ORIGINAL ARTICLE

HOUSING EXPANSION AND LANDSCAPE FRAGMENTATION: A MULTITEMPORAL LANDSCAPE-METRICS ANALYSIS

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ABSTRACT
Mapanget District is a peri-urban growth area of Manado City where residential development has altered the composition and configuration of land use. This study reanalyzes a consistent 2014, 2019, and 2024 land-use series and uses landscape metrics to distinguish patch proliferation from spatial consolidation. Google Earth imagery was interpreted visually, digitized on screen, processed in ArcMap 10.8, and converted to raster for FRAGSTATS 4.2 analysis. The 2026 map is reported only as a separate descriptive snapshot because its class legend is not equivalent to the 2014-2024 classification. Between 2014 and 2024, residential land increased by 172.82 ha, while plantation and wasteland decreased by 154.80 ha and 37.42 ha, respectively. At the landscape level, Number of Patches increased from 1,152 to 1,530, Patch Density from 21.63 to 28.70 patches per 100 ha, Edge Density from 102.38 to 119.33 m/ha, and Shannon's Diversity Index from 1.22 to 1.27. Residential patches increased from 489 to 747; however, the slight decline after 2019 and the rise in residential Largest Patch Index from 1.44% to 3.29% indicate partial coalescence alongside continued outward expansion. The 2026 snapshot records 1,199.26 ha of settlement and 2,699.91 ha of plantation, but these values are not used to infer a continuous trend. The findings support compact, infrastructure-connected growth and stronger protection of remaining non-built-up land. Interpretation is limited by the absence of an independent accuracy assessment, a harmonized 2026 legend, and a class-to-class transition matrix.
Keywords: Land-use Change; Landscape Fragmentation; Mapanget; Peri-urban Growth; Spatial Planning

INTRODUCTION

Mapanget District is a strategic peri-urban growth area in northeastern Manado City. Its designation as an Urban Service Center in the Manado City Spatial Plan for 2023-2042 has increased development pressure associated with housing, transportation, trade and services, offices, and public facilities (Pemerintah Kota Manado, 2023). Compared with the dense urban core, Mapanget retains substantial non-built-up land, making it simultaneously attractive for development and vulnerable to dispersed conversion. Peri-urban land-use change is not only a change in area; it also alters landscape composition and spatial configuration. Expansion that is contiguous with existing built-up areas may consolidate the urban structure, whereas disconnected or leapfrog growth can create additional patches, longer edges, and greater interaction between built-up and non-built-up land. Landscape metrics therefore provide complementary evidence about subdivision, dominance, aggregation, diversity, and edge complexity, but no single metric is sufficient to prove fragmentation or ecological impact (McGarigal & Marks, 1995; McGarigal, Cushman, & Ene, 2012). The 2014-2024 land-use series for Mapanget shows that residential land increased from 779.12 ha to 951.94 ha, while plantation land decreased from 3,645.08 ha to 3,490.28 ha and wasteland declined from 228.16 ha to 190.74 ha. These concurrent changes indicate a broad shift toward more urban land uses, but aggregate gains and losses do not by themselves demonstrate which source classes were converted directly to housing. Two previous Mapanget studies provide the immediate basis for this analysis. Sela, Malik, Tilaar, and Lestari (2024) modeled future settlement growth and potential deviation from the spatial plan, while Sela, Malik, Tilaar, Mambu, and Pelealu (2025) documented the 2014-2024 land-use series and reported residential changes in Number of Patches and Patch Density. The remaining gap is a joint interpretation of area change with additional configuration metrics - Largest Patch Index, Edge Density, Aggregation Index, and Shannon's Diversity Index - to determine whether residential growth reflects only dispersion or a combination of patch proliferation and partial consolidation.

The present study transparently reuses the published 2014-2024 Mapanget land-use series and extends its interpretation through class-level and landscape-level metrics. A 2026 map is included only to describe the latest mapped condition. Because the 2026 legend contains non-equivalent categories such as settlement, field, shrubs, and open land, it is not treated as a continuation of the 2014-2024 time series and is not used to calculate direct class changes or longitudinal metric trajectories. The study addresses three research questions: (1) How did residential, plantation, and wasteland areas change between 2014, 2019, and 2024? (2) How did landscape-level and class-level metrics characterize residential patch proliferation, edge complexity, dominance, and aggregation during 2014-2024? (3) What does the non-comparable 2026 snapshot reveal about the contemporary spatial distribution of settlement and non-built-up land?

Operationally, "residential" refers to the mapped 2014-2024 class, whereas "settlement" refers to the broader 2026 class; the terms are not assumed to be equivalent. The earlier expression "planned housing" is not retained because the available spatial data do not provide a separately mapped and validated planned-housing class. "Strategic area" refers to Mapanget's planning role as an Urban Service Center, and "fragmentation" is used cautiously to describe changes in mapped spatial pattern rather than demonstrated ecological function. The primary contribution is to urban and regional planning, GIS, and landscape-pattern analysis. For education research, the maps and locally grounded metrics may serve as place-based resources for geography, environmental education, and spatial-literacy instruction; however, this study does not measure learners, pedagogy, or educational outcomes. Accordingly, its educational relevance is contextual rather than an evaluation of an educational intervention.

METHOD

This study used a quantitative spatial design based on Geographic Information Systems (GIS). Mapanget District, located in northeastern Manado City, covers approximately 5,360 ha and comprises ten sub-districts: Kairagi Satu, Kairagi Dua, Paniki Bawah, Paniki Dua, Lapangan, Mapanget Barat, Kima Atas, Bengkol, Buha, and Paniki Satu (Badan Pusat Statistik Kota Manado, 2025). The district borders North Minahasa Regency to the north and east, Tikala District to the south, and Singkil District to the west. Figure 1 presents the study-area orientation.

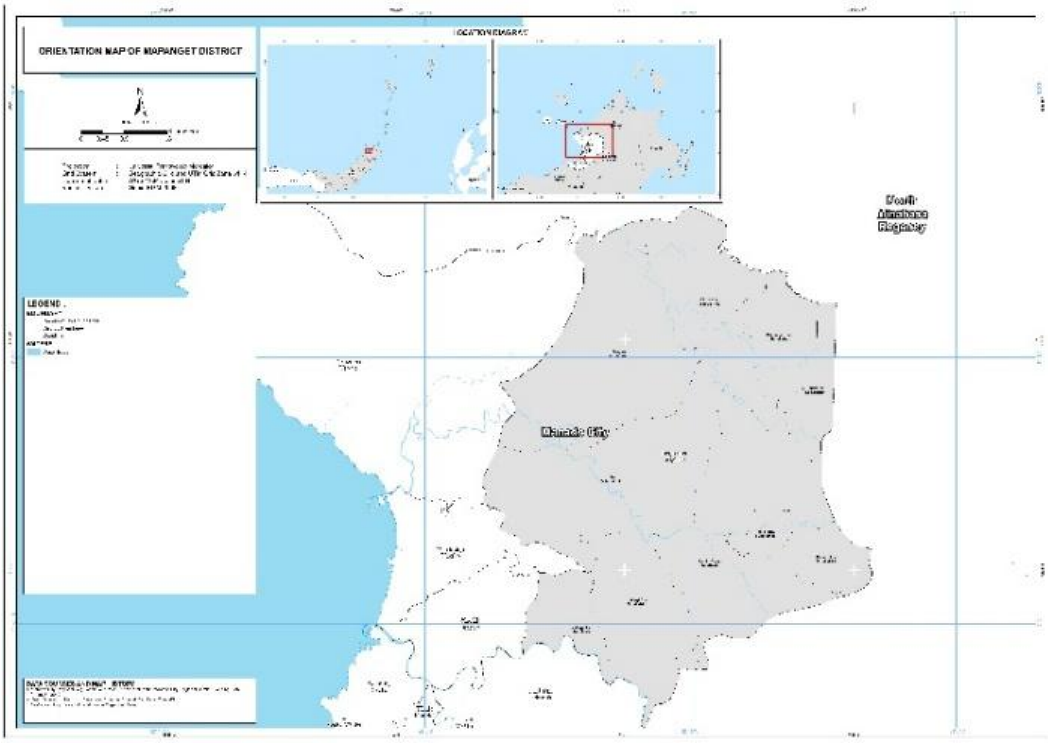

Figure 1. Orientation Map of Mapanget District
Source: Manado City Spatial Plan 2023-2042 (Pemerintah Kota Manado, 2023).

Bengkol (1,099 ha), Buha (1,045 ha), and Paniki Bawah (1,012 ha) are the largest sub-districts and contain much of the land potentially exposed to extensive spatial change. Paniki Satu (97 ha), Lapangan

(199 ha), and Paniki Dua (206 ha) are smaller and may experience development more through intensification than outward expansion. Table 1 lists the administrative areas.

Table 1. Total Area of Mapanget District

Sub-district	Area (ha)
Kairagi Satu	337
Kairagi Dua	458
Paniki Bawah	1,012
Paniki Dua	206
Lapangan	199
Mapanget Barat	293
Kima Atas	614
Bengkol	1,099
Buha	1,045
Paniki Satu	97

Source: Badan Pusat Statistik Kota Manado (2025).

The spatial-planning context is important because Mapanget is designated as an Urban Service Center. The concentration of transportation, commercial, office, public, and social-service functions can increase demand for built-up land. The analysis therefore focuses on whether residential growth is accompanied by greater subdivision and edge complexity in the remaining non-built-up landscape. The spatial database consists of visually interpreted Google Earth imagery for 2014, 2019, 2024, and 2026. Land use was delineated through on-screen digitization using visual cues such as color, texture, shape, pattern, size, association, and location. ArcMap 10.8 was used for editing, area calculation, overlay, and vector-to-raster conversion. Formal longitudinal analysis is restricted to 2014, 2019, and 2024 because those maps use the same 20-class legend. The 2026 map uses a different legend and is analyzed only as an independent snapshot.

The analytical workflow was: image interpretation -> polygon digitization -> geometry and class review -> area tabulation -> raster conversion -> FRAGSTATS calculation -> joint interpretation of composition and configuration. The historical class totals are 5,329.07 ha (2014), 5,332.51 ha (2019), and 5,334.06 ha (2024), leaving residual/unclassified areas of 30.93 ha, 27.49 ha, and 25.94 ha relative to the 5,360-ha administrative boundary. These residuals are reported explicitly in Table 2 rather than being assigned to a land-use class. FRAGSTATS 4.2 was used at class and landscape levels. Mapanget District was the fixed landscape extent, and each raster land-use category was treated as a patch type. The same workflow was applied to the 2014-2024 rasters. However, the available project archive does not preserve the exact image acquisition dates and providers, nominal image resolution, digitizing scale, minimum mapping unit, raster cell size, neighborhood rule, background code, boundary-edge treatment, or an independent validation sample. Therefore, no confusion matrix, kappa statistic, minimum detectable change, or grain-sensitivity test can be reported. Small differences and metric changes are interpreted cautiously, and these omissions are recognized as limitations requiring completion from the original GIS project files before final submission.

Metric definitions followed the FRAGSTATS documentation (McGarigal, Cushman, & Ene, 2012):

Number of Patches (NP): NP = n_i at class level, or NP = N at landscape level, where n_i is the number of patches of class i and N is the total number of patches. NP is interpreted only with area-standardized and configuration metrics. Patch Density (PD): PD = (n_i / A) x 1,000,000 at class level, or (N / A) x 1,000,000 at landscape level, where A is landscape area in square meters. Units are patches per 100 ha. Edge Density (ED): ED = (E / A) x 10,000, where E is total edge length in meters and A is landscape area in square meters. Units are meters per hectare. Aggregation Index (AI): AI_i = (g_ii / max-g_ii) x 100 at class level, where g_ii is the observed number of like adjacencies and max-g_ii is the maximum possible number. Landscape AI is the area-weighted mean of class AI values. AI ranges from 0 to 100%. Shannon's Diversity Index (SHDI): SHDI = -sum(p_i ln p_i), where p_i is the proportion of total landscape area occupied by class i. SHDI is a landscape-composition metric and increases with class richness and area evenness. Largest Patch Index (LPI): LPI = [max(a_ij) / A] x 100, where a_ij is the area of patch ij and A is total landscape area. LPI is the percentage of the landscape occupied by the largest patch and indicates dominance rather than fragmentation by itself. NP, PD, ED, AI, LPI, and SHDI were interpreted jointly. Higher NP, PD, and ED may be consistent with subdivision, while higher LPI and AI may indicate dominance or coalescence. Because metric values are sensitive to thematic resolution, grain, adjacency rules, and boundary treatment, the analysis is descriptive and associative rather than a causal test of ecological fragmentation

RESULTS AND DISCUSSION

The results are interpreted in relation to the two earlier Mapanget studies. The cellular-automata analysis by Sela, Malik, Tilaar, and Lestari (2024) identified strong future settlement pressure associated with existing settlements and infrastructure corridors. The land-use study by Sela, Malik, Tilaar, Mambu, and Pelealu (2025) supplied the 2014-2024 series used here and reported increases in residential NP and PD. The present analysis adds LPI, ED, AI, and landscape-level SHDI to evaluate whether dispersion occurred together with dominance or aggregation. Because no validated class-to-class transition matrix is available, the results do not claim that all plantation or wasteland losses were converted directly to housing. The wording "occurred alongside" is used for coincident aggregate changes, while spatial mechanisms are inferred cautiously from maps and metric combinations. Results are presented in four parts: land-use change for the comparable 2014-2024 series, landscape-level metrics for the same period, class-level metrics for major land uses, and a separate descriptive account of the non-comparable 2026 snapshot.

Land-Use Change in Mapanget District, 2014-2024

Figure 2 shows the comparable 2014, 2019, and 2024 land-use maps. Plantation remained the dominant class throughout the period. Residential growth was visible around existing settlements and road-accessible areas in the southern, eastern, and central parts of the district. The maps suggest both outward extension of existing residential areas and the appearance of additional patches, but the visual evidence alone cannot distinguish direct conversion pathways or formal growth modes such as infill, edge expansion, and leapfrog development.

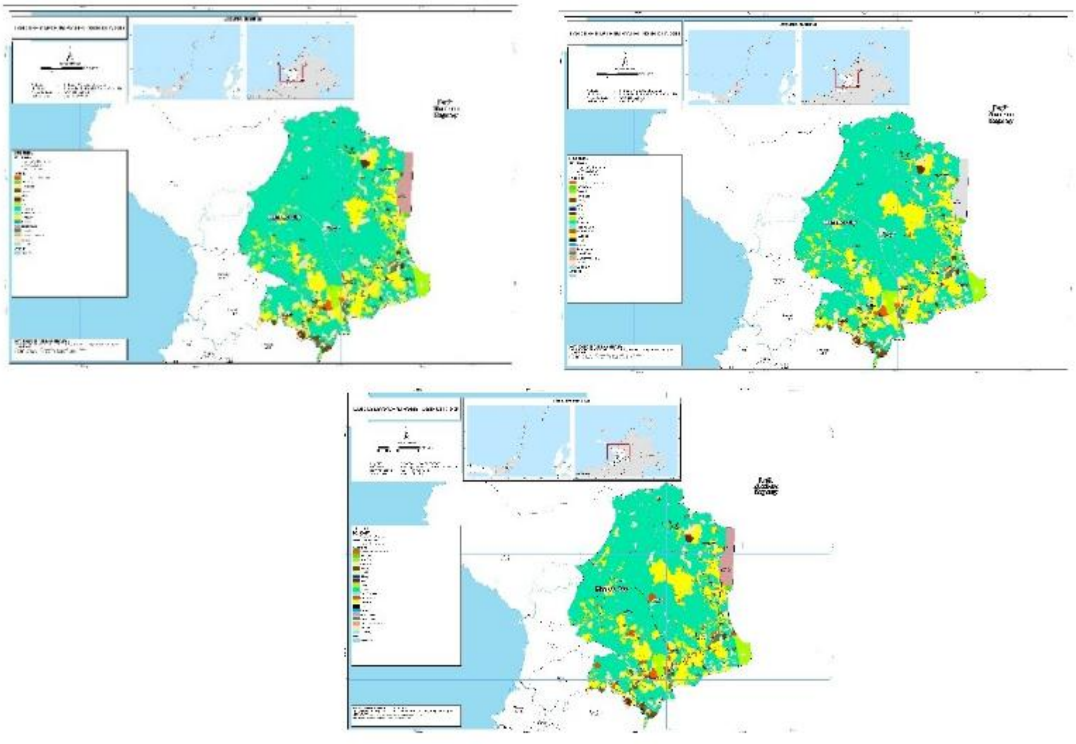

Figure 2. Land-Use Maps of Mapanget District in 2014, 2019, and 2024

Source: Research analysis based on the 2014-2024 land-use series reported by Sela et al. (2025).

Table 2 quantifies the changes. Residential land increased by 137.16 ha from 2014 to 2019 and by a further 35.66 ha from 2019 to 2024, for a net increase of 172.82 ha. Plantation declined by 128.44 ha and 26.36 ha in the two intervals, respectively, for a net decrease of 154.80 ha. Wasteland declined by 28.84 ha and 8.58 ha, for a net decrease of 37.42 ha. Growth and decline were therefore strongest during 2014-2019 and slower during 2019-2024.

Table 2. Land Use in Mapanget District, 2014-2024

Land-use class	2014 (ha)	2019 (ha)	2024 (ha)
Water body	48.76	53.38	53.38
Road	24.21	24.21	24.21
Public facilities	50.54	51.78	51.78
Horticulture	112.46	117.81	113.61
Industry	48.09	52.18	52.18
Urban infrastructure	0.31	3.62	0.20
Tourism	0.74	0.74	0.74
Public cemetery	10.14	12.46	12.46
Landfill	1.16	1.16	1.16
Commercial and services	32.82	33.87	38.11
Offices	41.70	41.90	41.90
Plantation	3645.08	3516.64	3490.28
Residential	779.12	916.28	951.94
Urban forest	66.19	66.68	66.68
Parks	109.60	109.73	109.73
Wasteland	228.16	199.32	190.74
Food crops	4.72	4.72	4.72
Transportation	125.27	125.27	125.27
Military	0.00	0.76	0.76
Green belt	0.00	0.00	4.21
Residual/unclassified area	30.93	27.49	25.94
Total administrative area	**5,360.00**	**5,360.00**	**5,360.00**

Source: Research analysis, 2026. Residual/unclassified area is reported to reconcile the mapped classes with the 5,360-ha administrative boundary.

The simultaneous expansion of residential land and decline of plantation and wasteland indicate increasing urban-development pressure. However, without a transition matrix, these aggregate changes support association rather than proof that housing directly caused each loss. The maps locate the broad pattern of pressure, while the landscape metrics clarify how spatial configuration changed.

The 2026 land-use map is retained as a separate descriptive snapshot because its classification system is not equivalent to the 2014-2024 legend. Categories such as settlement, field, shrubs, open land, hardened surface, and activity area cannot be matched one-to-one with residential, horticulture, wasteland, urban infrastructure, and public facilities. Direct changes, percentages, annual rates, and cross-year landscape-metric trajectories are therefore not calculated across the classification break.

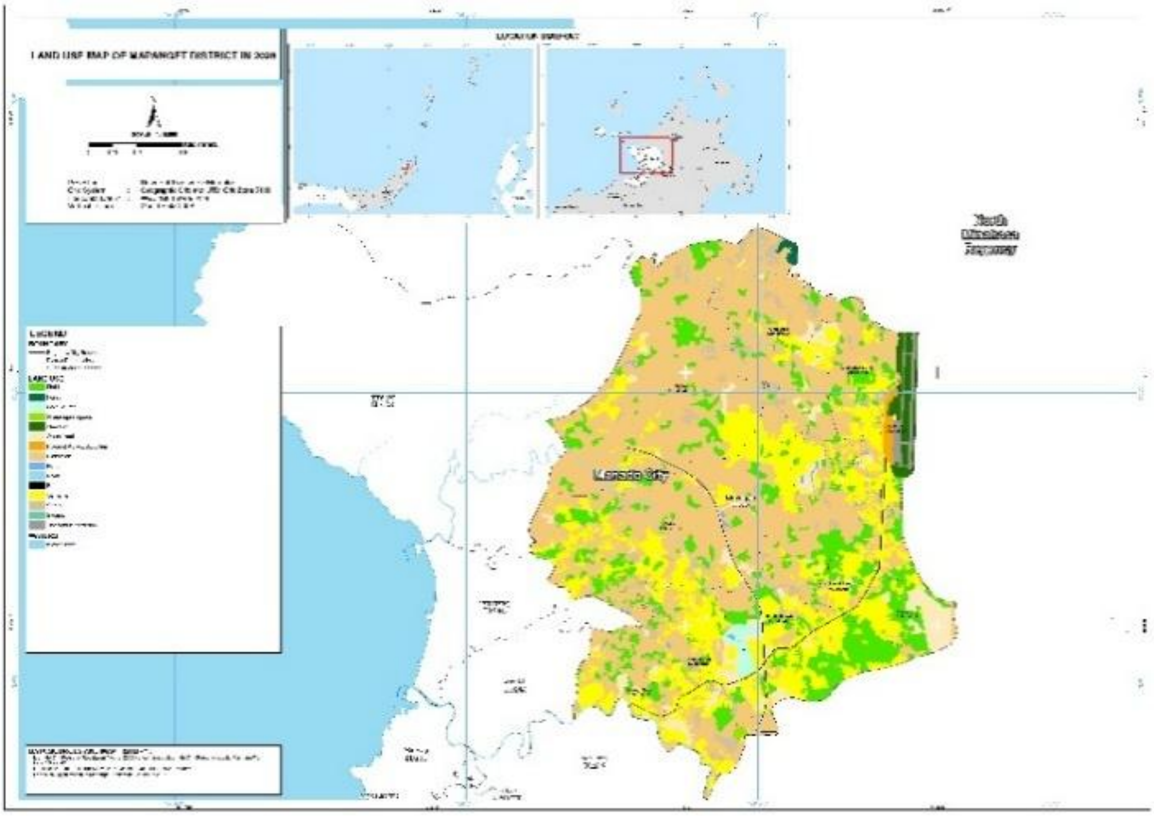

Figure 3. Land-Use Map of Mapanget District in 2026
Source: Research analysis, 2026.

Figure 3 shows a 2026 mosaic dominated by plantation (2,699.91 ha), settlement (1,199.26 ha), field (750.13 ha), open land (267.31 ha), and shrubs (180.24 ha). The snapshot confirms that substantial vegetated and open land remained alongside a large settlement component, but it does not provide a valid basis for calculating change from the earlier residential class.

Settlement patches occur in the southern, eastern, and central parts of Mapanget and are interspersed with plantation, field, shrub, and open-land categories. This spatial contact is consistent with a mixed peri-urban landscape. It should not be interpreted as proof of a specific conversion pathway or as a direct continuation of the 2014-2024 residential trend.

Table 3. Land Use in Mapanget District, 2026 (Descriptive Snapshot)

Land-use class	2026 (ha)
Forest	10.19
Road	23.06
Plantation	2699.91
Pond	13.35
Golf Course	33.02
Meadow	71.24
Hardened surface	38.00
Settlement	1199.26
Swamp	0.53
Green open space	13.71
Shrubs	180.24
River	38.54
Open land	267.31
Field	750.13

Land-use class	2026 (ha)
Activity area	22.04
Mapped total	**5,360.53**

Source: Research analysis, 2026. The mapped total is 5,360.53 ha, 0.53 ha above the stated administrative area; this small discrepancy should be checked against the final boundary geometry.

Table 3 is interpreted independently. Settlement is the second-largest mapped class after plantation, while field, open land, shrubs, green open space, forest, swamp, river, and ponds represent the remaining non-built-up or water-related mosaic. No direct equivalence is assumed between these classes and the 2014-2024 legend.

Accordingly, the former direct 2014-2026 comparison table and its percentage-change calculations have been removed. Formal temporal inference in this article is limited to the harmonized 2014-2024 series.

Landscape-Level Metrics, 2014-2024

Table 4 reports landscape-level metrics only for the comparable 2014, 2019, and 2024 maps. The 2026 row has been removed because a changed thematic legend can alter NP, PD, SHDI, LPI, ED, and AI independently of physical landscape change.

Table 4. Landscape-Level Metrics of Mapanget District, 2014-2024

Year	NP	PD (patches/100 ha)	SHDI	LPI (%)	ED (m/ha)	AI (%)
2014	1152	21.63	1.22	34.13	102.38	98.41
2019	1539	28.88	1.26	25.46	114.44	98.24
2024	1530	28.70	1.27	31.63	119.33	98.24

Source: Research analysis, 2026. PD is reported as patches per 100 ha; LPI and AI are percentages; ED is meters per hectare.

Relative to 2014, the 2024 landscape contained more patches (1,152 to 1,530), higher patch density (21.63 to 28.70 patches per 100 ha), greater edge density (102.38 to 119.33 m/ha), and slightly higher land-use diversity (SHDI 1.22 to 1.27). AI remained very high and changed only marginally (98.41% to 98.24%), indicating that substantial within-class aggregation persisted. LPI fell sharply to 25.46% in 2019 and then recovered to 31.63% in 2024, while NP and PD also peaked in 2019 and declined slightly by 2024. This combination is more accurately interpreted as strong subdivision during 2014-2019 followed by partial consolidation or coalescence during 2019-2024, not uninterrupted fragmentation.

Class-Level Metrics, 2014-2024

Class-level metrics identify which land-use categories contributed most to the landscape pattern. Tables 5A and 5B report NP, PD, LPI, ED, and AI for each comparable class. Interpretation emphasizes the residential, plantation, and wasteland classes and avoids treating metric values as direct evidence of ecological effect.

Table 5A. Class-Level NP, PD, and LPI of Mapanget District, 2014-2024

Land-use class	NP			PD (patches/100 ha)			LPI (%)		
	2014	2019	2024	2014	2019	2024	2014	2019	2024
Plantation	47	47	44	0.88	0.88	0.83	34.13	25.47	31.64
Horticulture	71	78	78	1.33	1.46	1.46	0.16	0.16	0.16
Residential	489	752	747	9.18	14.12	14.01	1.44	3.10	3.29
Waterbody	94	103	103	1.77	1.93	1.93	0.24	0.24	0.24
Industrial	42	49	49	0.79	0.92	0.92	0.12	0.12	0.12

Land-use class	NP			PD (patches/100 ha)			LPI (%)		
	2014	2019	2024	2014	2019	2024	2014	2019	2024
Tourism	12	1	1	0.23	0.02	0.02	0.06	0.01	0.01
Wasteland	133	140	135	2.50	2.63	2.53	0.35	0.33	0.33
Urban Forest	53	54	54	1.00	1.01	1.01	0.18	0.18	0.18
Office	46	48	48	0.86	0.90	0.90	0.19	0.19	0.19
Green belt	-	-	88	-	-	1.65	-	-	0.01
Public facilities	101	105	105	1.90	1.97	1.97	0.19	0.19	0.19
Transportation	1	1	1	0.02	0.02	0.02	2.35	2.35	2.35
Road	14	14	14	0.26	0.26	0.26	0.34	0.34	0.34
Park	6	7	7	0.11	0.13	0.13	1.14	1.14	1.14
Food crops	1	1	1	0.02	0.02	0.02	0.09	0.09	0.09
Urban infrastructure	20	100	15	0.38	1.88	0.28	0.00	0.01	0.00
Cemetery	1	15	15	0.02	0.28	0.28	0.02	0.09	0.09
Commercial and services	20	22	23	0.38	0.41	0.43	0.19	0.19	0.19
Military	-	1	1	-	0.02	0.02	-	0.01	0.01
Landfill	-	1	1	-	0.02	0.02	-	0.02	0.02

Table 5B. Class-Level ED and AI of Mapanget District, 2014-2024

Land-use class	ED (m/ha)			AI (%)		
	2014	2019	2024	2014	2019	2024
Plantation	68.92	74.46	79.71	99.21	99.09	99.08
Horticulture	9.00	9.64	9.59	96.90	96.82	96.77
Residential	50.99	59.03	61.90	97.39	97.39	97.46
Waterbody	20.72	21.17	21.81	81.80	82.84	82.84
Industrial	4.30	4.77	4.81	96.68	96.62	96.62
Tourism	1.16	1.34	1.09	96.32	96.54	97.53
Wasteland	18.46	17.70	17.65	96.74	96.43	96.40
Urban Forest	7.21	7.30	7.29	95.94	95.93	95.93
Office	3.39	3.47	3.50	97.13	97.09	97.09
Green belt	-	-	4.93	-	-	41.91
Public facilities	4.96	5.14	5.24	96.39	96.31	96.31
Transportation	0.80	0.80	0.80	99.83	99.83	99.83
Road	10.28	14.44	15.16	75.29	75.29	75.29
Park	1.68	1.71	1.71	99.51	99.50	99.50
Food crops	0.15	0.15	0.15	99.57	99.57	99.57
Urban infrastructure	0.23	5.13	0.14	74.11	44.00	78.49
Cemetery	0.08	0.08	1.34	98.04	98.04	96.54
Commercial and services	2.34	2.38	2.67	97.66	97.65	97.67
Military	-	0.08	0.08	-	99.32	99.32
Landfill	-	-	0.08	-	-	98.04

Source: Research analysis, 2026. Tables 5A-5B report PD as patches per 100 ha; LPI and AI as percentages; and ED as meters per hectare.

Residential NP rose from 489 in 2014 to 752 in 2019, then declined slightly to 747 in 2024. PD followed the same pattern (9.18, 14.12, and 14.01 patches per 100 ha). In contrast, residential area, LPI, and ED continued to increase: LPI rose from 1.44% to 3.29%, and ED from 50.99 to 61.90 m/ha. Residential AI was stable and slightly higher in 2024 (97.46%). Together, these values indicate rapid patch proliferation through 2019 followed by stabilization and partial coalescence, while residential boundaries continued to expand. Plantation NP declined from 47 to 44 and PD from 0.88 to 0.83, but ED increased from 68.92 to 79.71 m/ha and AI declined slightly from 99.21% to 99.08%. Plantation LPI fell in 2019 and partially recovered in 2024, suggesting that the dominant plantation structure was disturbed but not eliminated. Wasteland metrics changed only modestly, and its slight declines in LPI and AI are consistent with reduced dominance rather than definitive direct conversion to housing.

The 2026 class-level metrics are shown separately in Table 6. They describe the internal configuration of the 2026 legend and are not compared numerically with the earlier class metrics.

Table 6. Class-Level Metrics of Mapanget District in 2026 (Descriptive Snapshot)

2026 land-use class	NP	PD (patches/100 ha)	LPI (%)	ED (m/ha)	AI (%)
Plantation	139	2.59	19.98	89.89	98.65
Shrubs	88	1.64	0.19	17.93	96.16
Forest	1	0.02	0.19	0.31	99.02
Field	223	4.16	1.37	49.52	97.38
River	48	0.90	0.22	18.41	80.10
Open land	117	2.18	1.20	20.82	96.99
Settlement	400	7.46	3.05	67.92	97.77
Pond	46	0.86	0.04	2.60	92.92
Green open space	16	0.30	0.09	1.54	96.24
Swamp	1	0.02	0.01	0.13	94.03
Meadow	8	0.15	0.37	2.68	98.50
Hardened surface	1	0.02	0.71	2.35	97.97
Activity area	1	0.02	0.41	0.77	99.23
Road	1	0.02	0.43	7.10	88.15
Golf Course	1	0.02	0.62	1.06	99.23

Source: Research analysis, 2026. PD is patches per 100 ha; LPI and AI are percentages; ED is meters per hectare.

Within the 2026 legend, settlement had the highest NP (400) and a PD of 7.46 patches per 100 ha. Its LPI of 3.05%, ED of 67.92 m/ha, and AI of 97.77% indicate many settlement patches, extensive contact with other classes, and high within-class aggregation. Plantation remained the dominant class by LPI (19.98%) and had the highest ED (89.89 m/ha), showing a large but highly edged plantation structure. Field also had a high patch count (223) and PD (4.16), indicating subdivision within the open or productive land mosaic. Open land and shrubs contributed additional patch and edge complexity, while river and pond patterns reflected their linear or small-patch forms. These values describe the 2026 spatial configuration only. The settlement class cannot be labeled "planned housing" without a separate, validated map of formal housing estates.

Planning and Educational Implications

The evidence supports three planning priorities. First, new residential approvals should favor infill and edge-contiguous development connected to existing roads and services rather than isolated patches. Second, the remaining large plantation and open-land structures should be screened for ecological, agricultural, drainage, and green-space functions before conversion. Third, municipal monitoring should use a fixed land-use ontology, a consistent boundary and raster grain, documented imagery metadata, accuracy assessment, and class-to-class transition matrices. For geography and environmental education, the Mapanget maps can support local case-based learning on urban growth, map interpretation, and the limits of spatial indicators; such applications should be evaluated in separate educational research

CONCLUSION

This study shows that Mapanget District experienced substantial land-use transformation between 2014 and 2024. Residential land increased from 779.12 ha to 951.94 ha, representing an expansion of

172.82 ha, while plantation land decreased by 154.80 ha and wasteland declined by 37.42 ha. These changes indicate growing pressure on non-built-up land as residential development expanded across the district. The landscape metrics demonstrate that residential growth involved both spatial dispersion and partial consolidation. The Number of Patches for residential land increased from 489 in 2014 to 752 in 2019 and then decreased slightly to 747 in 2024. Patch Density followed a similar pattern, increasing from 9.18 to 14.12 before declining marginally to 14.01. At the same time, the residential Largest Patch Index increased from 1.44 to 3.29, while Edge Density rose from 50.99 to 61.90. These results suggest that new residential patches emerged throughout the landscape, while several existing residential areas also expanded and became more spatially connected. Therefore, housing expansion in Mapanget cannot be interpreted solely as continuous fragmentation; rather, it reflects a combination of dispersed growth, edge expansion, and localized consolidation. At the landscape level, the higher values of Number of Patches, Patch Density, Shannon's Diversity Index, and Edge Density in 2024 compared with 2014 indicate that Mapanget developed into a more diverse and spatially complex landscape. Although the Aggregation Index remained high, its slight decline suggests a gradual weakening of overall landscape compactness. Plantation land continued to dominate the district, but its decreasing area and increasingly complex boundaries indicate growing interaction between urban development and non-built-up land. The 2026 land-use data provide a recent descriptive overview of Mapanget but should not be used for direct longitudinal comparison because the land-use classification system differs from that applied in 2014, 2019, and 2024. Accordingly, formal temporal conclusions in this study are limited to the harmonized 2014–2024 dataset. The absence of a complete transition matrix and independent classification-accuracy assessment also means that the findings demonstrate spatial association rather than direct causation between housing expansion and the loss of specific land-use classes. The findings support the need for more effective spatial-use control in Mapanget. Future housing development should prioritize infill development, continuity with existing built-up areas, and efficient use of infrastructure, while limiting scattered or leapfrog development on plantation and open land. Future research should employ harmonized land-use classifications, detailed image metadata, accuracy assessment, class-to-class transition analysis, growth-mode classification, and sub-district-level hotspot analysis to provide stronger evidence for zoning, infrastructure planning, and the protection of remaining ecological and productive land.

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