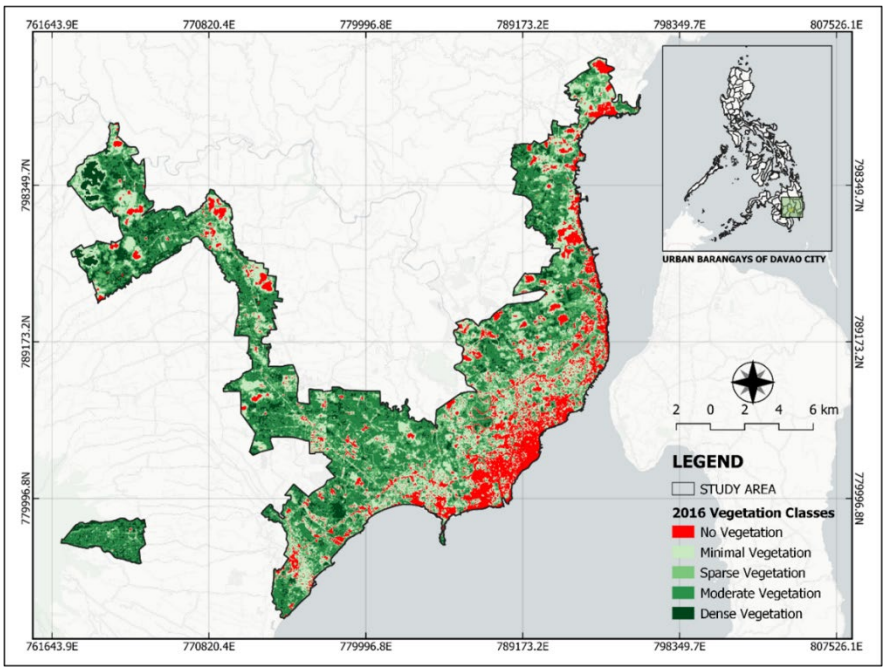


**Figure 5.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2016.

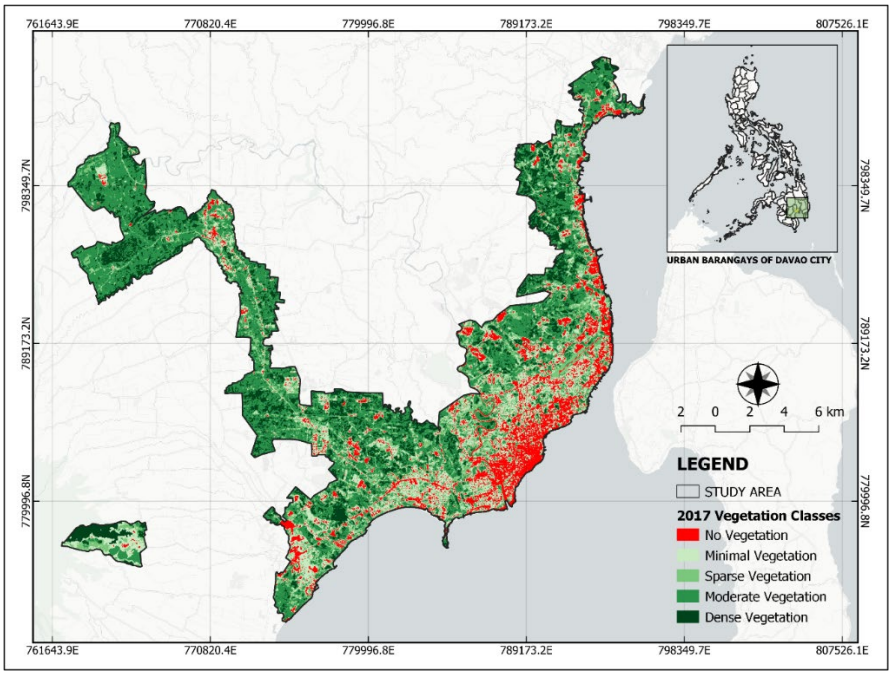


**Figure 6.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2017.

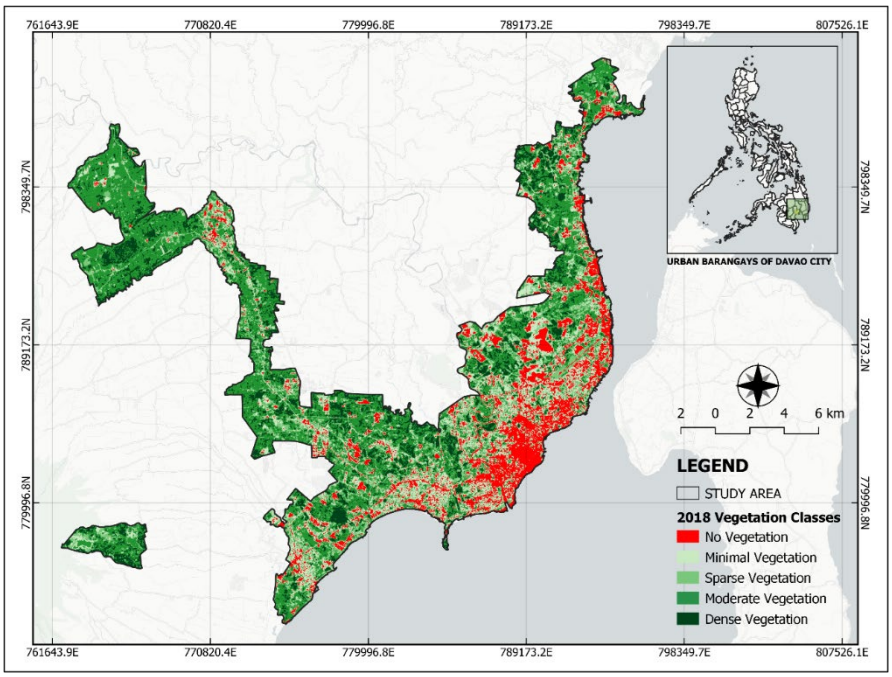


**Figure 7.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2018.

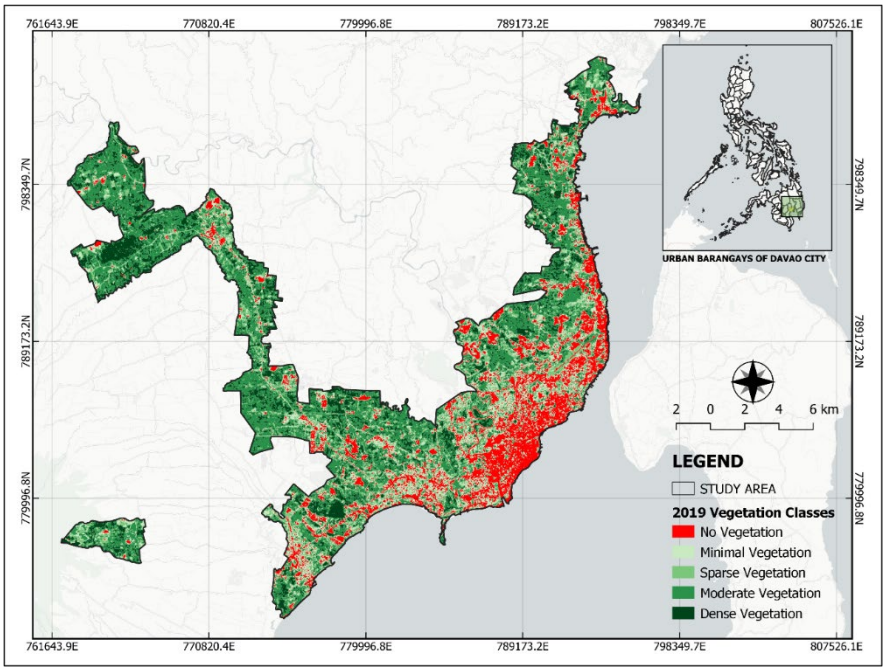


**Figure 8.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2019.

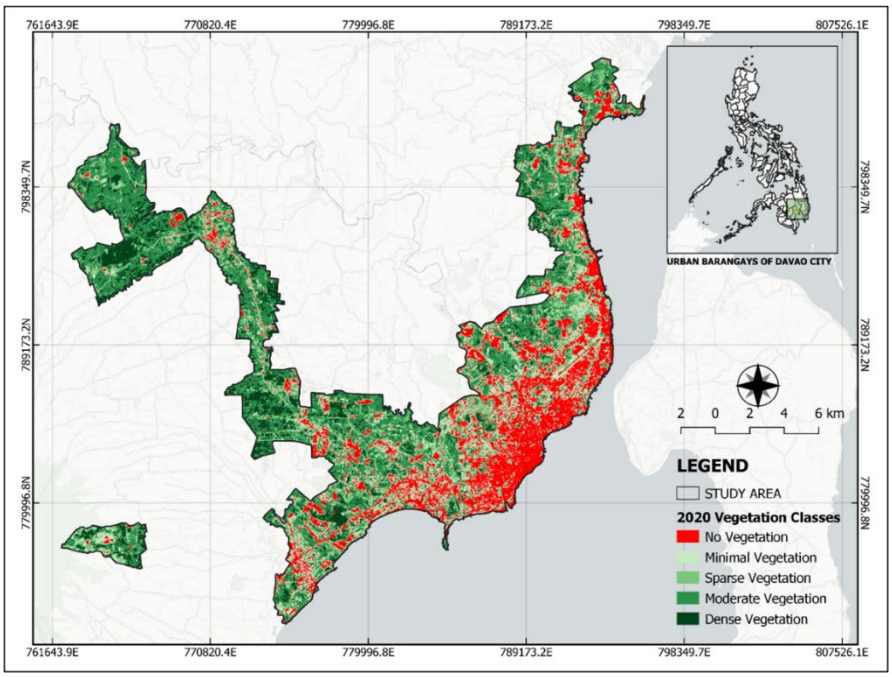


**Figure 9.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2020.

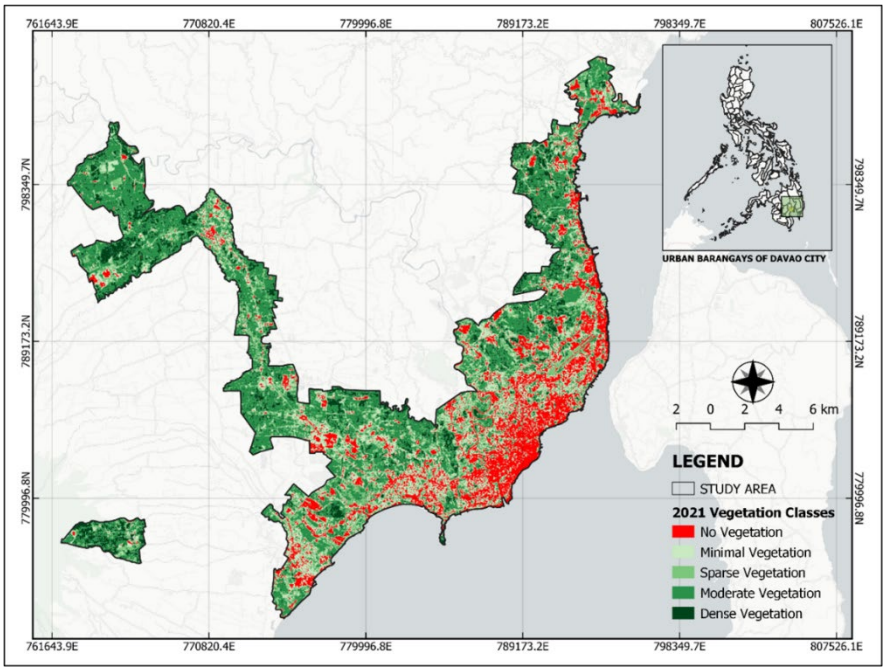


**Figure 10.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2021.

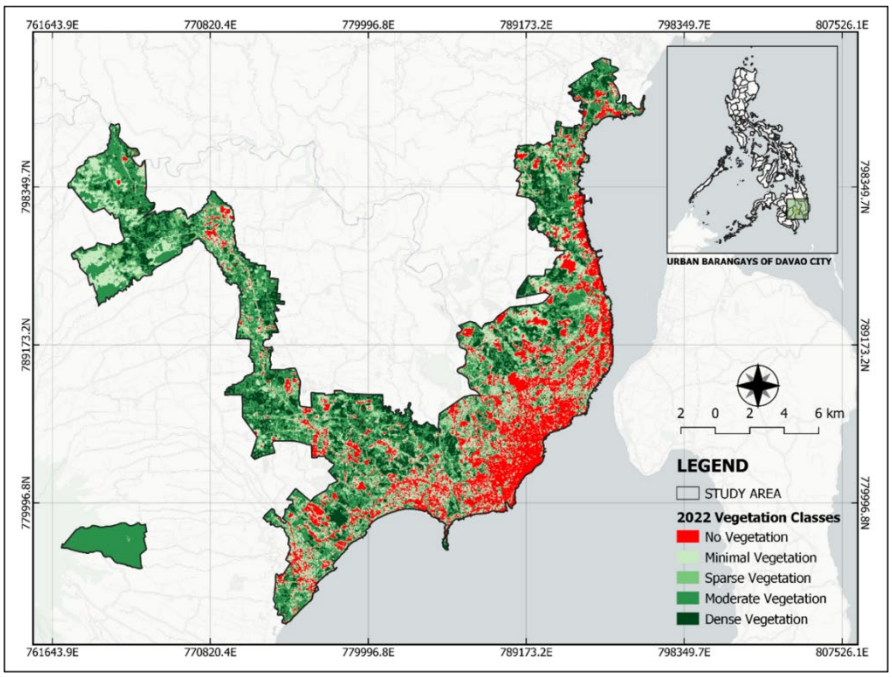


**Figure 11.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2022.

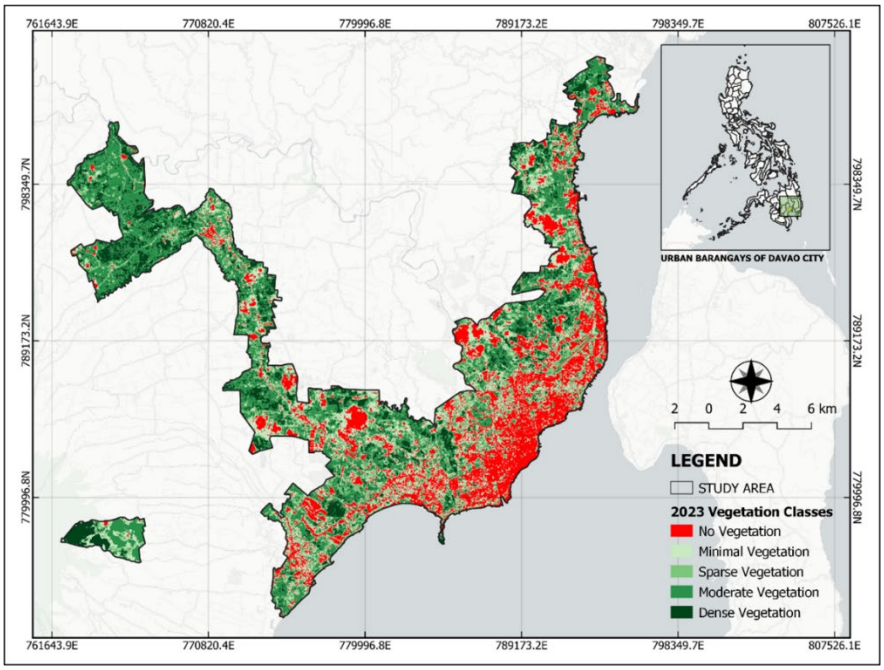


**Figure 12.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2023.

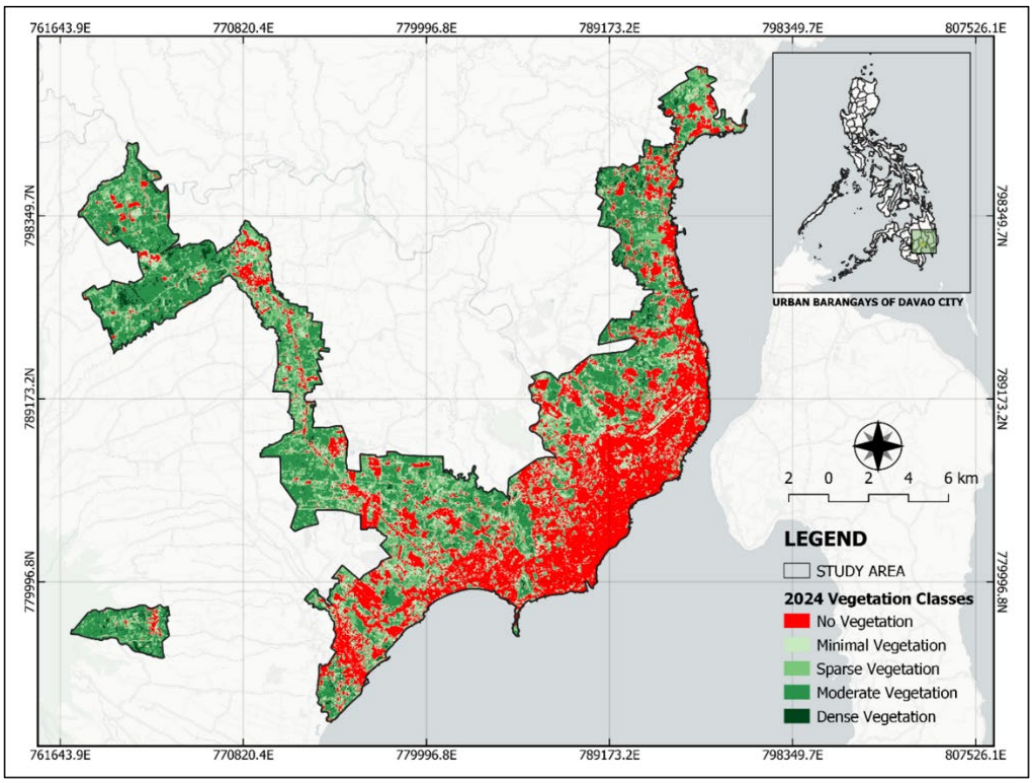


**Figure 13.** Map showing the spatiotemporal change of urban green spaces in Davao City in 2024.

As shown in Table 2, the listed data classified urban barangays with city change of area of the Urban Green Spaces (UGS), all the top 10 urban barangays of the city of Davao City can be found in the 1st Congressional District, wherein it has the highest area change of urban green spaces in Davao City. This means that the transformation of green space is spatially concentrated in one administrative district, which implies the application of greening to urban areas of the city or the reorganization of land use in this sector. The highest scores fall on the zones of Barangays 18-A, 9-A, and 10-A, which have the most aggressive redevelopment or reforestation program potential. The tendency can be seen as the changes in the cities' prioritization of urban planning, which highlights the position and importance of the district in the ecological restoration and climate resilience.

**Table 2.** Top 10 urban barangays in Davao City with highest area change of urban green spaces (UGS).

| Rank | Barangay | Congressional District |
|---|---|---|
| 1 | Barangay 18-A | 1st |
| 2 | Barangay 9-A | 1st |
| 3 | Barangay 10-A | 1st |
| 4 | Barangay 18-B | 1st |
| 5 | Barangay 13-B | 1st |
| 6 | Barangay 12-B | 1st |
| 7 | Barangay 4-A | 1st |
| 8 | Barangay 33-D | 1st |
| 9 | Barangay 32-D | 1st |
| 10 | Barangay 26-D | 1st |

**Comparison on the Changes in Urban Green Spaces (UGS) among the Urban Barangays Across the Three (3) Congressional Districts in Davao City**

**Congressional District I**

Table 3 shows the vegetation cover trends in District I between 2015 and 2024 in the form of No Vegetation, Minimal Vegetation, Sparse Vegetation, Moderate Vegetation, and Dense Vegetation. Persistently over the years, No Vegetation was on an upward trend of 12.5 km² to 13.5 km² in the years 2015 to 2024, respectively, which means urban development, forest clearing, or land loss. Minimum vegetation, being the most significant contribution to the space earlier on, reduced from 25.6 km² (27.7%) in 2015 to 21.1 km² (22.7%) in 2020. Then, it slightly reflected to 20.4 km² (22.0%) in 2024 because of vegetation loss and re-growth alternating periods, likely to be caused by a change in land use practices. Sparse Vegetation was varied, be-ginning with 18.7 km² (20.1%) in 2015, went up to 19.0 km² (20.5%) in 2020, reduced to 15.4 km² (16.6%) in 2023, and rose back to 17.0 km² (18.3%) in 2024. These variations could result from changes in seasonal land use, forest cover, or agricultural activity on vegetation density. Moderate Vegetation tended to grow in size, lying at 22.7 km² (24.5%) in 2015, 31.2 km² (34.1%) in 2021, and 28.1 km² (30.3%) in 2024. Dense Vegetation showed a decreasing trend beginning with 13.1 km² (14.1%) in 2015, going down to 9.9 km² (10.7%) in 2024.

**Table 3.** Changes in urban green spaces in Congressional District I from 2015 to 2024.

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 12.5 | 13.5 | - | 12.8 | 13.8 | 1.9 | 13.8 | 14.9 | 8.2 | 14.3 | 15.5 | 3.7 | 14.9 | 16.1 | 4.1 |
| Minimal Vegetation | 25.6 | 27.7 | - | 25.1 | 27.1 | -2.0 | 24.1 | 26.0 | -4.0 | 25.8 | 27.8 | 6.7 | 24.3 | 26.2 | -5.6 |
| Sparce Vegetation | 18.7 | 20.1 | - | 19.2 | 20.7 | 3.0 | 18.4 | 19.9 | -4.1 | 16.2 | 17.4 | -12.3 | 17.3 | 18.6 | 6.9 |
| Moderate Vegetation | 22.7 | 24.5 | - | 21.7 | 23.4 | -4.6 | 22.5 | 24.3 | 3.8 | 21.8 | 23.6 | -2.9 | 20.7 | 22.3 | -5.3 |
| Dense Vegetation | 13.1 | 14.1 | - | 13.9 | 15.0 | 5.8 | 13.8 | 14.9 | -0.6 | 14.6 | 15.7 | 5.9 | 15.5 | 16.7 | 6.1 |
| TOTAL | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | |

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | 2021 | | | 2022 | | | 2023 | | | 2024 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 15.6 | 16.8 | 4.3 | 16.2 | 17.5 | 4.3 | 16.3 | 17.6 | 0.6 | 17.2 | 18.6 | 5.4 | 17.3 | 18.6 | 0.3 |
| Minimal Vegetation | 21.1 | 22.7 | -13.3 | 21.7 | 23.4 | 3.1 | 21.0 | 22.6 | -3.4 | 21.6 | 23.2 | 2.7 | 20.4 | 22.0 | -5.4 |
| Sparce Vegetation | 19.0 | 20.5 | 10.1 | 18.4 | 19.8 | -3.3 | 18.5 | 19.9 | 0.3 | 15.4 | 16.6 | -16.5 | 17.0 | 18.3 | 10.3 |
| Moderate Vegetation | 25.1 | 27.0 | 21.2 | 28.9 | 31.2 | 15.4 | 24.4 | 24.4 | -15.7 | 27.6 | 29.7 | 13.2 | 28.1 | 30.3 | 2.0 |
| Dense Vegetation | 12.0 | 12.9 | -22.7 | 7.4 | 8.0 | -37.9 | 12.6 | 12.6 | 69.0 | 11.0 | 11.8 | 12.8 | 9.9 | 10.7 | -9.4 |
| TOTAL | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | | 92.7 | 100 | |

Figure 14 shows NDVI trends in District I over the past decade, highlighting significant vegetation loss. The No Vegetation category expanded from 12.5 km² in 1973 to 17.3 km² in 2003, while dense vegetation shrank from 13.1 km² to 10.7 km². This reflects rapid urban growth encroaching on ecologically vital green spaces that support biodiversity, climate regulation, and community resilience (Aronson et al. 2017). In contrast, moderate, sparse, and minimal vegetation types showed only slight changes, indicating a shift to less functional vegetation with reduced capacity for carbon sequestration, flood regulation, and wildlife support (Tzoulas et al. 2007). Such losses exacerbate urban heat islands (Gill et al. 2007), increase flood risks (Gunawardena et al. 2017), and limit equitable green space access, particularly for marginalized groups (Jennings et al. 2017). These trends underscore the urgent need for stronger land-use planning, dense vegetation protection, and inclusive greening initiatives.

Figures 15 to 24 show changes in District 1 (92.7 km²) from 2015 to 2024 due to urbanization. Vegetation declined from 14.1%

(13.1 km²) in 2015 to 10.7% (9.9 km²) in 2024, while built-up areas grew from 13.5% to 18.6%, driven by infrastructure expansion (Banzon et al. 2022, Boquet 2017). NDVI data reveals increasing non-vegetated zones in new developments. The decline of green spaces heightens risks of heat islands and flooding (Milanovich et al. 2012) as ecologically valuable areas continue to be converted (Estoque & Murayama 2013) despite calls for sustainable land-use planning (Ascano et al. 2021).

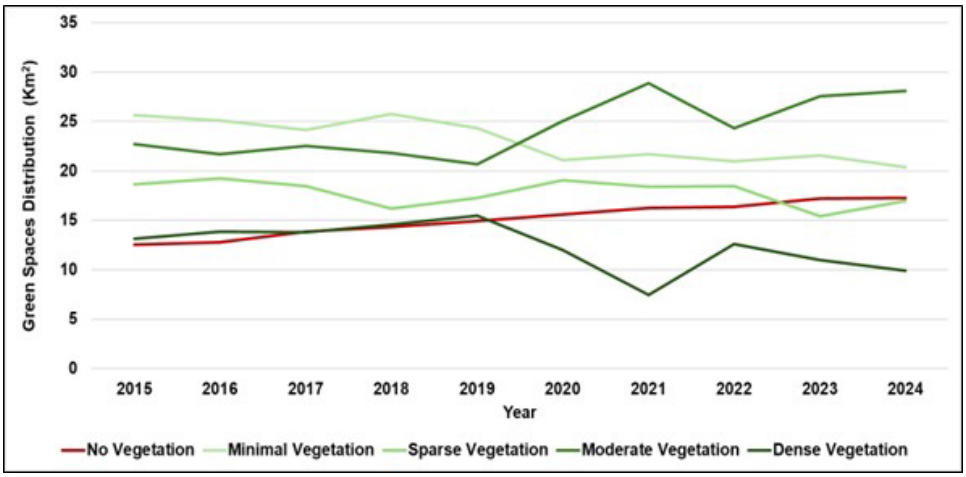


**Figure 14**. Trend graph showing the dynamics of urban green spaces indexes in Congressional District I from 2015 to 2024.

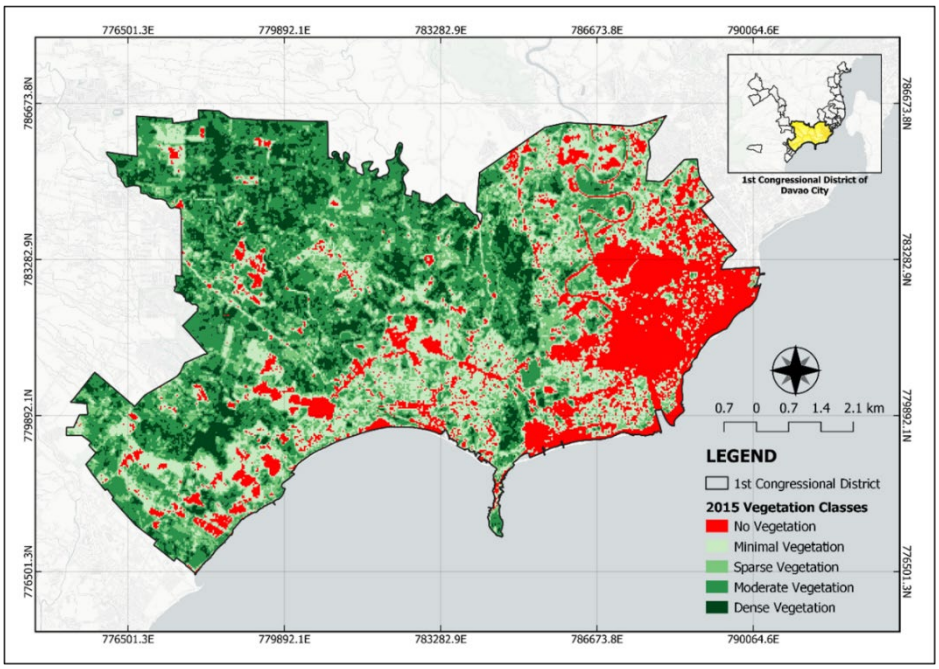


**Figure 15.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2015.

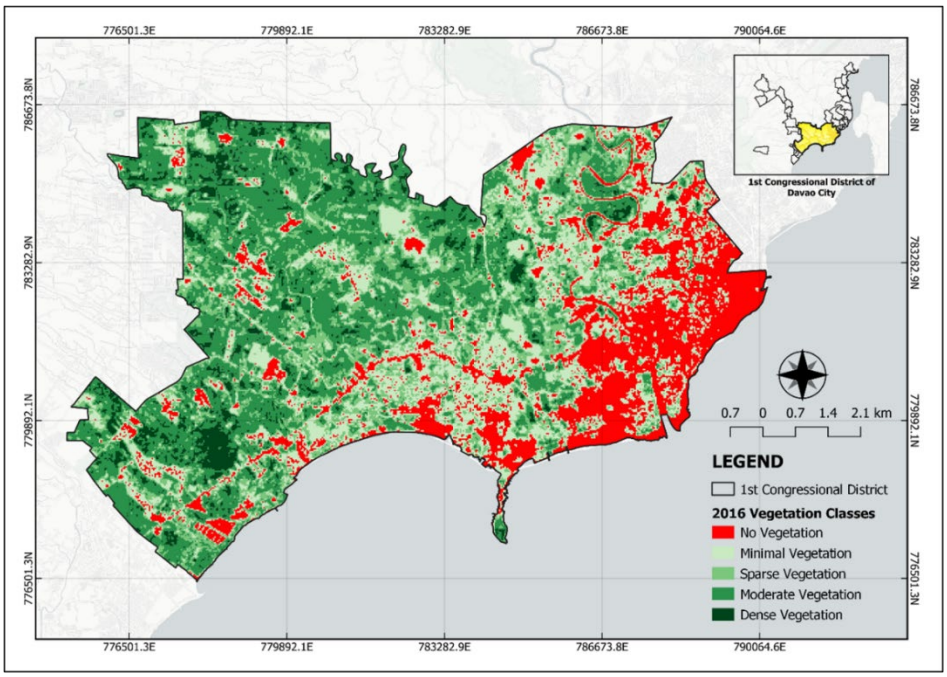


**Figure 16.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2016.

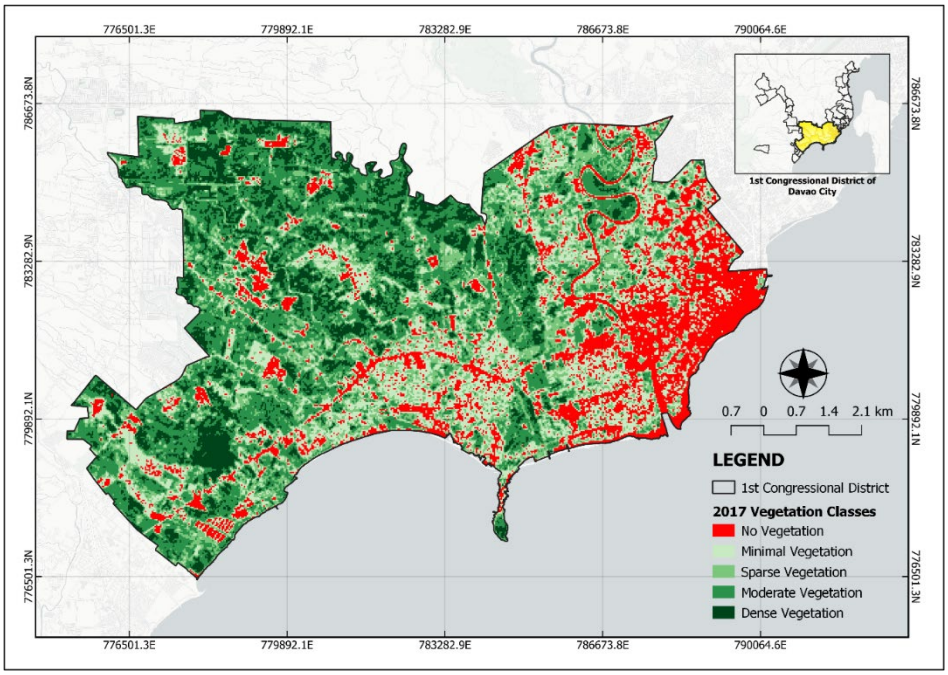


**Figure 17.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2017.

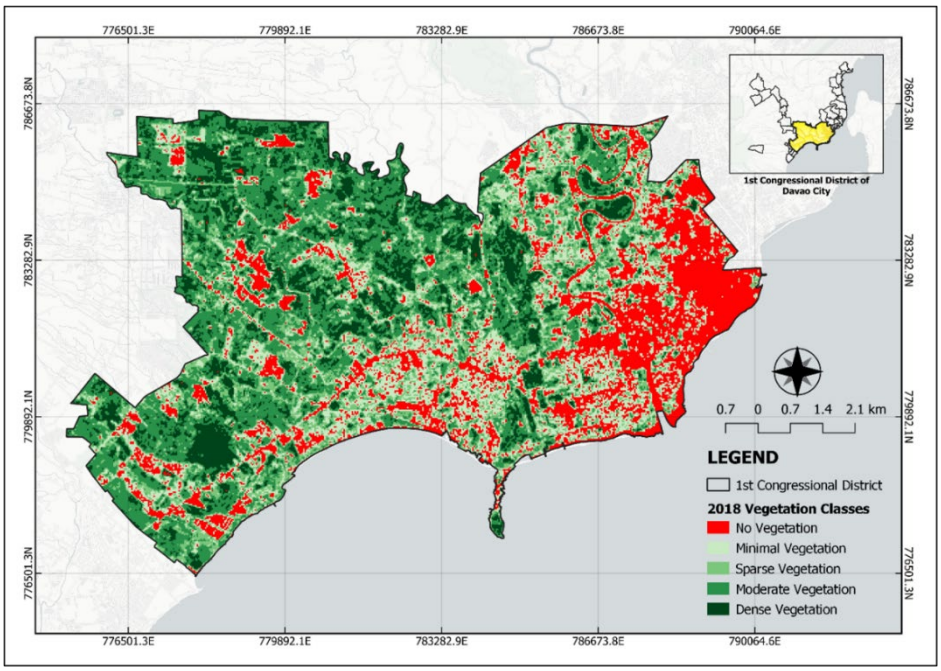


**Figure 18.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2018.

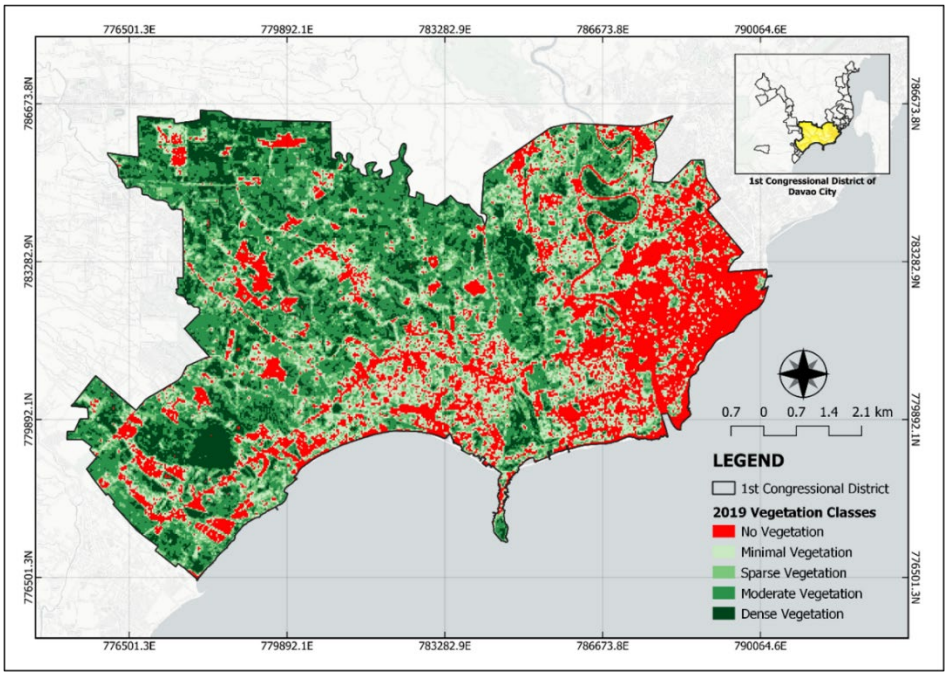


**Figure 19.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2019.

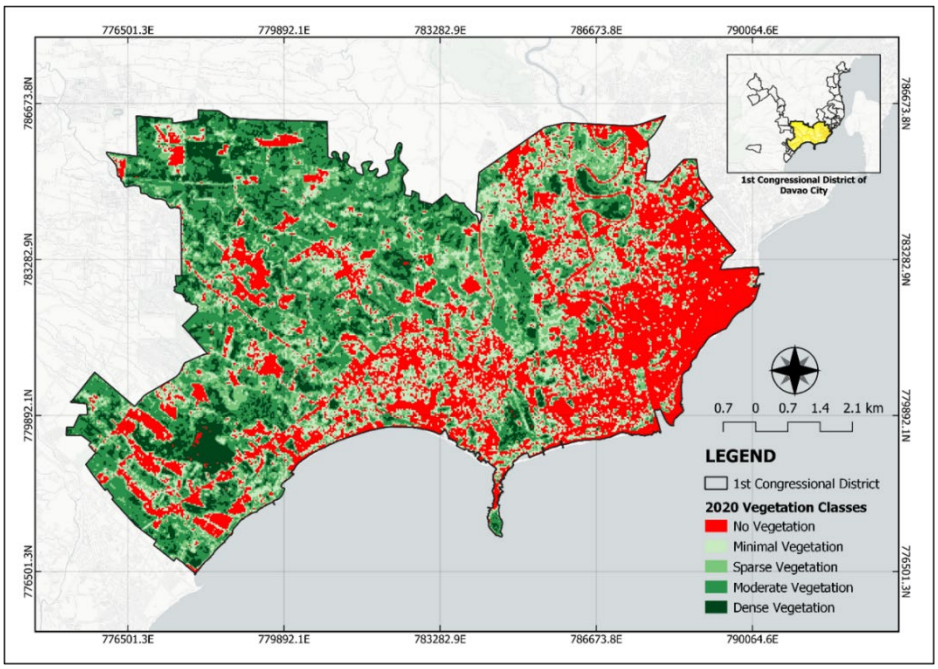


**Figure 20.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2020.

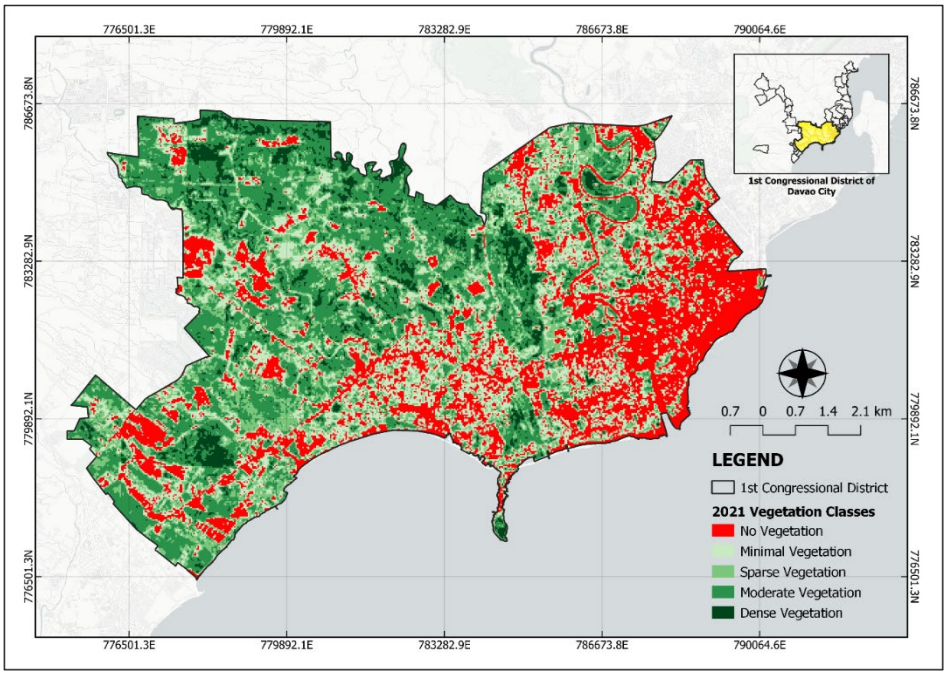


**Figure 21.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2021.

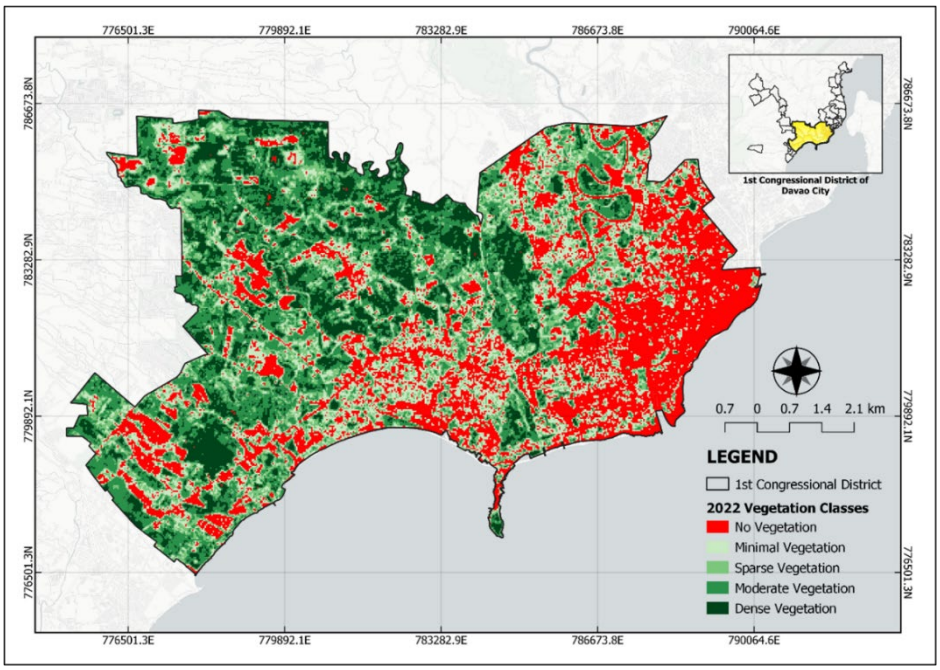


**Figure 22.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2022.

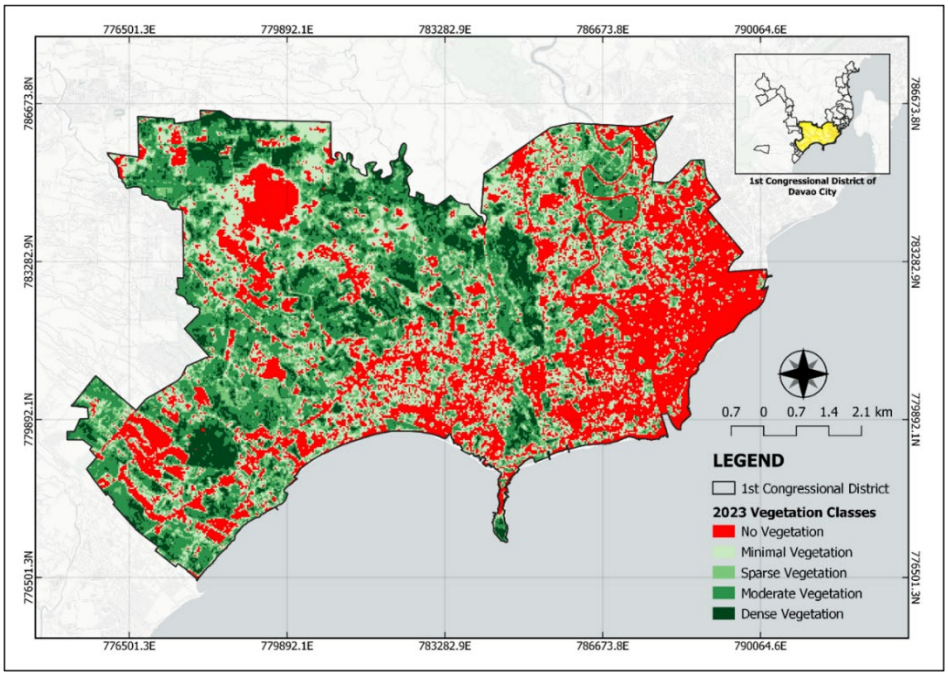


**Figure 23.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2023.

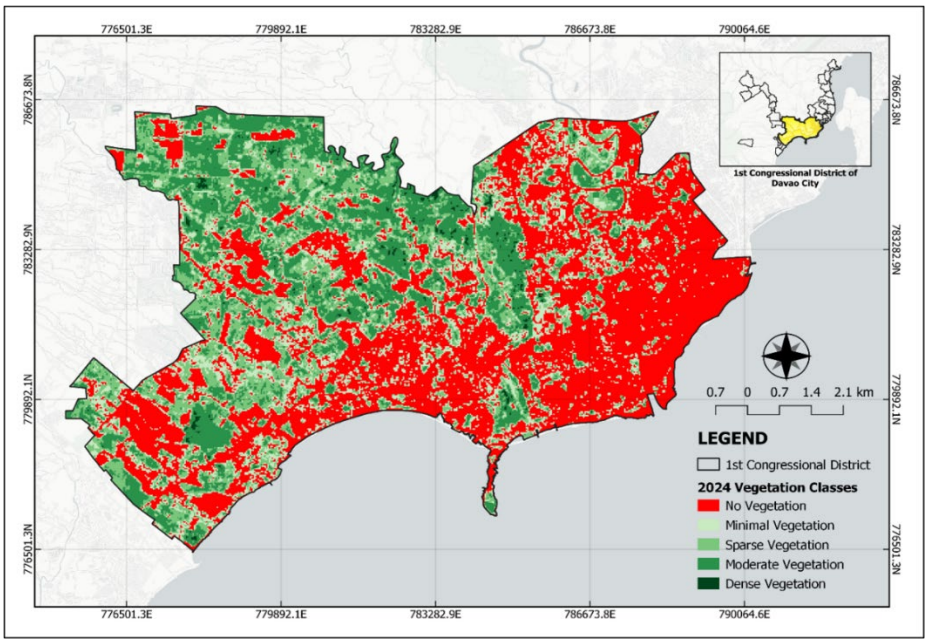


**Figure 24.** Map showing the spatiotemporal change of urban green spaces in Congressional District I in 2024.

**Congressional District II**

Table 4 shows NDVI-based vegetation classifications in District II, highlighting significant green cover changes from 2015 to 2024. In 2015, of the 104.2 km² area, Moderate Vegetation dominated (35.4 km², 33.9%), followed by Minimal (25.4%) and Sparse Vegetation (24.1%), with Dense and No Vegetation comprising 9.8% and 6.7%. A marked trend is the sharp rise in No Vegetation from 7.0 km² in 2015 to 23.7 km² in 2024—a 22.7% increase, reflecting intense urbanization and deforestation (Xiao et al. 2023, Zhao et al. 2022). Dense Vegetation rose slightly by 0.8%. Minimal Vegetation peaked at 38.4 km² in 2016 but dropped to 22.7 km² by 2024, while Moderate Vegetation also declined. These shifts suggest environmental degradation associated with urban expansion and increased impervious surfaces (Chen et al. 2023). Overall, statistics indicate a steady loss of green space in favor of built-up areas.

Figure 25 shows the NDVI-based trend of urban green space in District II from 2015 to 2024. The most evident change is the growth of the No Vegetation zone (red line), which expanded from 7.0 km² in 2015 to 23.7 km² in 2024, nearly tripling. This increase highlights the strong influence of urban development, infrastructure growth, surface paving, and the decline of natural vegetation (Zhao et al. 2022, Xiao et al. 2023). Dense Vegetation (dark green) exhibited fluctuations, beginning at 10.2 km² in 2015, falling to 3.9 km² in 2016, peaking at 17.5 km² in 2018, and decreasing to 11.1 km² in 2024. Such trends suggest progressive deforestation, urban expansion, and limited conservation (Huang et al. 2021). Moderate Vegetation (olive green) peaked prior to 2016, then declined with slight recovery after 2020, ending at 28.3 km² in 2024. Minimal and Sparse Vegetation (light green) followed similar irregular but generally negative trends after 2016. These changes demonstrate an overall decline in vegetation density and a notable increase in non-vegetated land, underscoring the intensification of land conversion in District II.

**Table 4.** Changes in urban green spaces in Congressional District II in the year 2015-2024.

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 7.0 | 6.7 | - | 10.5 | 10.1 | 50.9 | 14.8 | 14.2 | 40.1 | 15.1 | 14.5 | 2.5 | 16.3 | 15.6 | 7.8 |
| Minimal Vegetation | 26.5 | 25.4 | - | 38.4 | 36.9 | 45.1 | 23.9 | 23.0 | -37.7 | 23.8 | 22.9 | -0.5 | 21.6 | 21.6 | -9.5 |
| Sparce Vegetation | 25.2 | 24.1 | - | 24.8 | 23.8 | -1.4 | 19.2 | 18.4 | -22.8 | 20.0 | 19.2 | 4.4 | 19.9 | 19.1 | -0.6 |
| Moderate Vegetation | 35.4 | 33.9 | - | 26.6 | 25.5 | -24.9 | 35.1 | 33.6 | 31.9 | 27.8 | 26.7 | -20.7 | 29.1 | 27.9 | 4.6 |
| Dense Vegetation | 10.2 | 9.8 | - | 3.9 | 3.7 | -62.0 | 11.3 | 10.9 | 191.2 | 17.5 | 16.8 | 54.3 | 17.4 | 16.7 | -0.5 |
| TOTAL | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | |

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | 2021 | | | 2022 | | | 2023 | | | 2024 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 18.3 | 17.5 | 12.1 | 19.0 | 18.2 | 4.0 | 19.9 | 19.1 | 4.4 | 20.7 | 19.9 | 4.2 | 23.7 | 22.7 | 14.3 |
| Minimal Vegetation | 24.1 | 23.1 | 11.6 | 26.5 | 25.4 | 10.2 | 25.7 | 24.7 | -3.0 | 26.2 | 25.1 | 1.8 | 22.7 | 21.8 | -13.4 |
| Sparce Vegetation | 21.0 | 20.2 | 5.9 | 19.3 | 18.5 | -8.5 | 19.0 | 18.3 | -1.1 | 18.5 | 17.8 | -2.7 | 18.5 | 17.7 | -0.4 |
| Moderate Vegetation | 29.1 | 27.9 | 0.0 | 30.0 | 28.8 | 3.1 | 24.8 | 23.8 | -17.4 | 23.0 | 22.0 | -7.3 | 28.3 | 27.1 | 23.1 |
| Dense Vegetation | 11.8 | 11.3 | -32.4 | 9.4 | 9.1 | -19.7 | 14.8 | 14.2 | 56.9 | 15.8 | 15.2 | 6.6 | 11.1 | 10.6 | -29.8 |
| TOTAL | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | | 104.2 | 100 | |

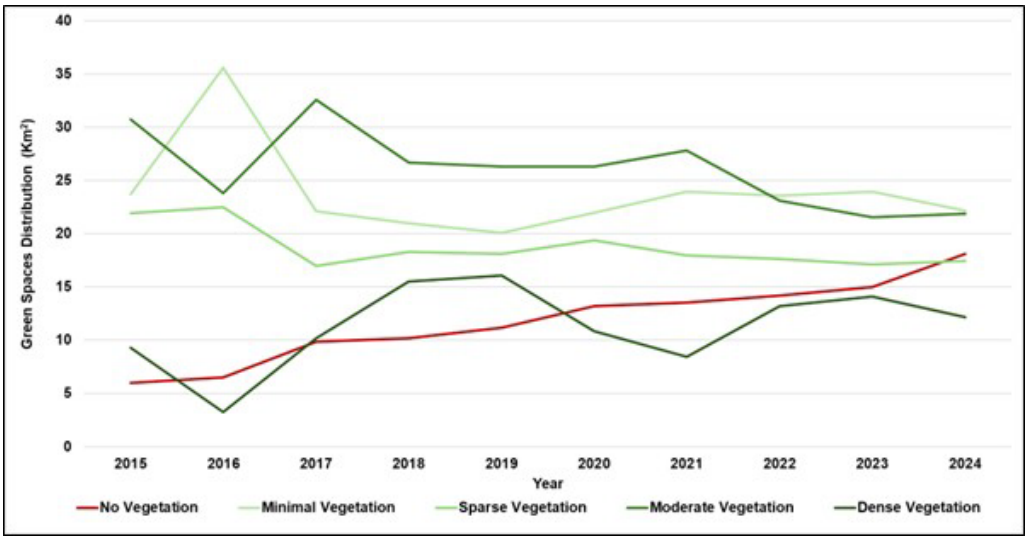


**Figure 25**. Trend graph showing the dynamics of urban green spaces in Congressional District II from 2015 to 2024.

Figures 26 to 30 highlight significant changes in District II's 104.2 km² urban landscape from 2015 to 2024. Green cover declined from 85.6 km² (93.44%) in 2015 to 71.9 km² (78.47%) in 2024, while non-vegetated land expanded by 23.7 km² due to rapid urbanization (Huang et al., 2007). The steepest decline occurred between 2015 and 2020, driven by population growth and land demand (Schiavina et al. 2021). These shifts contributed to urban heat island effects, stressing the need for sustainable planning (Singh et al. 2017). From 2015–2020, built-up areas increased 7.15 km² as green space shrank 8.38%, with new land uses: 53% commercial, 34% housing, and 13% institutional (Doquila 2018, Zharkaia et al. 2018, Fulgar 2023).

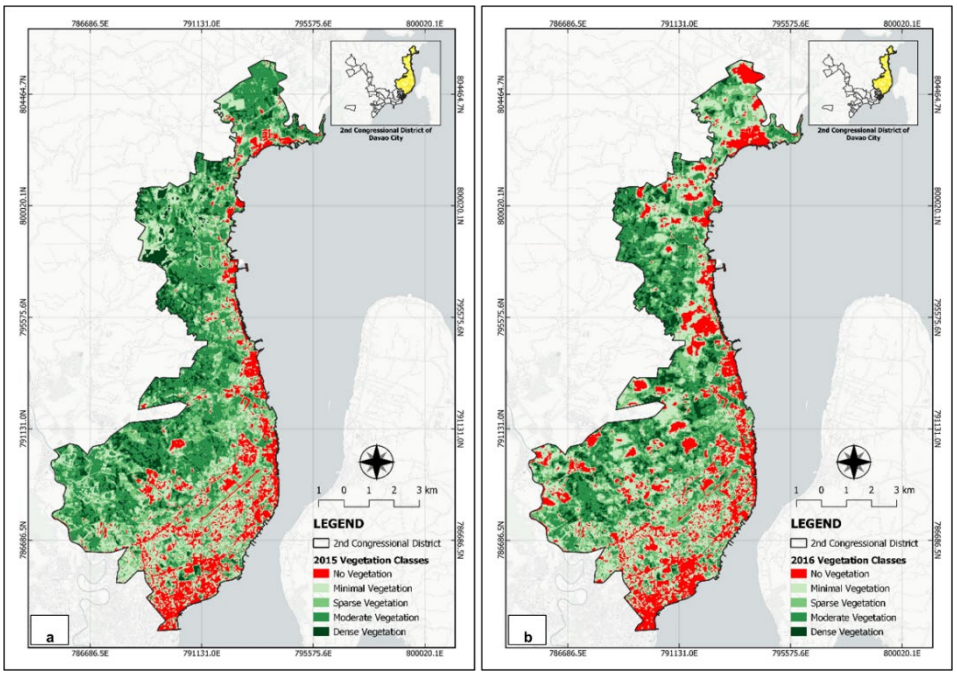


**Figure 26.** Map showing the spatiotemporal change of urban green spaces in Congressional District II in 2015 (a), 2016 (b).

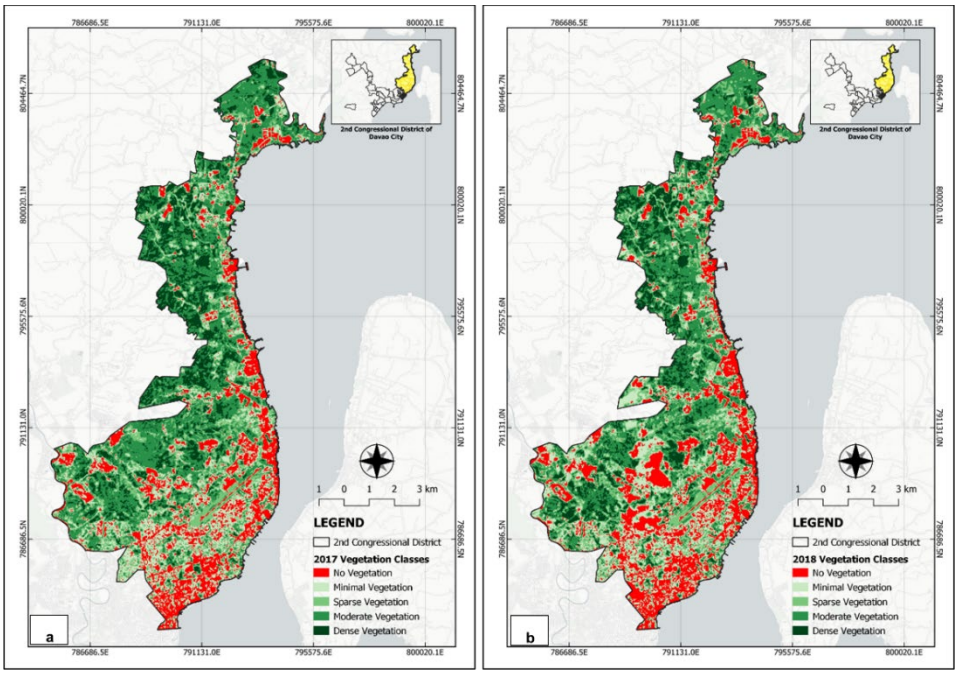


**Figure 27.** Map showing the spatiotemporal change of urban green spaces in Congressional District II in 2017 (a), 2018 (b).

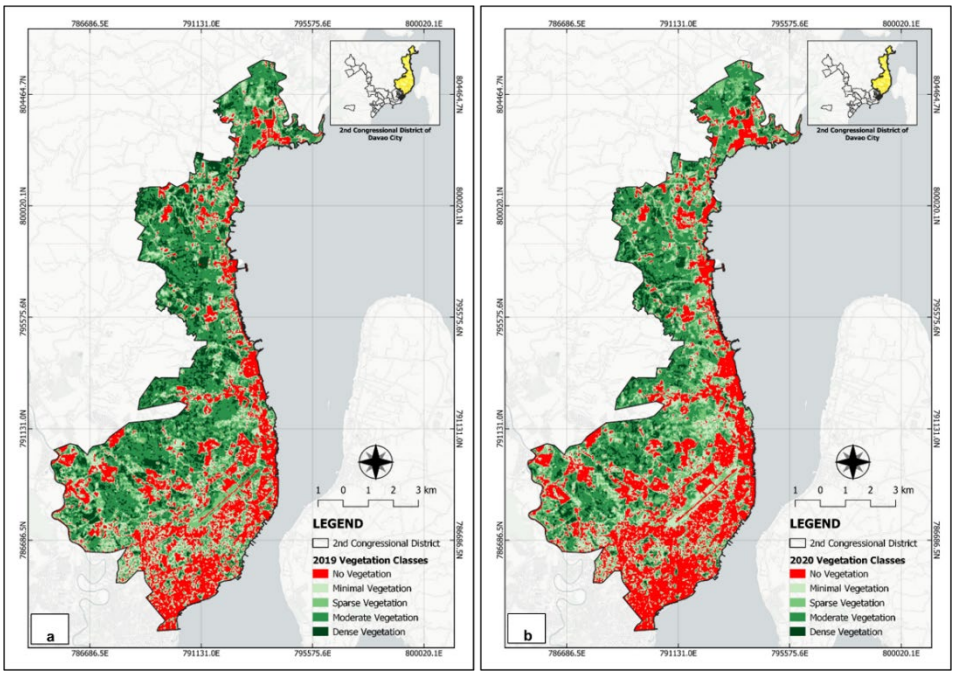


**Figure 28.** Map showing the spatiotemporal change of urban green spaces in Congressional District II in 2019 (a), 2020 (b).

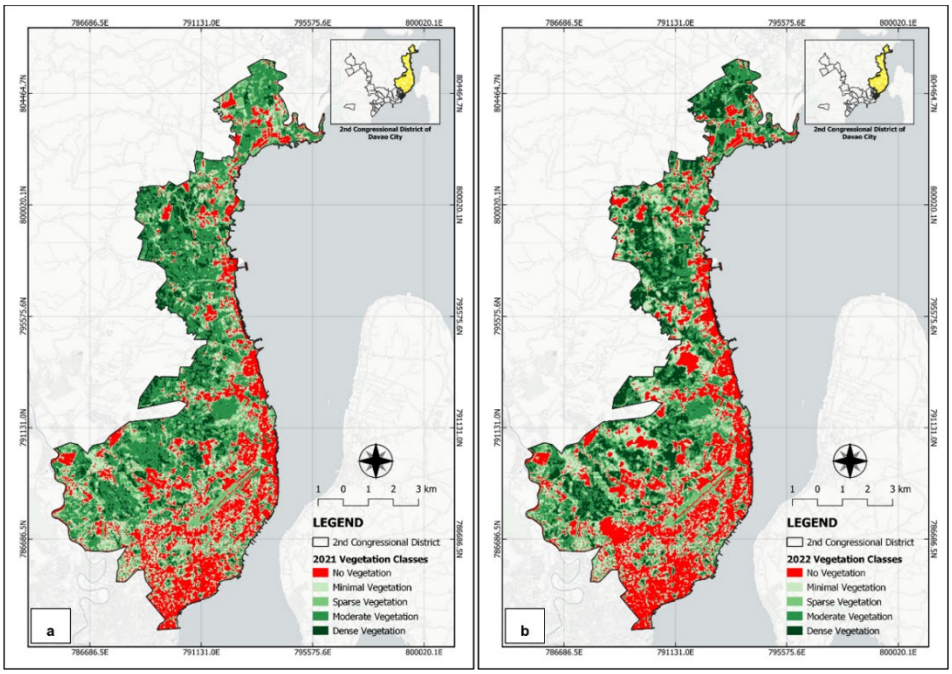


**Figure 29.** Map showing the spatiotemporal change of urban green spaces in Congressional District II in 2021 (a), 2022 (b).

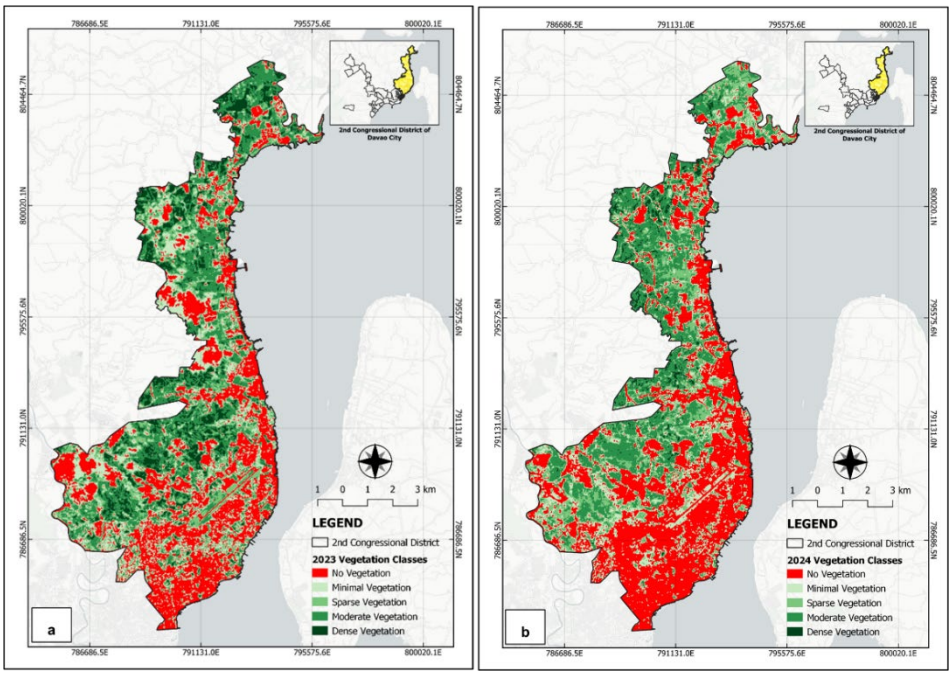


**Figure 30.** Map showing the spatiotemporal change of urban green spaces in Congressional District II in 2023 (a), 2024 (b).

**Congressional District III**

Table 5 shows District III's vegetation cover trends (96.9 km²) between 2015 and 2024 as either No, Minimal, Sparse, Moderate, or Dense Vegetation. The non-vegetated surface of 11.1 km² (11.6%) significantly increased urban development in 2016 to 2017 and 2023 to 2024 (Zhao et al. 2022). Low vegetation was variable, and it decreased in 2017, increased in 2018 to reach 20.5 km², and dropped to 7.1 km² in 2024 (Ahmed et al. 2021). The amount of sparse vegetation reached the maximum level of 30.3 km² (14.3%) in 2016 and has fluctuated substantially in 2017, with the final decrease to 18.7 km (19.3%) in 2024 (Wang & Zhang 2022). Vegetation that was moderately vegetated in the previous year was initially 46.7 km² (42.8%), then increased to 60.0 km² in 2017, and later decreased to 42.9 km² (44.3%) in 2024, depending on the practices of vegetation management (Li & Wu 2023). The area with the most changes was dense vegetation, which frequently changed under the pressure of development and reforestation (Zhou et al. 2023).

The plot in Figure 31 portrays the variation of the urban green space in District III between 2015 and 2024. No Vegetation was in a steady rise as the figures changed from 2.3 km² in 2015 to 13.4 km² in 2024, which further indicates the city's growth. Minimal Vegetation bore erratic variations, declining between 2015 and 2017, increasing in 2018, and falling again until 2024, probably because of adjustments in the land use. Sparse Vegetation peaked in 2016 and 2023 because of the scatterers regarding the land cover changes. The maximum was observed in 2017 when the average level of Moderate Vegetation was 0.44. Although it later varied, it stayed relatively constant over the last few years. Dense Vegetation was very volatile, having significant decreases in 2021 and 2023, a slight increase, and a sharp fall in 2024. Patterns outline urbanization's mixed and dynamic effects on green space distribution.

**Table 5.** Changes in urban green spaces in Congressional District III in the year 2015 to 2024.

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 2.3 | 2.4 | - | 3.9 | 4.0 | 69.3 | 6.5 | 6.7 | 68.1 | 7.2 | 7.5 | 11.1 | 7.5 | 7.7 | 3.9 |
| Minimal Vegetation | 12.4 | 12.8 | - | 8.9 | 9.2 | -28.4 | 3.7 | 3.8 | -58.3 | 20.5 | 21.2 | 451.5 | 2.4 | 2.5 | -88.2 |
| Sparce Vegetation | 17.2 | 17.8 | - | 30.3 | 31.2 | 75.6 | 13.9 | 14.4 | -54.0 | 25.5 | 26.3 | 83.3 | 12.4 | 12.4 | -52.9 |
| Moderate Vegetation | 46.7 | 42.8 | - | 35.4 | 36.6 | -24.2 | 60.0 | 61.9 | 69.3 | 27.2 | 28.1 | -54.7 | 39.6 | 39.6 | 41.1 |
| Dense Vegetation | 18.2 | 18.8 | - | 18.4 | 19.0 | 1.3 | 12.8 | 13.2 | -30.7 | 16.5 | 17.0 | 28.9 | 37.8 | 37.8 | 122.2 |
| TOTAL | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | |

| NDVI CLASSES | YEAR | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | 2021 | | | 2022 | | | 2023 | | | 2024 | | |
| | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) | Area (km²) | % | %(-/+) |
| No Vegetation | 10.5 | 10.8 | 39.5 | 11.1 | 11.5 | 6.6 | 11.0 | 11.3 | -1.6 | 9.9 | 10.2 | -10.2 | 13.4 | 13.8 | 35.8 |
| Minimal Vegetation | 6.9 | 7.1 | 185.5 | 18.0 | 18.5 | 160.6 | 10.2 | 10.6 | -43.0 | 8.9 | 9.2 | -13.3 | 7.1 | 7.3 | -20.4 |
| Sparce Vegetation | 14.1 | 14.6 | 17.7 | 19.1 | 19.7 | 35.0 | 16.8 | 17.4 | -11.9 | 16.8 | 17.3 | -0.3 | 18.7 | 19.3 | 11.4 |
| Moderate Vegetation | 40.3 | 41.6 | 5.0 | 44.4 | 45.8 | 10.1 | 41.5 | 42.9 | -6.4 | 23.8 | 24.6 | -42.6 | 42.9 | 44.3 | 80.0 |
| Dense Vegetation | 25.1 | 25.9 | -31.4 | 4.3 | 4.5 | -82.7 | 17.3 | 17.9 | 299.4 | 37.6 | 38.8 | 116.8 | 14.9 | 15.3 | -60.4 |
| TOTAL | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | | 96.9 | 100 | |

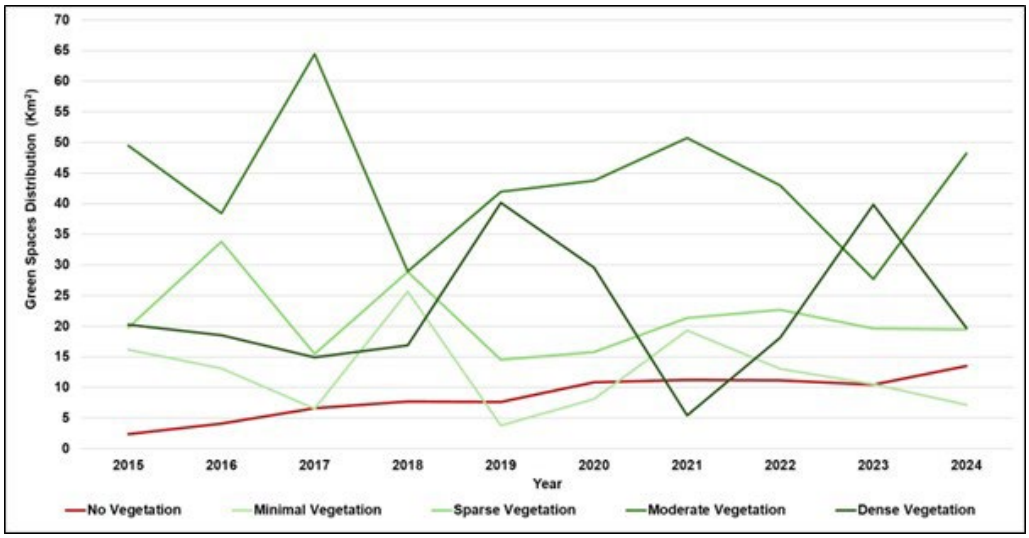


**Figure 31.** Trend graph showing the dynamics of urban green spaces in Congressional District III from 2015 to 2024.

In 2015, as Figure 32 shows, the green spaces took up much of District III, crucial in carbon storage, air purification, and biodiversity (Engemann et al. 2019). These were also the most significant areas that helped eliminate the stress put on the environment in urban areas and improve the health of the masses. However, by 2020, the green cover had reduced to a large extent because of the increased rate of construction. The land area under parks makes up only 0.06% of the total in Davao City, and the open space is 1.26% (Songcayauon 2022), restricting access to the natural surroundings of the inhabitants. This limited exposure may ill-consider mental well-being (Engemann et al. 2019). As the city, in 2020, increased its population

to 1,776,949 (Philippine Statistics Authority 2020), the urban pressure exacerbated, turning into general land conversion and a worsening of the environment (Belhaj 2022, Vanbergen et al. 2020, Muhammad et al. 2022). Green land loss stems from poor pollution and climate control, and sustainable land use is needed to support environmental and human health (Pataki et al. 2011).

In comparison, the trend in 2015 to 2024 analysis of NDVI data of Districts I, II, and III reveals important though contrasting developments relating to the vegetation changes that can be regarded as influential attributes taken into consideration, and which are likely to be influenced by urbanization, population growth, and industrialization. District II, the green spaces located there decreased, while the built-up spaces increased nearly 6.7% to over 22.7%, meaning a loss of vegetation under developed high urbanization and development pressure. On the District III level, vegetation varied with no significant decline in the values of NDVI, suggesting that the trend is likely to be challenged not only due to the population alone but also due to the development of the infrastructure. District XI was the most volatile when it comes to NDVI trends with spurt variations in the vegetation density, which indicated the land use diversion because of the active deforestation, industrial activity, and deforestation. These trends reflect vegetation changes driven by population growth and industrialization, highlighting the need for sustainable, balanced urban development planning.

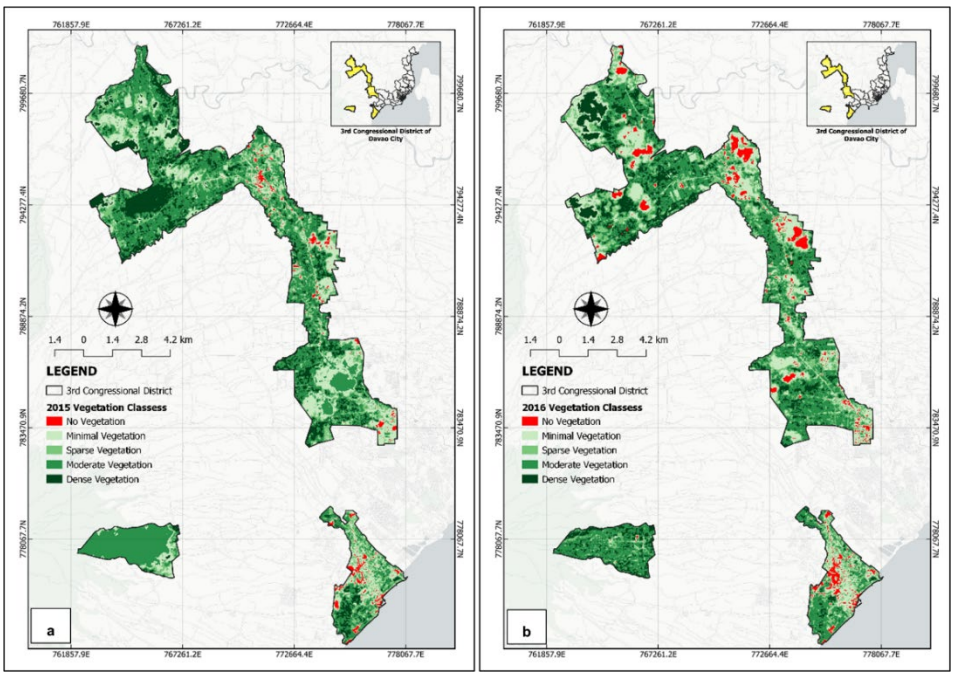


**Figure 32.** Map showing the spatiotemporal change of urban green spaces in Congressional District III in 2015 (a), 2016 (b).

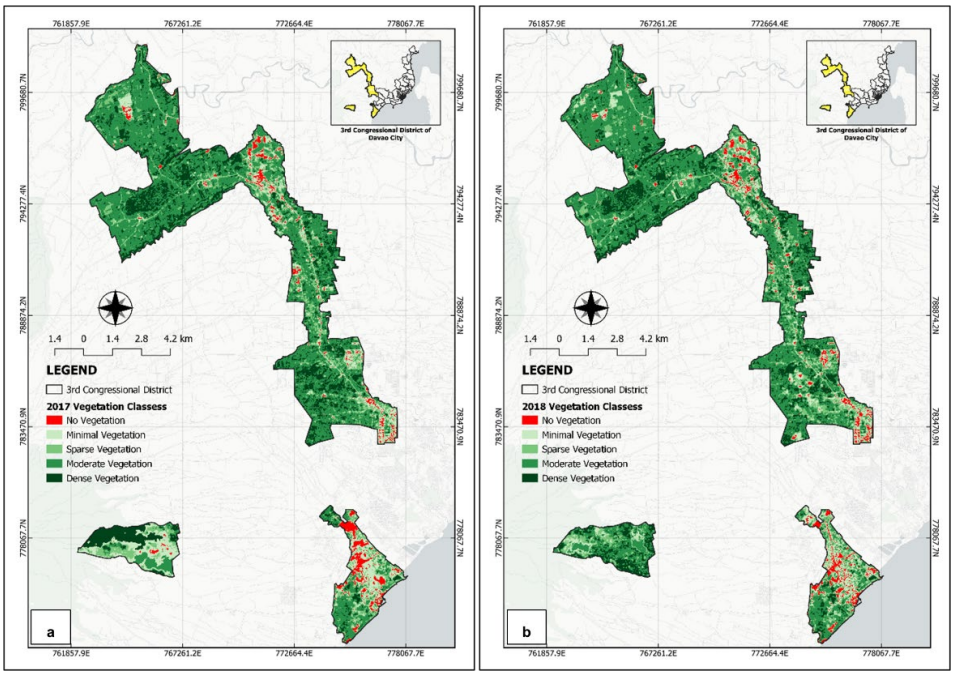


**Figure 33.** Map showing the spatiotemporal change of urban green spaces in Congressional District III in 2017 (a), 2018 (b).

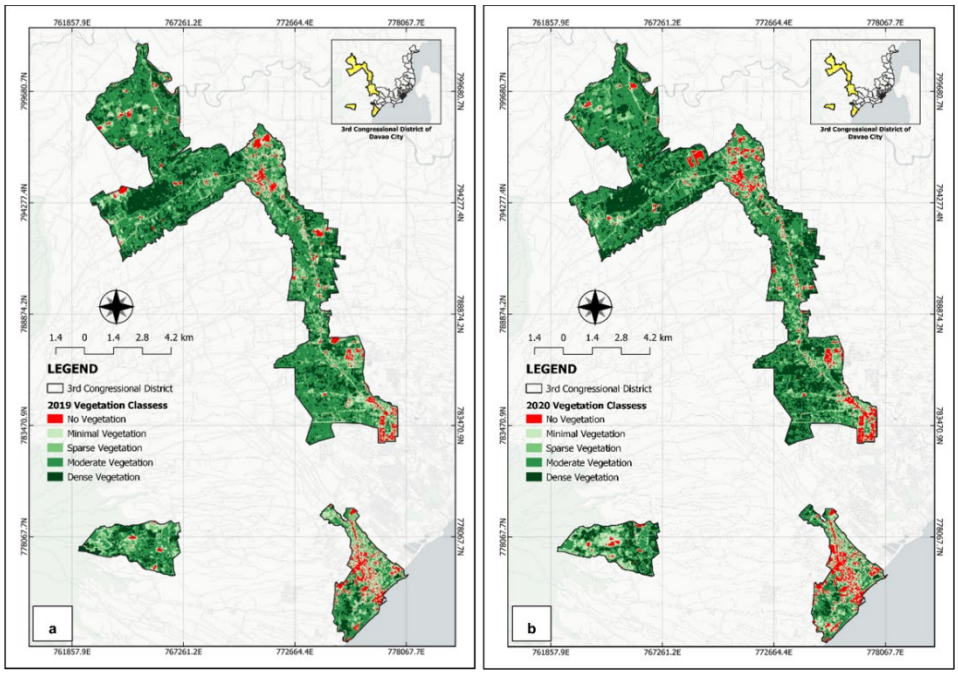


**Figure 34.** Map showing the spatiotemporal change of urban green spaces in Congressional District III in 2019 (a), 2020 (b).

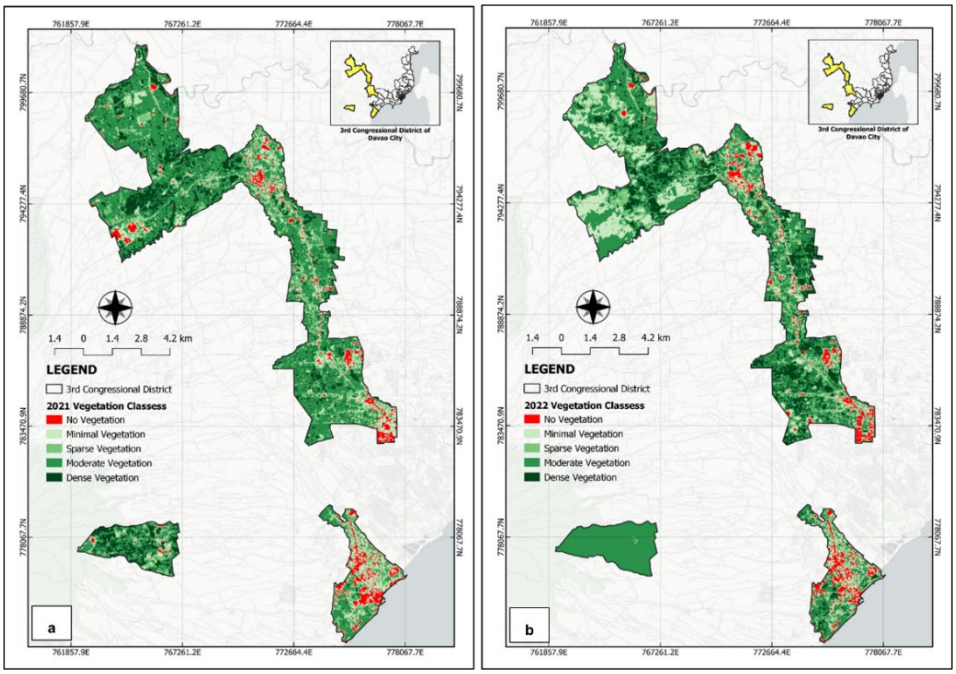


**Figure 35.** Map showing the spatiotemporal change of urban green spaces in Congressional District III in 2021 (a), 2022 (b).

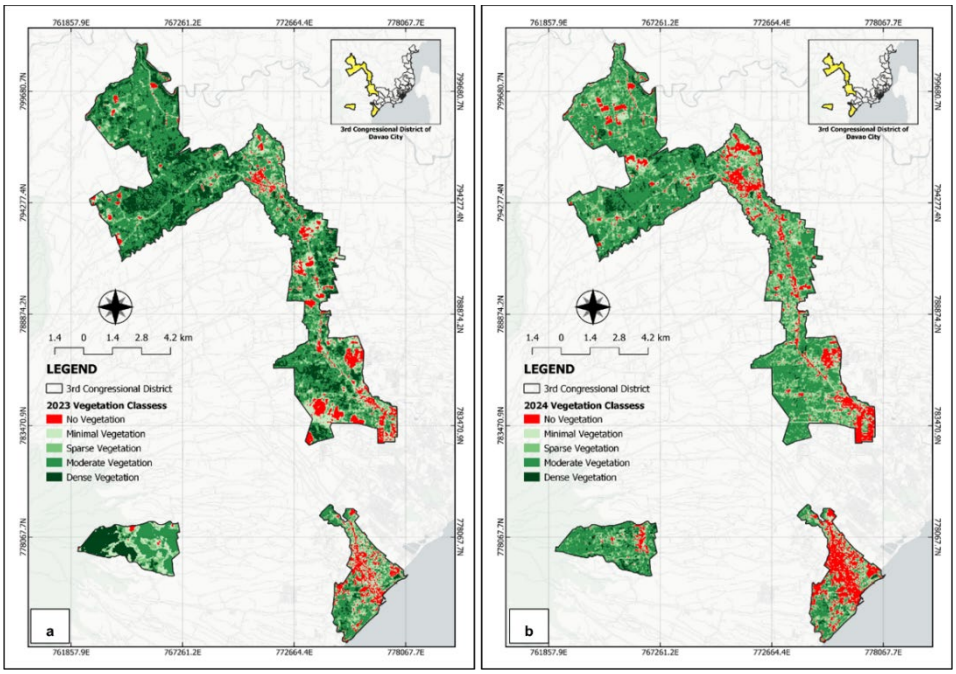


**Figure 36.** Map showing the spatiotemporal change of urban green spaces in Congressional District III in 2023 (a), 2024 (b).

## CONCLUSIONS

Thereupon, this study provides a comprehensive spatiotemporal analysis of urban green spaces in Davao City from 2015 to 2024, revealing a clear trend of vegetation loss and land conversion driven by rapid urbanization and infrastructure development. The use of NDVI and GIS tools allowed for precise quantification and visualization of changes across the city's three congressional districts. The findings demonstrate a consistent increase in non-vegetated areas and a notable decline in dense and moderate vegetation, especially in Districts I and II, underscoring the environmental cost of unchecked urban expansion. District III, while retaining substantial green coverage, displayed unstable patterns, reflecting fluctuating land-use priorities. These shifts not only threaten biodiversity and ecological integrity but also compromise the city's climate resilience and public well-being. The observed patterns of uneven development affirm the theoretical framing of the study and point to the urgent need for integrated and equitable urban planning approaches. Sustained efforts in monitoring, conservation, and inclusive policymaking are essential to safeguarding urban green spaces and ensuring a balanced coexistence between development and environmental sustainability in Davao City.

## RECOMMENDATIONS

Based on the findings from 2015 to 2024, significant changes in vegetation were observed in Davao City's urban barangays, underscoring the need for sustainable urban development. The researchers recommend that the Office of the City Planning and Development Coordinator (OCPDC) conduct long-term monitoring of vegetation to track ongoing changes. They also urge the agency to prioritize green projects and promote urban green spaces to mitigate heat and enhance livability. The Environmental Management Bureau is encouraged to assess how vegetation changes impact ecosystem services and biodiversity to guide conservation efforts. Urban developers should evaluate existing vegetation in barangays to balance growth with environmental preservation. Community participation in greening programs is vital, and successful initiatives from other areas may serve as models. Lastly, the academe and future researchers are advised to conduct interviews or focus group discussions to understand public perceptions and inform the city's plans for green space design and management.

## ACKNOWLEDGEMENTS

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