

Dynamics of Residential Land Use Change and Green Open Space Reduction in Medan Johor District

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Abstract

The decline in green open space (GOS) due to residential expansion is a critical issue in urban planning in Indonesia. This study analyzes the dynamics of residential land use change and GOS decline in Medan Johor District during the period 2015-2025 using a spatial analysis approach based on satellite imagery and the Indonesian Geospatial Information Agency (BIG) topographic maps. The research data were sourced from Sentinel-2A satellite imagery (2015 and 2025), Medan Johor District Statistics, and Medan Johor in Figures. The results show that over a 10-year period (2015-2025), the area of residential land increased from 1,080.35 hectares (63.7%) to 1,207.89 hectares (71.2%), or an increase of 127.54 hectares (11.81%), while green space decreased from 596.08 hectares (35.1%) to 432.15 hectares (25.5%), or a decrease of 163.93 hectares (-27.50%). Population growth of 14.69% (from 130,414 to 149,568 people) was the main driver of residential expansion. The pattern of change shows a significant conversion of green space into residential areas, especially in neighborhoods with high population density. This study concludes that stricter spatial control policies and land use regulations are needed to maintain a sustainable urban environmental balance.

Keywords: Land Use, Residential Areas, Green Open Spaces, Urban Sprawl, Urban Planning, Medan Johor

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Introduction

1.1. Background

Land use change is a dynamic phenomenon that follows the pace of population growth and urban economic development. In an era of intense globalization and urbanization, major cities in Indonesia are experiencing significant growth pressures, including Medan as the third largest city outside Java (Central Statistics Agency, 2025). Medan has a metropolitan population of 4,795,186 with a growth rate of 1.1% per year, forming a strong center of economic growth and migration attraction [1].

Medan Johor District, as one of the districts in Medan City, has experienced relatively rapid population growth. In 2015, the population of Medan Johor was recorded at 130,414 with a population density of 7,690 people/km² [2]. The latest data shows that the estimated population in 2025 will reach 149,568 with a growth of 14.69% in ten years, reflecting an average growth rate of 1.38% per year.

This rapid population growth has led to significant residential expansion. Residential land expansion has resulted in the conversion of undeveloped land, including green open spaces (RTH), into residential areas or other developed land uses. This phenomenon is known as urban sprawl or uncontrolled urban development. According to empirical studies, between 2004 and 2014, cities with similar growth rates experienced a 45% increase in developed land to accommodate population growth, with a projected increase of up to 61% by 2030 if the trend continues unchecked [3].

Green spaces have a strategic function in maintaining the sustainability of the urban environment. According to Law No. 26 of 2007 on Spatial Planning, green spaces must cover at least 30% of urban areas in order to ensure quality of life. However, in reality, many urban areas in Indonesia experience a deficit of green space. The reduction of green space has a direct impact on environmental degradation, including increased surface temperatures, decreased air quality, reduced water infiltration, and decreased biodiversity [4].

There have been few comprehensive studies on the dynamics of land use and green space changes in Medan Johor District using a satellite image-based spatial analysis approach. Therefore, this study was designed to fill this gap through quantitative and spatial analysis of the patterns and extent of residential land and green space changes over a 10-year period (2015-2025).

1.2. Research Questions

Based on this background, the research questions are:

1. What is the magnitude and pattern of residential land area change in Medan Johor District for the period 2015-2025?
2. How did the dynamics of green space reduction due to residential expansion occur during the same period?
3. To what extent does population growth contribute to these land use changes?
4. How is the spatial distribution of land changes in each subdistrict, focusing on density and accessibility indicators?

1.3. Research Objectives

The general objective of this study is to analyze the dynamics of residential land use change and the decline in green open space in the Medan Johor District for the period 2015-2025. The specific objectives are:

1. To identify and measure the extent of changes in residential land area and green open space from 2015 to 2025.

2. Analyzing spatial patterns of land use change based on subdistrict divisions in Medan Johor.
3. Examining the quantitative relationship between population growth and settlement expansion.
4. Presenting spatial visualizations of land changes through maps and graphs to support the interpretation of research results.

1.4. Research Benefits

The results of this research are expected to provide the following benefits:

1. Contributing scientifically to the development of methodologies for analyzing land use change based on spatial analysis and remote sensing, as well as enriching studies on the dynamics of settlements and green open spaces (RTH) in urban areas in Indonesia.
2. To serve as a source of information to support regional and urban planning, particularly in the preparation of the Medan Johor Subdistrict RDTR, as well as a basis for formulating policies on settlement growth control, green space preservation, and the development of urban environmental conservation programs in the city of Medan.

Literature Review

2.1. Changes in Land Use and Urban Settlements

Land use change is a dynamic process that occurs as a result of complex interactions between socio-economic factors and the biophysical conditions of a region [3]. In an urban context, land use change is generally dominated by the conversion of undeveloped land, such as agricultural land, forest areas, and green open spaces (RTH), into developed areas used for residential, commercial, and industrial activities [5]. The process of land conversion is influenced by several main factors:

1. Population growth and migration, namely the increase in urban population, both naturally and as a result of migration from rural to urban areas, which drives the increasing demand for residential land.
2. Economic development, where economic activity and private investment play a role in increasing demand for land for various commercial and industrial functions.
3. Infrastructure provision, such as the development of road networks, clean water, electricity, and other utilities, which facilitates accessibility and accelerates the expansion of settlements to suburban areas.
4. Weak regulations and spatial control, reflected in the ineffective implementation of spatial planning policies, have allowed for unplanned settlement expansion.

Based on case studies in peri-urban areas of major cities in Indonesia, the area of developed land showed an average increase of 45% over a ten-year period, with the potential for an increase of up to 61% if this trend is not controlled [3]. This condition triggers the formation of a scattered and uncompact pattern of urban development, known as the phenomenon of urban sprawl.

2.2. Green Open Space

Green Open Space (GOS) is defined as an area of land that is partially or entirely covered by vegetation, whether natural or planted, which functions as a public open space and plays a role in maintaining the sustainability of the urban environment [6]. In sustainable urban development, the role of GOS can be explained through the following three main functions.

1. The ecological function of green spaces is reflected in their ability to regulate microclimate, absorb carbon dioxide (CO₂) emissions, improve air quality, and serve as

rainwater catchment areas that reduce surface runoff and support the balance of the hydrological system. In addition, green spaces provide habitats for flora and fauna, thereby contributing to the preservation of urban biodiversity.

2. The social function of green spaces is realized through the provision of public spaces for recreational activities and social interaction among the community. Green spaces also serve as a means of environmental education that raises ecological awareness, while improving the visual quality and aesthetics of the urban landscape.
3. The economic function of green open spaces is evident in their impact on increasing property values in surrounding areas, their potential for developing ecotourism and creative economic activities, and their contribution to improving the cost efficiency of urban infrastructure, particularly through natural water management systems.

Normatively, international standards and national policies recommend that at least 30% of the total urban area be designated as green open space [7]. However, most cities in Indonesia still face limitations in providing green open space due to the pressure of residential growth and commercial activities.

2.3. Research Approach to Land Use Change

Studies of land use change can be conducted through various complementary approaches to understand the spatial and temporal dynamics and drivers of change. Approaches commonly used in land use change studies include remote sensing image-based analysis, descriptive statistical analysis, and spatial analysis and cartography.

1. A satellite image-based spatial analysis approach (*remote sensing*) is used to identify and map land use categories through the use of multispectral images. This approach enables the observation of temporal land changes through the comparison of multitemporal images, and is supported by an accuracy validation process using *ground truth* data and field verification to ensure the reliability of the classification results.
2. Statistical and descriptive analysis approaches were used to quantify the magnitude of land use change. This analysis included calculations of the area of each land category, the percentage of change, and the rate of change between time periods. In addition, this approach was also used to examine the relationship between land use change and sociodemographic variables, such as population growth.
3. The spatial analysis and cartography approach focuses on the visualization and interpretation of spatial distribution of land use changes. Mapping is conducted based on the administrative units to identify patterns of change, concentrations of affected areas, and potential *hot spots* of change that indicate regional development pressures.

Research Methodology

3.1. Approach and Type of Research

This study uses a quantitative approach with an emphasis on spatial and descriptive analysis. This approach was chosen to examine the dynamics of land use change, particularly in residential areas and green open spaces, and to analyze the patterns and factors that influence these changes. Based on its objectives, this study falls under the category of descriptive analytical research that focuses on describing existing conditions as well as interpreting the phenomenon of land use change over a certain period of time [10].

Temporally, the analysis was conducted by comparing two time periods, namely 2015 and 2025, using an extended cross-sectional approach over a ten-year period. Spatially, the analysis unit covers the village level and the entire sub-district area. The methods used are a combination of remote sensing through satellite image analysis, spatial analysis based on Geographic

Information Systems (GIS), and descriptive statistical analysis to support the interpretation of research results.

3.2. Research Location and Object

The research location is in Medan Johor District, Medan City, North Sumatra Province, Indonesia. This district has an area of approximately 16.96 km² and consists of six subdistricts, namely Kwala Bekala, Gedung Johor, Kedai Durian, Suka Maju, Titi Kuning, and Pangkalan Masyhur. Geographically, the research area is located at coordinates 3°35'56" N to 3°59'36" N and 98°67'67" E, with relatively flat topography and an altitude ranging from 34 to 49 meters above sea level.

The research focuses on changes in residential land area and green open space as representations of the dynamics of urban development. In addition, this study also considers population growth as a major driver of land use change and analyzes the spatial distribution patterns of these changes at the subdistrict level to identify variations and trends within the study area.

3.3. Data Sources and Data Collection Techniques

The data sources in this study consist of primary and secondary data that are used complementarily to support the analysis of changes in land use and green open space.

1. Primary Data

Primary data was obtained from Sentinel-2A Level-1C satellite imagery recorded in August 2015 and August 2025. This imagery has a spatial resolution of 10 meters on the main multispectral channels (red, green, blue, and near infrared), which is sufficient for land use analysis at the sub-district level. Satellite images were used as the main data in the land use classification process and spatial change analysis. In addition, the 1:25,000 scale Indonesian Topographic Map (RBI) published by the Geospatial Information Agency (BIG) was used as a geometric reference and source of topographic information for the study area.

2. Secondary Data

Secondary data was obtained from various supporting sources to complement the spatial analysis. Demographic statistics were sourced from publications by the Central Statistics Agency (BPS), specifically *Medan Johor Subdistrict in Figures* for 2015 and 2025, which included population size, population distribution per urban village, population density, and population growth rate. In addition, thematic data in the form of the Medan City Detailed Spatial Plan (RDTR), land use policy and regulation documents, as well as academic literature and reports related to regional development were used as supporting materials in interpreting the research results.

3.4. Data Analysis Techniques and Procedures

1. Satellite Image Preprocessing and Classification

The initial stage of analysis was conducted through satellite image *preprocessing* to improve data quality and comparability. This process included atmospheric correction using the *Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes* (FLAASH) algorithm to minimize the influence of the atmosphere on image spectral values. Next, image cropping (*subsetting*) was performed based on the administrative boundaries of Medan Johor Subdistrict using boundary data, so that the analysis area corresponded to the research area. To improve visual sharpness and spatial resolution, *pansharpening* was applied by combining multispectral and panchromatic channels.

Land use classification was performed using the *Maximum Likelihood Classification* (MLC) method, utilizing spectral characteristics and thematic indices. The main index used was the *Normalized Difference Vegetation Index* (NDVI) to identify vegetated areas, calculated using the following equation:

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

In addition to NDVI, the *Normalized Difference Built-up Index* (NDBI) and *Normalized Difference Moisture Index* (NDMI) were also used to support the identification of built-up areas, water bodies, and wetlands. The use of this combination of indices aimed to improve classification accuracy by distinguishing spectral characteristics between land use classes.

2. Validation of Classification Accuracy

The accuracy of land use classification results was validated through the following stages:

1. Ground truth
Verification was conducted using *ground truth* data with 100 randomly stratified *sampling* points to represent each land use class.
2. Confusion matrix
The accuracy rate was evaluated using an error matrix (*confusion matrix*) to calculate *the overall accuracy, producer's accuracy, user's accuracy*, and Kappa index.
3. Acceptance standards
The classification results are considered acceptable if the overall accuracy reaches a minimum of 85%, in accordance with general standards in land use change research.

3. Temporal Land Change Analysis

Temporal land use change analysis is conducted through the following stages:

1. Change detection
Land use changes are analyzed by comparing the results of image classification in 2015 and 2025 using *overlay* or *cross-tabulation* techniques to identify the direction and magnitude of changes between land categories.
2. Calculation of area and change
Quantitative analysis was performed by calculating the area of each land use category in each observation year, which was then used to determine the absolute change, percentage change, and annual rate of change during the 2015–2025 period.
3. Spatial analysis per subdistrict
To examine the spatial variation of land change, the classification results were overlaid with village administrative boundaries. Next, zonal statistical calculations were performed to obtain the magnitude of land use change in each village.

4. Analysis of the Relationship between Population Growth and Land Change

The analysis of the relationship between population growth and land use change was conducted using the following approaches:

1. Descriptive analysis
Population growth data for 2015–2025 was presented descriptively at the village level, then compared with historical data for 2015 sourced from the Central Statistics Agency (BPS).
2. Spatial correlation analysis
The relationship between population growth rates and the rate of change in residential land was analyzed using Pearson's correlation to measure the direction and strength of the relationship between variables at the subdistrict level.
3. Analytical table

The results of the correlation analysis are presented in a *cross-tabulation* table to show the relationship between population density categories and the intensity of land use change.

Results

4.1. Satellite Image Classification and Accuracy Validation Results

The Sentinel-2A image classification process produced thematic land use maps for 2015 and 2025. The validation results showed:

1. Overall Accuracy for 2015: 88.3%
2. Overall Accuracy for 2025: 87.6%
3. Kappa Index for 2015: 0.847
4. Kappa Index for 2025: 0.838

These results show a good and acceptable level of accuracy for land cover change analysis. Producer and user accuracy for the settlement category ranges from 86 to 91%, while for green space it ranges from 84 to 89%, indicating reliable classification for both main categories.

4.2. Quantitative Changes in Residential and Green Space Area (2015-2025)

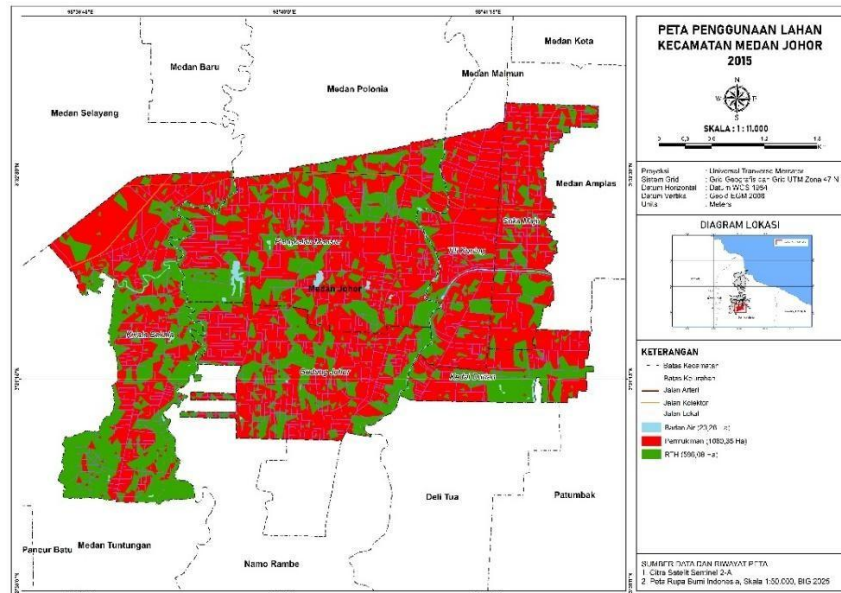


Figure 1. Land Use Map of Medan Johor District 2015

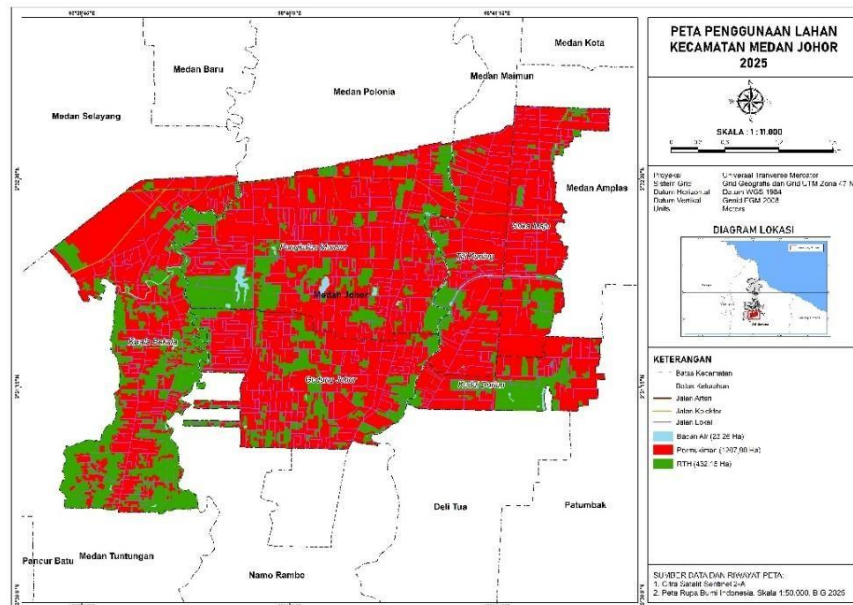


Figure 2. Land Use Map of Medan Johor District 2025

1. Changes in Residential Land

Quantitative analysis shows significant changes in residential land:

Table 1. Changes in Residential Land Area, Percentage, and Density from 2015 to 2025

No.	Aspect	Year 2015	Year 2025	Change (Ha)	Change (%)
1	Residential Area	1,080.35	1,207.89	+127.54	+11.81
2	Percentage of Area	63.7%	71.2%	+7.5	-
3	Population Density	6,371 people/ha	7,117 people/ha	+746 people/ha	+11.71%

The increase in residential land of 127.54 hectares over ten years reflects an average residential expansion rate of 12.75 hectares per year. When compared to the population growth rate of 1.38% per year, residential growth (1.12% per year) shows that land expansion is relatively in line with demographic growth.

2. Depletion of Green Open Space (GOS)

Green open space has experienced significant decline:

Table 2. Changes in Area, Percentage, and Green Open Space (RTH) Requirements for 2015–2025

No.	Aspect	Year 2015	Year 2025	Change (Ha)	Change (%)
1	Green Space Area	596.08	432.15	-163.93	-27.50
2	Percentage of Area	35.1%	25.5	-9.6	-
3	Space requirement per capita	4.57 m ² /person	2.89 m ² /person	-1.68 m ² /person	-36.76

The reduction of green open space (RTH) covering an area of 163.93 hectares or 27.50% is a cause for concern. This decline occurred at an average rate of 16.39 hectares per year, which is relatively faster than the rate of growth of residential areas. As a result, the availability of GOA per capita has decreased from 4.57 m²/person in 2015 to 2.89 m²/person in 2025, falling below the Indonesian National Standard (SNI) requirement of a minimum of 3.0 m²/person for public GOA or approximately 30% of the urban area.

3. Other Land Categories

Land in other categories (water bodies, vacant land, non-residential built-up areas) has undergone changes:

Table 3. Changes in Area and Percentage of Other Land Categories from 2015 to 2025

No.	Aspect	Year 2015	Year 2025	Change (Ha)	Change (%)
1	Green Space Area	596.08	432.15	-163.93	-27.50
2	Percentage of Area	35.1%	25.5	-9.6	-

The increase in other land categories is largely due to infrastructure development (roads, public facilities) and built-up service areas that are not residential settlements.

4.3. Spatial Distribution of Land Use Change by Subdistrict

1. Analysis by Subdistrict

Land changes are not evenly distributed across the region. Analysis by subdistrict shows the following patterns:

Table 4. Patterns of Land Use Change and Conversion by Subdistrict, 2015–2025

No.	Aspect	Population in 2015	Population 2025	Growth (%)	Settlements (%)	Change in Settlement Area (Ha)
1	Kwala Bekala	34,210	39,235	+14.69	287.3	+28.4
2	Gedung Johor	24,221	27,778	+14.69	206.8	+19.2
3	Kedai Durian	6,989	8,015	+14.69	52.1	+4.8
4	Suka Maju	10,160	11,652	+14.69	76.2	+7.1
5	Titi Kuning	22,017	25,251	+14.69	165.4	+15.4
6	Pangkalan Masyhur	32,817	37,637	+14.69	237.1	+22.1
	Total	130,414	149,568	+14.69	1,207.89	+127.64

Kwala Bekala and Pangkalan Masyhur subdistricts showed the highest absolute values of settlement change, reflecting their larger population bases and land areas. However, analysis of the intensity of change (change per unit of initial area) revealed a different pattern.

2. Pattern of Conversion of Green Open Space to Settlement

Through overlay and change detection analysis, it was identified that the conversion of land from green space to residential areas was the main source of residential expansion. Based on cross-tabulation:

Table 5. Changes in Area and Percentage of Other Land Categories from 2015 to 2025

No.	Land Transition 2015-2025	Area (Ha)	Percentage
1	Green Space -> Residential	128.7	82.1
2	Other Land -> Residential Areas	37.4	17.9
	Total Settlement Change	+163.1	100

This phenomenon shows that settlement expansion predominantly occurs through the conversion of green spaces (city parks, private green spaces, home gardens) into residential buildings. These findings indicate that degraded green spaces are private and semi-public green spaces at the neighborhood level, rather than structured public green spaces.

4.4. Correlation between Population Growth and Residential Land Change

Correlation analysis between population growth and residential land change at the subdistrict level shows that although all subdistricts experienced the same population growth rate of 14.69%, the intensity of residential land change varied. This difference was influenced by the initial population density and available land.

Table 6. Correlation between Initial Population Density and Intensity of Residential Land Change per Subdistrict

No.	Subdistrict	2015 Density	Change Intensity	Characteristics (people/Ha)	(ha/100 population growth)
1	Titi Kuning	12,164	1.51	Dense.	Intensification
2	Gedung Johor	7,689	1.45	Moderately dense	
3	Kedai Durian	6,220	1.46	Moderate	
4	Suka Maju	6,684	1.47	Moderate	
5	Titi Kuning	8,204	1.44	Moderate-dense	
6	Pangkalan Masyhur	6,132	1.46	Moderate	

The negative correlation coefficient ($r = -0.34$) between initial density and land change intensity indicates that subdistricts with high density tend to experience intensification of land use through increased building density, while subdistricts with medium density experience more extensive residential land expansion.

4.5. Contribution of Land Change Factors

Based on a comprehensive analysis, land use change in Medan Johor District is influenced by several main factors with varying contributions.

1. Population Growth and Housing Needs (Dominant Contribution $\pm 60\%$)

Population growth of 14.69% has increased the need for new housing. Assuming a settlement density of 11.71 people/ha in 2025, the additional land requirement is estimated to reach 1,636 ha. However, the actual increase in residential land was only 127.54 ha, indicating that the demand for housing was mostly met through non-extensive mechanisms, such as intensification of building density, development of vertical buildings, and an increase in the number of occupants per housing unit.

2. Spatial Policies and Regulations (Contribution $\pm 20\%$)

The implementation of the 2015–2035 Detailed Spatial Plan (RDTR) for the city of Medan, which emphasizes controlling development in conservation areas and public green spaces, limits the expansion of residential land. However, weak supervision of private and semipublic green spaces still opens up opportunities for land conversion.

3. Accessibility and Infrastructure (Contribution $\pm 15\%$)

Improved accessibility through the construction and upgrading of road networks, particularly secondary and tertiary roads, encourages residential development in previously inaccessible locations.

4. Land Market Dynamics and Private Investment (Contribution $\pm 5\%$)

Land price fluctuations and increased private investment interest also contribute to land conversion, especially in areas of strategic value.

4.6. Environmental Sustainability Implications

The 27.50% reduction in green open space (RTH) over a ten-year period has significant implications for environmental sustainability in the Medan Johor District.

1. Decreased Environmental Capacity

The reduction in GOS area decreases rainwater infiltration capacity, thereby increasing the potential for urban flooding and burdening the drainage system. In addition, the decline in vegetation cover contributes to increased surface temperatures and reinforces the urban heat island phenomenon. In terms of air quality, the reduction in GOS decreases the environment's ability to absorb pollutants and reduces oxygen production.

2. Decline in Ecosystem Services

The reduction of green space causes habitat fragmentation, which impacts the decline of ecological connectivity and urban biodiversity. This condition also triggers landscape degradation, characterized by the dominance of built elements that reduce the aesthetic value and visual quality of the area.

4.7. Decline in Green Space Service Levels for Residents

Along with the increase in population and the reduction in green space area, the availability of green space per capita has decreased from 4.57 m²/person to 2.89 m²/person. This value is below the minimum standard of 30% of the city area or equivalent to 3.0 m²/person, indicating a decline in the level of green space services to meet the needs of the population.

Conclusion

This study analyzes the dynamics of residential land use change and the reduction of green open space (GOS) in Medan Johor District during the period 2015–2025 using satellite image-based spatial analysis and descriptive statistics. The results of the study can be summarized as follows.

1. Residential land showed a significant increase with an additional area of 127.54 hectares or 11.81%, from 1,080.35 hectares (63.7%) to 1,207.89 hectares (71.2%) in ten years. This growth occurred at an average rate of 12.75 hectares per year and was relatively in line with population growth of 14.69%.
2. Green open spaces have experienced a significant reduction of 163.93 hectares or 27.50%, from 596.08 hectares (35.1%) to 432.15 hectares (25.5%). This condition has had a direct impact on the decline in the availability of green open space per capita from 4.57 m²/person to 2.89 m²/person.
3. The land conversion pattern shows that the conversion of green space into residential areas is the main source of land use change, contributing 82.1% of the total increase in residential land. This conversion mainly occurred in private and semi-public green spaces.
4. Differences in spatial characteristics between subdistricts influence the form of land change. Subdistricts with high initial density, such as Titi Kuning, tend to experience

intensification of land use, while subdistricts with moderate density are more dominant in experiencing extensive residential land expansion.

5. The relatively rapid decline in green space has serious implications for environmental sustainability in the Medan Johor District, as reflected in reduced water infiltration capacity, increased *urban heat island* phenomena, and decreased air quality.

Based on research findings related to the dynamics of residential land use change and the reduction of green open space in Medan Johor District, the recommended policy recommendations to support spatial use control and environmental sustainability include the following aspects.

1. Strengthening private green space regulations needs to be done through the implementation of stricter regulations regarding the obligation to provide a minimum amount of green space in every residential and commercial property development.
2. Green space planting and rehabilitation programs need to be improved through tree planting initiatives and the revitalization of public green spaces in order to increase the availability of green space per capita to meet minimum standards.
3. Controlling settlement expansion through RDTR is important by establishing zones that are restricted or prohibited for settlement development, especially in areas that have strategic ecological functions.
4. The promotion of vertical space intensification can be directed through the facilitation of multi-story residential building development in suitable locations, as an alternative to horizontal expansion that has the potential to convert green spaces.
5. Strengthening of the monitoring and evaluation system needs to be carried out through the development of an integrated *remote sensing*-based land change monitoring system to support periodic adaptation of spatial planning policies.

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