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Assessing residential land cover dynamics in Medan Deli Sub-district, Medan City from 2014 to 2024 using GIS technology

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ABSTRACT

Urban growth in Medan Deli Sub-district has intensified demand for settlement land and increased pressure on remaining non-built-up land. This study quantified settlement land cover dynamics in 2014, 2019, and 2024 using Landsat 8 Collection 2 surface reflectance imagery processed in Google Earth Engine and GIS-based post-classification comparison. Seven land cover classes were interpreted: water body, mixed garden, open land, mangrove, settlement, shrubs, and pond. The settlement class remained dominant in all observation years and increased from 1,443.67 ha (74.27%) in 2014 to 1,446.04 ha (74.39%) in 2019 and 1,505.77 ha (77.46%) in 2024. The net settlement expansion during 2014-2024 was 62.10 ha, with the largest gross conversions to settlement originating from open land (114.43 ha), mixed garden (46.65 ha), shrubs (16.96 ha), mangrove (4.29 ha), pond (1.52 ha), and water body (1.17 ha). The change matrix also shows that 122.93 ha of land classified as settlement in 2014 shifted to other classes by 2024, indicating heterogeneous urban land-cover dynamics rather than one-directional expansion alone. These results highlight the need to limit settlement growth, protect green and water-sensitive areas, and incorporate remote-sensing-based monitoring into urban spatial planning in coastal Medan.
Keyword: GIS, Landsat 8, Land Cover Change, Medan Deli, Remote Sensing, Settlement

1. Introduction

While land use describes how people use and manage such surfaces, land cover documents the materials found on Earth's surface. Both ideas are closely related in urban and peri-urban settings, as satellite imagery typically shows settlement growth as an increase in built-up areas and a decrease in vegetation, open land, or water-sensitive areas. Because unchecked conversion can affect hydrological processes, decrease green open space, and exacerbate the effects of urban heat islands, identifying these changes is crucial for urban planning [1,2].

Geographic information systems (GIS) and remote sensing provide a useful foundation for tracking land-cover trends over multiple observation years. Because Landsat imagery offers a long, reliable archive for medium-resolution monitoring, it is especially helpful for this purpose. After cloud masking and pre-processing, Landsat Collection 2 surface reflectance data can also be used for land-cover classification, and Google Earth

Engine (GEE) allows for repeatable image filtering, compositing, and imagery extraction for specific years [3,4]. Recent research on land-use change and spatial environmental assessment, including works published in the Global Forest Journal [5]-[7], has used similar methodologies.

Land use in Medan Deli Sub-district in the northern part of Medan City is characterized by land use related to the coast, transportation, industry, and habitation. According to the official publication Kecamatan Medan Deli Dalam Angka 2024, in December 2023, Medan Deli had a population of 196,523 inhabitants with a population density of 10,226 persons/km2 [8]. This revised figure is used in this publication to avoid overestimating population density. In particular, areas with open space, mixed gardens, mangroves, ponds, and shrublands are under pressure from high population density and land-use pressures.

As the mapped class includes more than just individual houses, the term "settlement" is used in this study rather than "residential". The classification results include built-up surfaces associated with residential neighborhoods and supporting urban buildings that are spectrally perceived as settlement/built-up land. This language reduces uncertainty in interpreting maps and change matrices and is more consistent with land-use and land-cover studies.

The process of urbanization and population growth in Medan City and other cities in Indonesia has the potential to alter land cover composition and put pressure on the environment's carrying capacity [9,10]. A specific assessment of settlement land-cover dynamics in Medan Deli over 10 years is still needed to demonstrate overall changes in the area and the transition paths from non-settlement classes to settlement. Thus, the objectives of this study are to: (1) measure the land-cover composition in Medan Deli Sub-district in 2014, 2019, and 2024; (2) determine the extent and direction of settlement land-cover change in 2014–2019, 2014–2024, and 2019–2024; and (3) talk about the consequences of settlement expansion for sustainable spatial planning in coastal urban areas.

2. Method

2.1. Time and Location

The research activities were carried out from November 2024 to April 2025 in Medan Deli Sub-district, Medan City, North Sumatra, Indonesia. The study area covers the administrative boundary of Medan Deli Sub-district. The image analysis used Landsat 8 imagery for the target years 2014, 2019, and 2024. The 2024 map was derived from imagery available in the 2024 Landsat archive; therefore, the analysis period refers to the target image year, while the writing and laboratory activities continued into 2025. Data analysis was conducted at the Forest Management Laboratory, Campus II, Kwala Bekala, Forestry Study Program, Faculty of Forestry, Universitas Sumatera Utara.

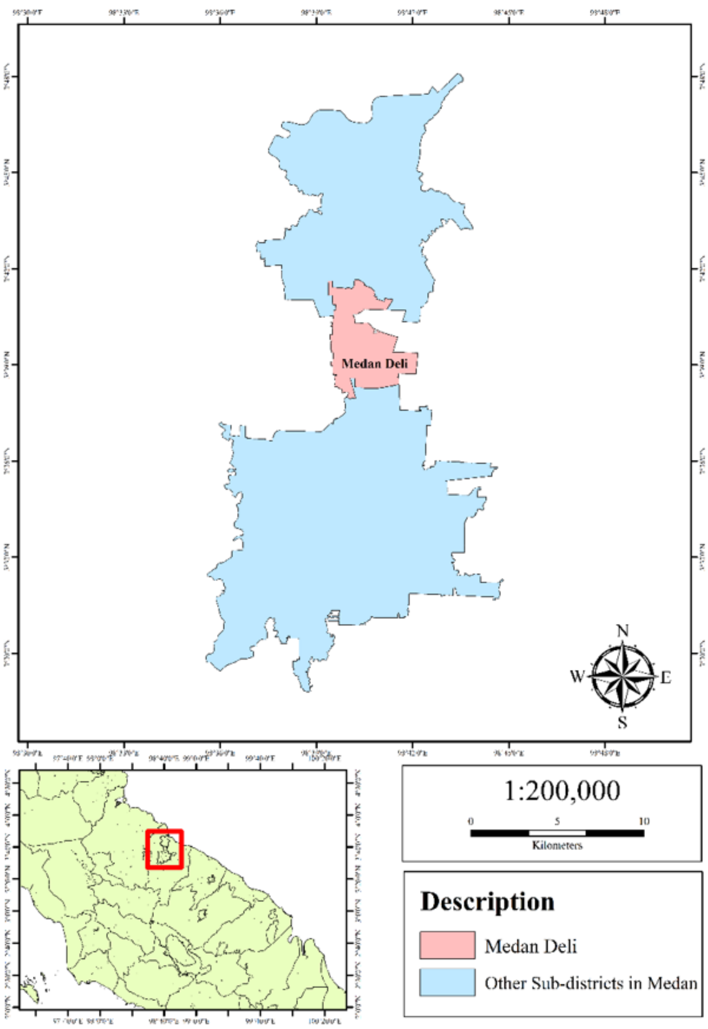

Figure 1. Research Map Location

2.2. Tools and Materials

Tools used in this study included a laptop, ArcGIS 10.8, Avenza Maps, Microsoft Word, Microsoft Excel, Google Earth Pro, and Google Earth Engine. Primary and secondary data are presented in Table 1.

Table 1. Materials and data sources used in the study.

No.	Data	Data type	Source/description
1	Ground-check points	Primary	Field observation using Avenza Maps/GPS and visual interpretation records
2	Administrative boundary of Medan Deli and Medan City	Secondary	Badan Informasi Geospasial and official administrative boundary data
3	Topographic/base map of Medan City	Secondary	Badan Informasi Geospasial
4	Landsat 8 OLI/TIRS Collection 2 Level 2 Surface Reflectance, 2014	Secondary	GEE collection LANDSAT/LC08/C02/T1_L2; filtered for 2014
5	Landsat 8 OLI/TIRS Collection 2 Level 2 Surface Reflectance, 2019	Secondary	GEE collection LANDSAT/LC08/C02/T1_L2; filtered for 2019
6	Landsat 8 OLI/TIRS Collection 2 Level 2 Surface Reflectance, 2024	Secondary	GEE collection LANDSAT/LC08/C02/T1_L2; filtered for 2024
7	Population and supporting statistical data	Secondary	BPS Kota Medan, Kecamatan Medan Deli Dalam Angka 2024

2.3. Image Selection and Pre-processing

Google Earth Engine was used to select Landsat 8 Collection 2 Level 2 surface reflectance images for 2014, 2019, and 2024. Images that crossed the Medan Deli boundary for each target year were filtered, scaled to surface reflectance values, cropped to the study boundary, and masked for clouds and cloud shadows using the QA_PIXEL band. The goal of using a standardized sensor and pre-processing procedure was to improve three-year comparability.

The precise scene ID, acquisition date, month, year, and time should be exported from the GEE metadata and added to the data table prior to resubmission if the final submission employs single-date scenes rather than yearly cloud-free composites. The reviewer requested a thorough photographic record, so this step is required.

2.4. Land-cover Classification

Water bodies, mixed gardens, open land, mangroves, settlements, shrubs, and ponds were the seven land-cover types identified. Field observation locations, high-resolution visual interpretation in Google Earth Pro, and the spectral look of each class in Landsat imagery were combined to create training regions. The Maximum Likelihood technique, which allocates pixels to the class with the highest probability based on the statistical distribution of the training data, was then used for supervised classification [11].

The settlement class encompasses not only individual residential buildings it also built-up and settlement-related surfaces. Title, abstract, map captions, tables, results, and conclusion all use this term consistently.

2.5. Accuracy Assessment

Classification accuracy was assessed using a confusion matrix derived from validation points independent of the training interpretation. The main metrics were user accuracy, producer accuracy, overall accuracy, and Kappa accuracy. The following formulas were updated and written consistently:

$$\text{User Accuracy (UA\_i)} = (\text{x\_ii} / \text{x\_i+}) \text{ x } 100 \tag{1}$$

$$\text{Producer Accuracy (PA\_i)} = (\text{x\_ii} / \text{x\_} + \text{i}) \text{ x } 100 \tag{2}$$

$$\text{Total Accuracy (OA)} = (\text{sum x\_ii} / \text{N}) \text{ x } 100 \tag{3}$$

Kappa = [(N sum x_ii) – sum (x_i+ x_x_+i)] / [N^2 - sum(x_i+ x_x_+i)] x 100, where N is the total number of validation samples, x_ii is the diagonal element of the confusion matrix, x_i+ is the row total, and x_+i is the column total. To prevent confusion, the spelling, correctness, and notation were standardized.

2.6. Change Detection Analysis

Settlement change was analyzed using a post-classification comparison approach. The classified maps for 2014, 2019, and 2024 were overlaid in GIS to generate cross-tabulation matrices. From these matrices, two types of change were calculated: gross conversion into settlement from each non-settlement class, and conversion from settlement into other classes. The net settlement change was calculated as the difference between the final and initial settlement areas for each period.

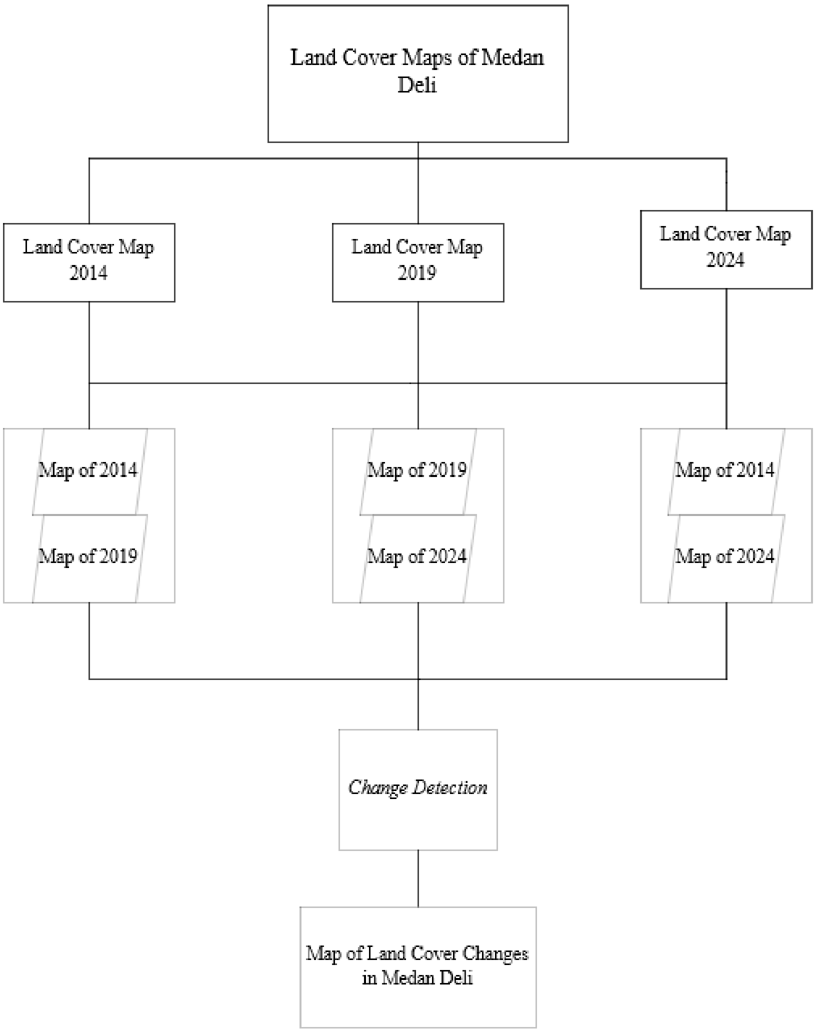

Figure 2: Input-process-output flowchart for identifying changes in settlement and classifying land cover.

3. Results and Discussion

3.1. Land-cover Composition in Medan Deli Sub-district

According to the classification results, Medan Deli's predominant land-cover class across all observation years was settlement. 1,443.67 acres, or 74.27%, of the research area was inhabited in 2014. In 2019, this percentage rose marginally to 1,446.04 ha (74.39%), and in 2024, it reached 1,505.77 ha (77.46%). Although the rate of change varied over time, the growth shows that settlement-related surfaces continued to expand.

Table 2. Land cover area in Medan Deli Sub-district in 2014, 2019, and 2024

Land Cover Class	2014		2019		2024	
	Area (Ha)	Area (%)	Area (Ha)	Area (%)	Area (Ha)	Area (%)
Water Body	1.80	0.09	1.17	0.06	6.47	0.33
Mixed Garden	148.53	7.64	163.41	8.41	71.21	3.66
Open Land	257.17	13.23	71.27	3.67	50.59	2.60
Mangrove	12.45	0.64	8.79	0.45	3.24	0.17
Settlement	1,443.67	74.27	1,446.04	74.39	1,505.77	77.46
Shrubs	74.64	3.84	236.87	12.19	292.69	15.06
Pond	5.67	0.29	16.38	0.84	13.95	0.72
Total	1,943.93	100	1,943.93	100	1,943.93	100

The most notable change was the loss of open land from 257.17 ha in 2014 to 50.59 ha in 2024, and the decline of mixed garden from 148.53 ha to 71.21 ha, along with the rise of settlement. The mangrove area also shrank from 12.45 ha to 3.24 ha. In contrast, the bushes grew from 74.64 ha to 292.69 ha. According to this pattern, the land-cover change of Medan Deli encompasses more than just the straightforward shift from vegetation to settlement; it also includes transient or transitory land conditions, including newly cleared regions, unmanaged unoccupied land,

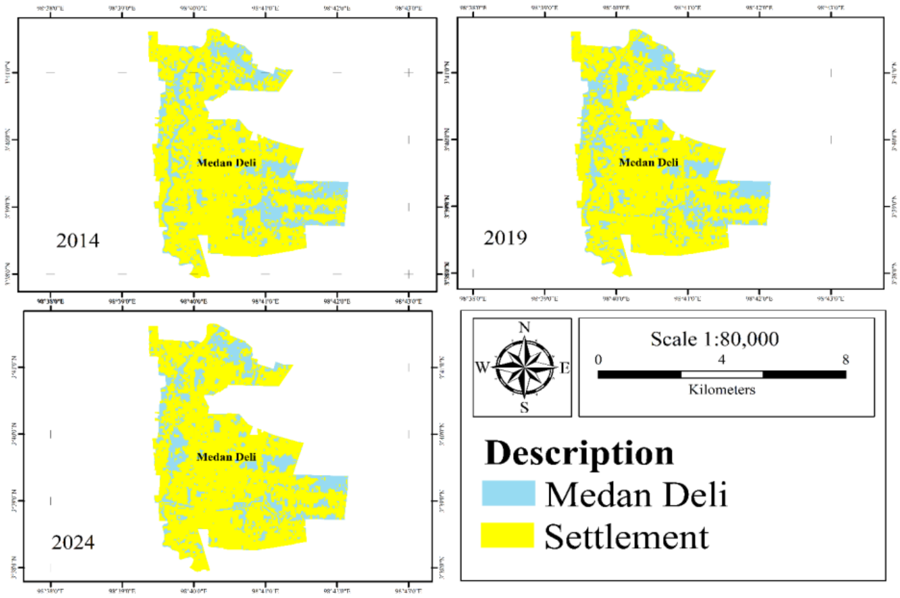

Figure 3. Settlement land-cover map of Medan Deli Sub-district for 2014, 2019, and 2024.

3.2. Settlement Change and Transition Pathways

The settlement class increased by only 2.37 ha during 2014-2019, but it increased by 59.73 ha during 2019-2024. Over the full period of 2014-2024, the net increase was 62.10 ha. The transition matrix provides a more informative explanation than the previous tables because it distinguishes between gross conversion into settlement and settlement areas that changed to other classes.

Table 3. Summary of settlement change and dominant transition pathways.

Period	Initial settlement area (ha)	Final settlement area (ha)	Gross conversion into settlement (ha)	Settlement converted to other classes (ha)	Net settlement change (ha)	Dominant source transitions
2014-2019	1,443.67	1,446.04	136.02	133.65	+2.37	Open land to settlement (91.28 ha), mixed garden to settlement (29.52 ha), shrubs to settlement (10.33 ha)
2014-2024	1,443.67	1,505.77	185.02	122.93	+62.10	Open land to settlement (114.43 ha), mixed garden to settlement (46.65 ha), shrubs to settlement (16.96 ha)
2019-2024	1,446.04	1,505.77	150.36	90.62	+59.73	Shrubs to settlement (57.96 ha), open land to settlement (42.99 ha), mixed garden to settlement (41.41 ha)

During 2014-2019, 136.02 ha of non-settlement land changed into settlement, but 133.65 ha of settlement land changed to other classes, producing a small net increase of 2.37 ha. The largest conversion into settlement came from open land (91.28 ha), followed by mixed garden (29.52 ha) and shrubs (10.33 ha). This suggests that the early period of change was characterized by local rearrangements of land-cover classes rather than significant net expansion. Data on changes in settlements in Medan Deli District are presented in Table 4.

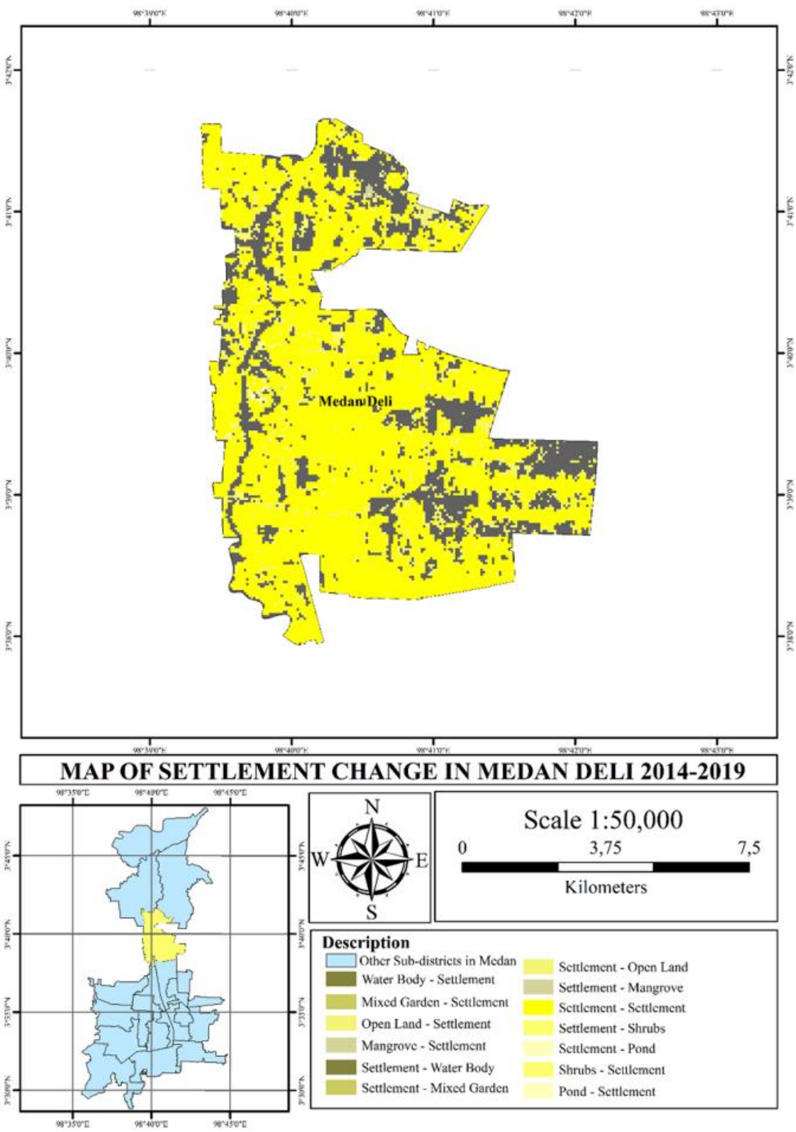

Figure 4. Settlement change map of Medan Deli Sub-district, 2014-2019.

For the ten-year interval, the change matrix shows that 185.02 ha of non-settlement land in 2014 became settled by 2024. The largest source was open land (114.43 ha), followed by mixed garden (46.65 ha), shrubs (16.96 ha), mangrove (4.29 ha), pond (1.52 ha), and water body (1.17 ha). At the same time, 122.93 ha of areas classified as settlement in 2014 shifted to other classes by 2024. Therefore, the net increase of 62.10 ha is lower than the gross conversion into settlement. This finding addresses the reviewer's comment that settlement-to-other and water-body-to-settlement changes should be explicitly explained.

Table 4. Main settlement transition components during 2014-2024.

2014 class	Gross conversion to settlement in 2024 (ha)
Water body	1.17
Mixed garden	46.65
Open land	114.43
Mangrove	4.29
Shrubs	16.96
Pond	1.52
Total non-settlement to settlement	185.02
Settlement in 2014 converted to other classes by 2024	122.93
Net settlement change 2014-2024	+62.10

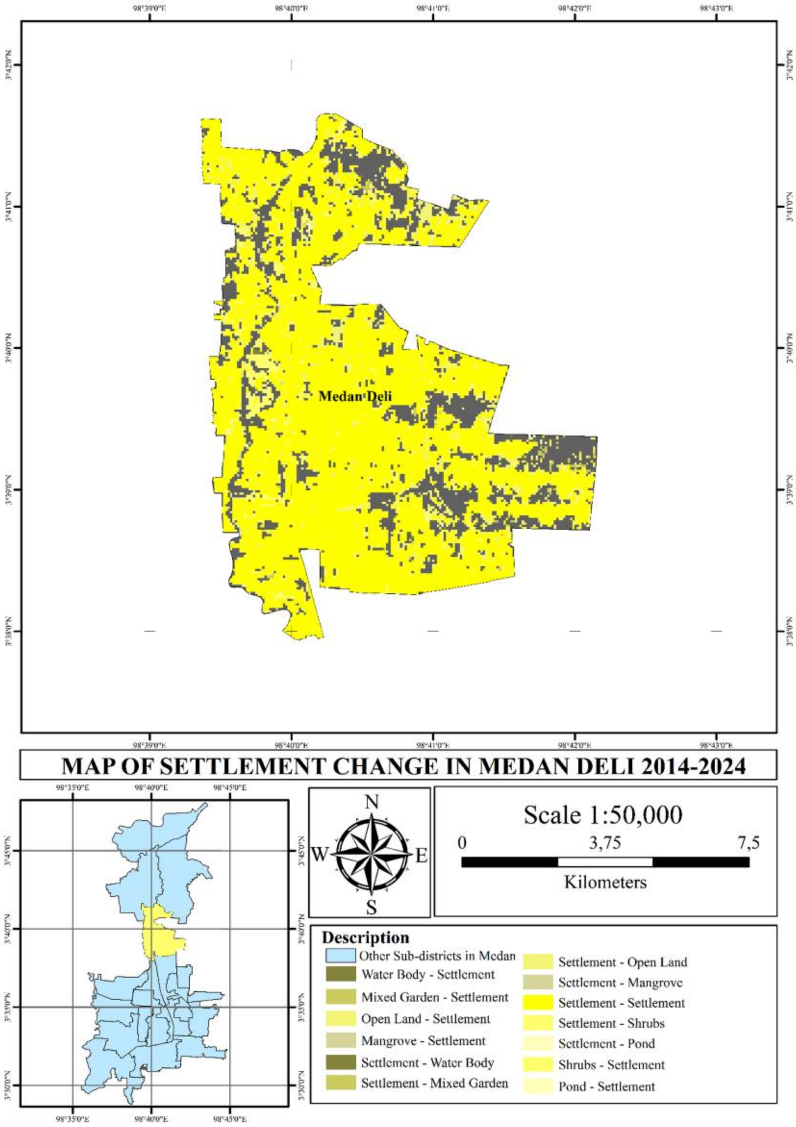

Figure 5. Settlement change map of Medan Deli Sub-district, 2014-2024.

From 2019 to 2024, the expansion of settlements became increasingly apparent. Of non-settlement land, 150.36 ha were converted to settlement, and 90.62 ha of settlement were reclassified to other categories. The main sources were bushes (57.96 ha), open ground (42.99 ha), and mixed garden (41.41 ha). The substantial presence of bushes indicates that previously disturbed or unmanaged land may have been a transitional phase to settlement development.

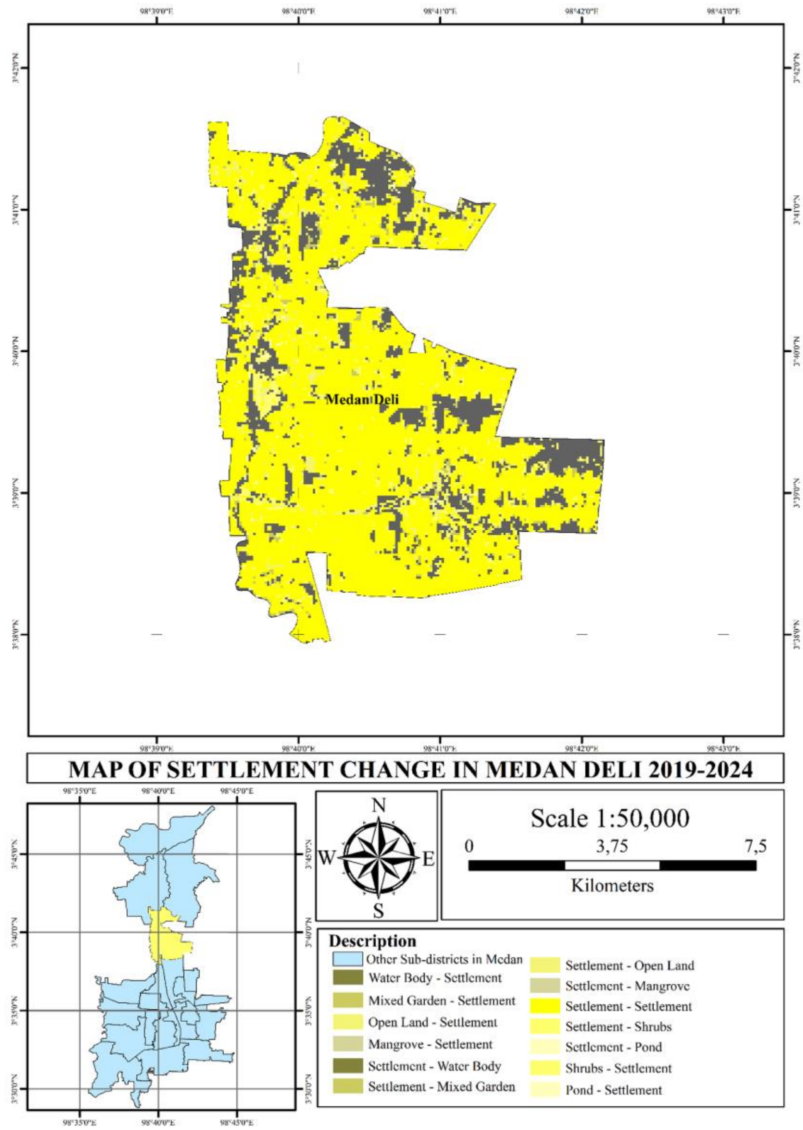

Figure 6. Settlement change map of Medan Deli Sub-district, 2019-2024.

3.3. Environmental and Spatial Planning Implications

There are many ecological implications of the detected change. Firstly, the loss of open land and mixed gardens reduces permeable surfaces that can absorb rainfall. In urban coastal areas, this condition can increase the risk of runoff and local flooding, especially if the drainage is insufficient. Secondly, it is important to note that the mangrove area decreased from 12.45 hectares in 2014 to 3.24 hectares in 2024, while mangroves provide ecological protection in coastal areas, including shoreline stabilization, habitat provision, and water quality enhancement. Thirdly, the spread of towns and the degradation of vegetative areas can lead to higher surface temperatures. It is well known that urban areas retain more heat than vegetated or aquatic areas. These results are consistent with previous studies that showed that land-cover composition affects urban heat conditions and spatial environmental risk [1,10]. The findings are in line with GIS-based spatial assessment studies published in the Global Forest Journal, which highlight the significance of land use, land suitability, and water catchment mapping for environmental management and planning [5]-[7].

The regulation of the settlement needs to be in sync with the preservation of green open space, mangrove conservation, and land management sensitive to drainage for planning purposes in Medan Deli. Priority monitoring should focus on the converted land from open land, mixed gardens, and shrubs into settlements, as this area is classified as a main land reserve for future urban expansion. Regular remote sensing assessments every five years can help local planners to decide whether settlement expansion is in line with spatial planning and environmental carrying capacity.

4. Conclusion

The results of this study reveal that settlement is the dominant land cover type in Medan Deli Sub-district, with its area increasing from 1,443.67 hectares in 2014 to 1,505.77 hectares in 2024. During the decade, the net settlement expansion was 62.10 hectares, while the gross conversion of non-settlement areas to settlements was 185.02 hectares. The primary source categories were open land, mixed gardens, and bushes.

The data suggest that settlement dynamics in Medan Deli involve both growth and reclassification of existing areas, rather than a unidirectional increase. The reduction of open land, mixed gardens, and mangrove areas significantly impacts urban environmental quality. Reduced permeability and vegetated areas can increase runoff, diminish ecological functions, and exacerbate urban heat island effects. Therefore, the expansion of settlements in Medan Deli should be guided by integrated spatial planning that safeguards green and water-sensitive areas while addressing the needs of a densely populated metropolitan region.

The use of Landsat images, Google Earth Engine, and GIS-based post-classification comparison is a good approach for monitoring land cover change in rapidly urbanizing coastal areas. Future studies could improve the analysis by using higher-resolution images, more extensive ground verification, and consistent accuracy assessments for each observation year.

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