



IDENTIFICATION OF URBAN SPRAWL TYPES BASED ON THE SPRAWL EXPANSION PATTERN INDEX IN SIX PERI-URBAN DISTRICTS OF MANADO CITY, INDONESIA

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Abstract

This paper attempts to identify the typology of urban sprawl or the horizontal physical expansion of built-up land in 6 districts that constitute the peri-urban area of Manado City, Indonesia. The study is based on the Sprawl Expansion Pattern Index metric values, which is the ratio between the area and perimeter of new built-up land expansion plots in the last two decades (2004-2024). This metric value is quantified using the ArcGIS application, utilizing the results of the extraction of built-up and unbuilt land (black-and-white hypothesis) from spatiotemporal satellite imagery data with the help of Google Earth Engine. The analysis results show that the dominant sprawl typology occurring in the study area is the Edge Sprawl type, which reaches a proportion of 80.30% of the total physical expansion of built-up land during that period. This type of sprawl occurs through physical expansion at the edges of pre-existing built-up land clusters. Edge sprawl that occurs between 2 or more built-up land clusters can in principle be seen as a type of Infill Development, which over time will lead to the merging of previously built-up land clusters to form a larger and more compact cluster. The dominance of another identified sprawl type is Leapfrog Sprawl with a proportion of 18.94%. Leapfrog sprawl is identical to a jumping physical expansion pattern, which passes through open land and creates spatial fragmentation. Ribbon Sprawl type, namely linear expansion along the main road corridor, was identified to occur with a very small proportion of 0.76%.

Keywords: Urban Sprawl, Peri-urban Area, Sprawl Pattern Expansion Index, Edge Sprawl, Infill Development, Leapfrog Sprawl, Ribbon Sprawl

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INTRODUCTION

Urban growth in Indonesia has generally driven the expansion of built-up areas into peri-urban areas in response to increasing population and economic activity (Basman et al., 2025). Manado, as the center of regional activity in North Sulawesi, also exhibits similar symptoms, with increasing pressures on accessibility, investment, and urbanization in its peri-urban areas. Unmanaged physical expansion usually leads to urban sprawl, characterized by inefficient and unconsolidated distribution of built-up land. This phenomenon can trigger various negative consequences, including increased spatial fragmentation, massive conversion of undeveloped land, environmental degradation, and increased public dependence on private vehicles. Urban sprawl often causes a decline in the quality of public services and economic (Ebraheem et al, 2024; Rogi et al., 2024; Yasin et al., 2020).

To minimize these negative impacts, local governments need a proper understanding of spatial development patterns, particularly the typology of urban sprawl (Wang et al., 2020; Artmann et al., 2019). This is crucial because each type of sprawl has distinct development characteristics and policy implications for spatial planning (Yasin et al., 2020; Ewing & Hamidi, 2015). For example, edge sprawl tends to be associated with urban consolidation and is relatively manageable, while leapfrog sprawl leads to more extreme fragmentation of urban spatial structures (Zhang et al., 2023; Shukla & Jain, 2019). Thus, identifying sprawl typologies in the peri-urban areas of Manado is a strategic basis for formulating more anticipatory and sustainable spatial use control policies (Lord et al, 2015; Wiewel & Persky, 2015).

This study was conducted to answer the question: "How are the variations and dominance of urban sprawl typologies developing in six districts in the peri-urban area of Manado City over the past two decades?" The purpose of this study was to identify, quantify, and interpret the patterns and proportions of urban sprawl types that occurred based on the characterization results of the Sprawl Expansion Pattern Index (SEPI) metric (Shukla & Jain, 2019). The results of this study are expected to provide a more comprehensive spatial understanding of the dynamics of peri-urban area development and serve as a basis for making spatial planning policies (Sareen & Haque, 2023; Ahani & Dadashpoor, 2021).

This study conducted spatial mapping of built-up land changes during the period 2004–2024 using a binary classification of built-up and unbuilt-up land using satellite image processing in Google Earth Engine. Built-up land expansion patches were analyzed using a geoprocessing tool in ArcGIS to obtain patch area and perimeter values. The Sprawl Expansion Pattern Index (SEPI) metric was calculated as the ratio of the area and perimeter of each expansion patch. It was used to determine whether the growth pattern falls into the edge, leapfrog, ribbon (linear), or other patterns according to the formulated typology. This approach

allows for robust spatial identification of the character of urban expansion in the study area (Shukla & Jain, 2019).

By understanding the dominant type of sprawl, planners and policy makers can implement appropriate spatial utilization control strategies according to the development characteristics of the peri-urban areas of Manado City, so that the urbanization process can be directed in a more structured and sustainable direction (Lord et al, 2015; Wiewel & Persky, 2015).

LITERATURE REVIEW

Peri-urban Areas and the Phenomenon of Urban Sprawl

Peri-urban areas are defined as transition zones located on the outskirts of a city, where urban and rural functions meet and blend. These areas are dynamic and a primary locus of land-use change due to the pressures of urbanization and infrastructure development (Elgar, 2023; Ahani & Dadashpoor, 2021).

In many mid-sized cities in developing countries, including Indonesia, pressure on land in peri-urban areas often triggers rapid, unstructured physical expansion of settlements. This phenomenon is commonly referred to as urban sprawl, which is synonymous with the loss of productive land, declining ecosystem quality, fragmentation of open spaces, and increased reliance on private transportation (Rogi et al., 2025).

Some studies also emphasize the importance of assessing the character and consequences of sprawl locally, rather than just its extent, as planning and policy implications depend heavily on how sprawl manifests spatially in a given peri-urban area (Yasin et al., 2020).

Urban Sprawl Typology: Categories and Implications

Sprawl typologies are usually classified into several general patterns: edge expansion, ribbon, leapfrog, and infill, each with different formation mechanisms and spatial implications (Shukla & Jain, 2019; Ewing & Hamidi, 2015). Edge expansion occurs when built-up areas expand from the edges of existing clusters, thus maintaining spatial connectivity; leapfrog appears as new patches far from existing clusters, thus causing fragmentation; ribbon relates to longitudinal growth along road corridors; while infill refers to filling gaps within existing urban structures (Li et al, 2025; Karthik et al, 2025; Ewing & Hamidi, 2015).

This typology analysis is relevant because effective policies differ between types. Infill tends to be more easily encouraged through densification policies, while leapfrog requires interventions such as controlling land conversion and regulating public infrastructure networks to prevent fragmentation (Marquis & Barthelemy, 2025; Turvey, 2019).

Urban Expansion Index

One approach to identifying sprawl typologies is the use of the Urban Expansion Index (UEI). The UEI is calculated as the ratio of the length of the common boundary between the new and existing urban patches to the perimeter of the new patch. UEI values can vary from 0 to values close to 1, although in classification practice, they use certain ranges to define typologies (Chettry, 2022).

In another study, UEI was modified into the Sprawl Expansion Pattern Index (SEPI), with a different mathematical premise, using the area-perimeter ratio. This approach is often used to assess compactness versus complexity of patch shapes, where the larger the area relative to the perimeter, the more compact the patch shape tends to be; the smaller the area/perimeter ratio, the more complex the patch shape tends to be. This method is also widely used in landscape metrics analysis (Khan, 2025; Shukla & Jain, 2019). The interpretation of sprawl typologies using SEPI can be done as follows:

Table 1: Interpretation of the Sprawl Expansion Pattern Index

Sprawl / Expansion Type	Value Criteria (UEI / SEPI)	Spatial Characteristics
Edge Expansion (Contiguous)	$0 < SEPI \leq 0.50$	New patches grow outward from the edges of old built-up clusters; growth is relatively continuous, indicating an extension of the existing area (Chettry, 2022).
Ribbon / Linear Development	$0.50 < SEPI \leq 0.75$	New patches are elongated and oriented along corridors (e.g., main roads); the patch shape is relatively elongated, thin, and follows the existing accessibility network (Chettry, 2022).
Leapfrog / Scatter Expansion	SEPI = 0 (no common boundary)	New patches appear far apart from the old built-up zones — indicating fragmentation, jumping across vacant land, tending to create new enclaves within existing ones (Chettry, 2022).
Infill / Contiguous – Compact Growth	SEPI > 0.75 (depending on modification)	New patches emerge within or very close to old built-ups, filling “gaps” within the old urban fabric — signaling densification & spatial consolidation (Khan, 2025; Shukla & Jain, 2019).

Source: Research Team Literature Review, 2025

The strength of SEPI is its ability to capture the relational aspect of sprawl expansion, whether growth is an extension of existing clusters or the emergence of new, isolated patches, which facilitates interpretation of sprawl typologies and contiguity-based policy recommendations. SEPI is also relatively easy to calculate from multi-temporal binary map overlays (built-up vs. non-built-up) and patch geometry calculations in GIS (Shukla & Jain, 2019). However, SEPI has several limitations: it is sensitive to data resolution (small patches in low-resolution imagery can introduce bias), and it does not directly incorporate contextual factors such as proximity to the road network or

topographic characteristics. Therefore, SEPI should be combined with analysis of road proximity, buffer corridors, and other spatial attributes to ensure robust typology classification (Jatayu, 2023; Wang et al., 2020).

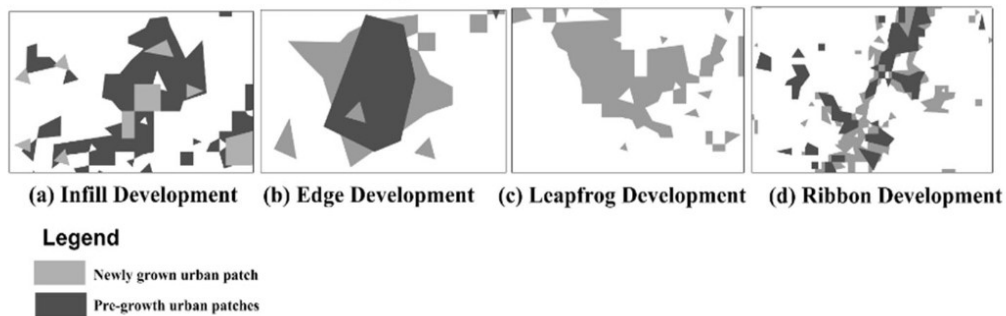


Figure 1: Urban Expansion Types
Source: Shukla & Jain, 2019

RESEARCH METHODOLOGY

This study uses a quantitative-spatial approach based on geospatial data analysis to identify urban sprawl types in six peri-urban districts of Manado City from 2004 to 2024. The analysis was conducted computationally, utilizing multi-temporal satellite imagery and techniques for extracting and quantifying built-up land change patches. The primary unit of analysis was built-up expansion patches during the study period. The analysis was conducted within district administrative boundaries to ensure the interpretation of the results remains relevant to the spatial planning policy framework.

Satellite imagery data comes from the Google Earth Engine (GEE) platform, utilizing Landsat imagery (Landsat 5/7 for 2004 and Landsat 8/9 for 2024), which is considered adequate in terms of temporal and spatial resolution for studying urban land dynamics. Administrative and boundary data were obtained from the Badan Informasi Geospasial (BIG) Indonesia. All data were converted to a consistent coordinate system before further processing.

The initial stage includes baseline image correction and a median composite to reduce cloud interference. Separation of built-up and unbuilt land is performed through a binary classification procedure using spectral indices such as the Normalized Difference Built-up Index (NDBI) and Modified Normalized Difference Water Index (MNDWI), and adaptive thresholding based on the pixel's surroundings. Visual validation is performed using point samples and high-resolution imagery in Google Earth to minimize classification errors. The results are several binary map layers: 2004, 2012, 2018, and 2024.

The resulting classification maps for each period were then overlaid to extract areas of change that became built-up land expansion patches. The patches

were then analyzed using geoprocessing in ArcGIS to calculate the main geometric parameters, namely the area and perimeter, of the expansion patches, to identify the spatial characteristics of patch growth (Shukla & Jain, 2019).

The SEPI metric is calculated as the ratio of the area of an expansion patch to its perimeter. The SEPI value is then used to classify sprawl types into several categories, such as edge, leapfrog, ribbon, and infill development. The classification criteria refer to the approach of Shukla & Jain (2019), which assesses patches based on their location relative to existing built-up clusters and their proximity to the main road network.

The distribution of each typology was analyzed as a percentage of the total expansion area and the total number of patches. The results were interpreted to identify dominant patterns and the direction of physical development in the study area. The interpretation took into account the context of infrastructure development, the physical characteristics, and local economic dynamics to ensure more applicable policy recommendations.

ANALYSIS AND DISCUSSION

General Description of the Study Area

The study area covers six peri-urban districts of Manado City: Malalayang, Wanea, Tikala, Paal Dua, Mapanget, and Bunaken. These districts were selected because they are located on the periphery of Manado City, bordering Minahasa Regency and North Minahasa Regency (Figure 2).

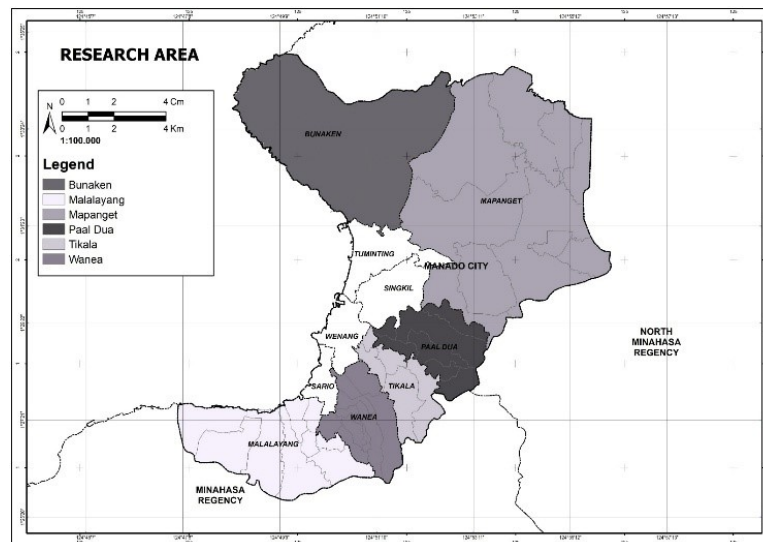


Figure 2: Delineation of the Study Area

Source: Processed Data by the Research Team, 2025

The highest elevation in Manado City is in Bunaken District, reaching an altitude of approximately 582-807 meters above sea level. Approximately 85.26% of the study area lies at elevations below 97 meters above sea level. Elevations above 96 meters above sea level are found only in Bunaken, Malayang, Mapanget, and Wanea districts. Approximately 69.75% of the study area has relatively gentle slopes between 0-15%, with the remainder having slopes above 15%. There are three districts with slopes greater than 40%: Malalayang, Bunaken, and Mapanget. Mapanget has the largest proportion of flat to gently sloping areas (0-15%), accounting for 90.31% of its total area. Meanwhile, Bunaken has only about 47.82% of its area with flat to gently sloping areas (0-15%). Overall, on the six peri-urban districts, data shows that the proportion of buildable areas (0-15%) reaches 69.75% of the total area.

Morphologically, these six districts are characterized by volcanic lava flows and hills with a total proportion reaching 42.175%. Two districts are identified as having mountainous areas: Malalayang and Bunaken. In Bunaken District, mountainous areas account for 45.39% of the total area. Areas with tidal swamps and mangrove habitats have also been identified within this District. All six districts, with the exception of Tikala, have plains, accounting for 45.23%. Mapanget District, in particular, is the most dominant plains morphology, accounting for 82.03% of its area.

The majority of the study area falls under the low disaster risk category, reaching 97.67% of the total area. Common hazards include flooding in the catchment areas of several rivers flowing into Manado City, and landslides in areas with steep slopes and volcanic soils.

Built-up Land of the Study Area

Figure 3 shows the results of the identification of built-up land in the six districts within the study area from 2004 to 2024. The images show the periodic changes in built-up land area with different shades. The distribution of built-up land in Wanea, Tikala, and Malalayang districts tends to have almost the same pattern, where the concentration of built-up land tends to be in the zone relatively close to the service center of Manado City (Sario and Wenang districts), and decreases with increasing distance from the city center. On the other hand, in Paal Dua, Mapanget, and Bunaken districts, the distribution of built-up land looks more irregular and tends to follow the pattern of the main road network in the districts.

Table 2 shows the quantified built-up land and its percentage on each district during 2004-2024. It can be seen that in the study area, the percentage of built-up land area tends to increase over time. Wanea has the largest proportion of built-up land area, reaching approximately 45% in 2024. Bunaken has the lowest proportion of built-up land at <5% in 2024. Mapanget also has a low proportion of built-up land (<15%), while the other 3 districts (Tikala, Paal Dua,

and Malalayang) have a fairly high proportion (approximately 30%). The very low proportion in Bunaken is mainly due to its landscape conditions, which are dominated by hilly areas with steep slopes and the presence of the protected zone of Mount Tumpa and Bunaken National Park. Mapanget District is the district with the largest buildable land area and is planned as a new development zone.

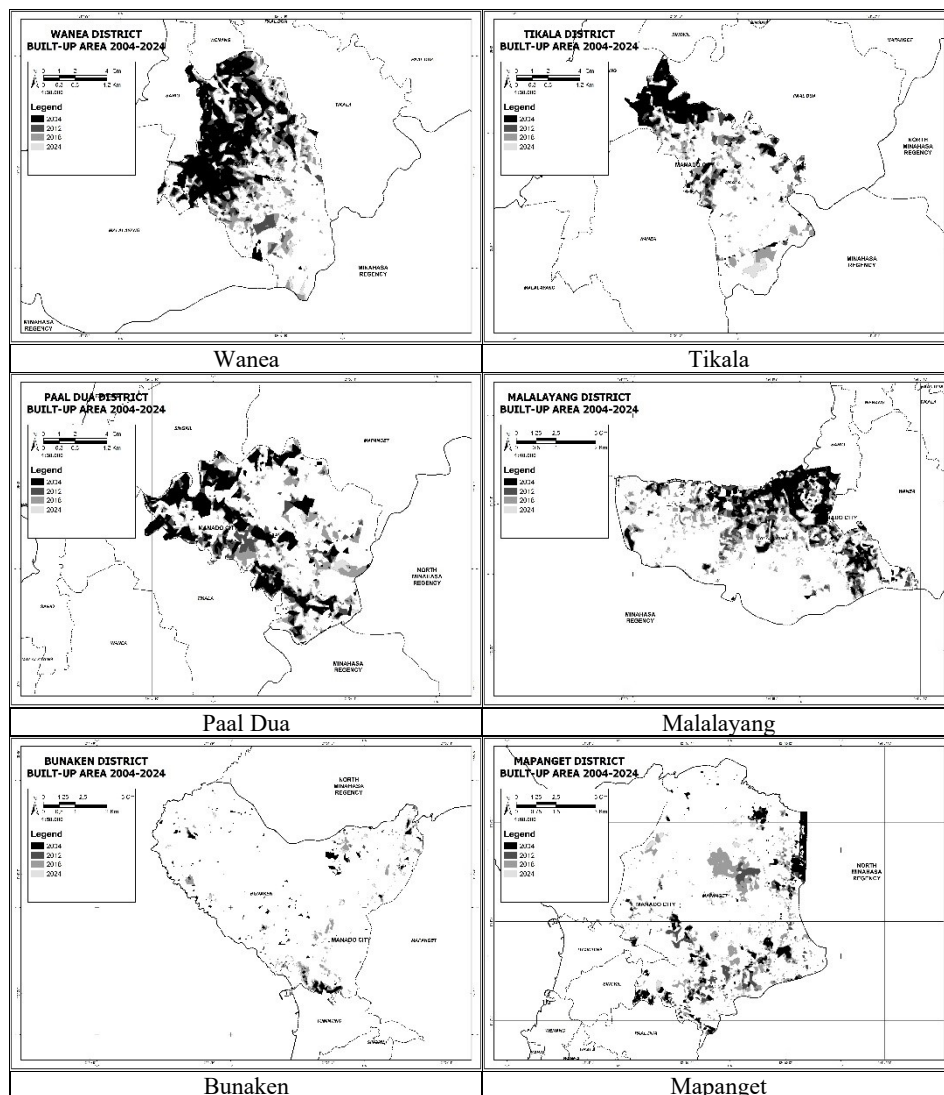


Figure 3: Map of Built-up Land Growth in the Study Area 2004-2024

Source: Processed Data by the Research Team, 2025

Table 2: Built-up Land Conditions of the Study Area

Districts	Total Area	Built-up Land							
		2004		2012		2018		2024	
		Ha	%	Ha	%	Ha	%	Ha	%
Wanea	857,45	246,62	28,76	278,94	32,53	364,43	42,50	391,27	45,63
Tikala	668,44	102,50	15,33	123,91	18,54	179,29	26,82	194,33	29,07
Paal Dua	937,26	199,17	21,25	230,48	24,59	287,86	30,71	294,00	31,37
Malalayang	1.780,84	257,08	14,44	335,86	18,86	476,11	26,74	530,74	29,80
Bunaken	3.171,65	60,89	1,92	64,79	2,04	82,19	2,59	105,35	3,32
Mapanget	5.377,33	272,32	5,06	364,68	6,78	652,06	12,13	718,21	13,36
Total	12.792,98	1.138,58	8,90	1.398,67	10,93	2.041,94	15,96	2.233,90	17,46

Source: Research Team Analysis Results

Table 3 below shows the growth rate dynamics of the built-up land in the study area, over three observation periods. A relatively similar pattern is evident, with an increase in the growth rate from 2012 to 2018 compared to the previous, longer period from 2004 to 2012. Conversely, there is a significant downward trend in the growth rate from 2018 to 2024, even lower than the growth rate from 2004 to 2012, except in Bunaken, which showed a slight increase compared to the previous period. The drastic decline from 2018 to 2024 is thought to be closely related to the COVID-19 pandemic, which has significantly impacted the economy and development in both the private and public sectors. Considering this, the decline in the growth rate during this period can be seen as a unique situation. Therefore, it is also estimated that the trend will likely rebound in the following period, mirroring the previous period. So, there is an urgency to replicate this study at least five years into the future to obtain a more valid trend.

Table 3: Growth of Built-up Land in the Study Area 2004-2024

Districts	Growth Rate (%)		
	2004-2012	2012-2018	2018-2024
Wanea	13,11	30,65	7,36
Tikala	20,89	44,70	8,38
Paal Dua	15,72	24,89	2,14
Malalayang	30,65	41,76	11,48
Bunaken	6,40	26,85	28,18
Mapanget	33,92	78,80	10,14
Total	22,84	45,99	9,40

Source: Research Team Analysis Results

Sprawl Expansion Pattern Index & Its Interpretation

According to the methodology, using the previously mapped built-up land patches from 2004 to 2024, the SEPI values then were calculated and interpreted to indicate the types of sprawl. Figure 4 is the resulting thematic maps that depict the distribution of sprawl types that occurred in the six peri-urban districts of Manado City as the study area, based on the observation period.

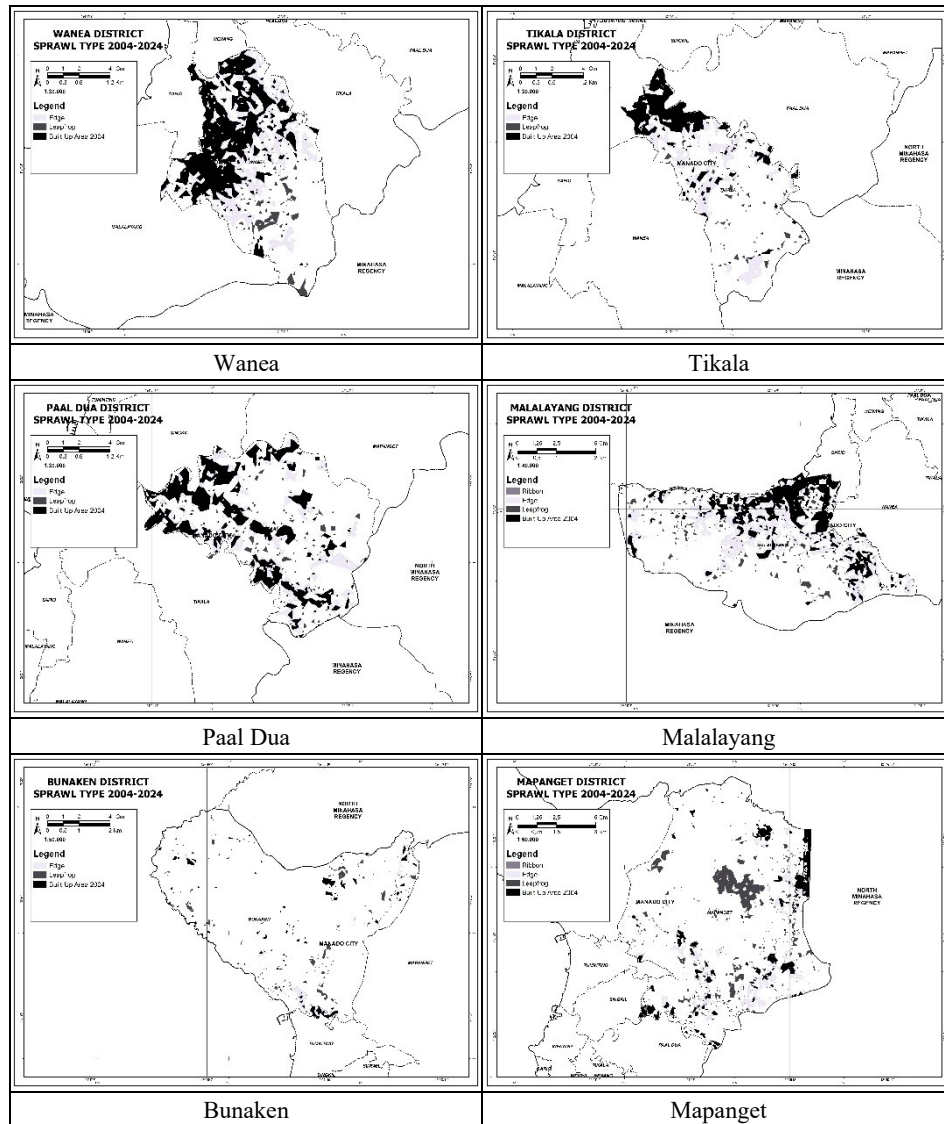


Figure 4: Sprawl Type Distribution Map in the Study Area, 2004-2024
 Source: Research Team Analysis Results

Based on these thematic maps, Table 4 below quantitatively describes the types of sprawl that occurred in the study area based on the observation period. The table shows that in all peri-urban districts of Manado City, the dominant type of sprawl is edge sprawl, with a tendency to increase periodically. Field observations also indicate that this is primarily related to the expansion of

housing clusters developed utilizing the availability of undeveloped land bordering existing housing areas, driven by efforts to optimize the availability of pre-existing infrastructure and public facilities. This expansion is also suspected to be driven by considerations of land economic value and sociocultural factors, which favor building in zones with relatively established neighborhoods. In the context of expansion of several clusters of built-up land that are relatively close together, this type of sprawl is identical to infill development, which over time unites these built-up land clusters into a compact built-up cluster, encouraging increased land use efficiency and reducing open space fragmentation. This can be appreciated as a positive aspect, despite the other negative effects of sprawl.

Table 4: Sprawl Types in the Study Area 2004-2024

Districts	Sprawl Types	2004-2012		2012-2018		2018-2024	
		(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Wanea	Leapfrog	8,26	25,55	7,49	8,76	1,19	4,42
	Edge	24,06	74,45	78,00	91,24	25,17	93,77
	Ribbon	0,00	0,00	0,00	0,00	0,48	1,80
Tikala	Leapfrog	3,38	15,80	10,83	19,56	0,90	5,96
	Edge	18,03	84,20	44,52	80,39	14,02	93,26
	Ribbon	0,00	0,00	0,03	0,05	0,12	0,78
Paal Dua	Leapfrog	3,90	12,45	4,74	8,27	0,25	4,00
	Edge	27,28	87,14	51,61	89,95	5,90	95,96
	Ribbon	0,13	0,41	1,03	1,79	0,00	0,04
Malalayang	Leapfrog	10,41	13,21	20,04	14,29	3,63	6,65
	Edge	68,24	86,62	120,20	85,71	49,88	91,31
	Ribbon	0,13	0,17	0,00	0,00	1,12	2,05
Bunaken	Leapfrog	1,35	34,52	7,81	44,90	5,77	24,91
	Edge	2,55	65,48	9,59	55,10	17,33	74,82
	Ribbon	0,00	0,00	0,00	0,00	0,06	0,27
Mapanget	Leapfrog	41,57	45,00	64,43	22,42	11,51	17,40
	Edge	48,31	52,30	222,95	77,58	51,90	78,45
	Ribbon	2,49	2,69	0,00	0,00	2,74	4,14
Total	Leapfrog	68,86	26,48	115,35	17,93	23,24	12,11
	Edge	188,47	72,47	526,87	81,90	164,19	85,53
	Ribbon	2,75	1,06	1,05	0,16	4,53	2,36

Source: Research Team Analysis Results

Another type of sprawl observed to be quite significant is leapfrog sprawl, or "jump-over" development, which is a major contributor to open space fragmentation. While significantly different in extent from edge expansion, this type is quite prominent in Bunaken and Mapanget districts. In Bunaken district, field observations indicate that this is caused by sporadic development practices by various parties in locations separate from existing built-up land clusters. This is thought to be driven by the highly dynamic landscape conditions in this district,

which are related to its slopes. In Mapanget district, leapfrog sprawl is typically driven by the emergence of new housing clusters separate from previously built-up land clusters. To reduce the continuation of leapfrog sprawl in peri-urban Manado, more specific spatial control mechanisms are required. In Mapanget District, where large areas of developable land remain available, local government should prioritize contiguous development through phased land development permits, mandatory adjacency requirements for new housing projects, and infrastructure sequencing policies that prioritize areas directly connected to existing built-up clusters. In Bunaken and Malalayang Districts, where topographic constraints encourage scattered development, stricter zoning enforcement and development suitability assessments should be applied to prevent isolated residential clusters on environmentally sensitive or inaccessible land. The provision of new road infrastructure and utility networks should also be selectively limited in fragmented expansion areas in order to discourage inefficient spatial growth patterns.

Ribbon sprawl is very small in proportion and is more concentrated along several main roads or new roads, such as the Manado City ring road corridor that traverses these districts.

The following Table 5 compares the cumulative growth of built-up area by sprawl type from 2004 to 2024 across the six districts of the study area. They indicate that the dominant sprawl type in all districts is edge sprawl, followed by leapfrog sprawl, while ribbon sprawl has a very small proportion.

Table 5: Comparison of Sprawl Types in the Study Area 2004-2024

Districts	Built-up Land Expansion Area (Ha) Based on Sprawl Type			
	Leapfrog	Edge	Ribbon	Total
Wanea	16,93	127,23	0,48	144,65
Tikala	15,11	76,57	0,15	91,83
Paal Dua	8,89	84,79	1,16	94,83
Malalayang	34,08	238,33	1,25	273,66
Bunaken	14,93	29,47	0,06	44,46
Mapanget	117,51	323,16	5,23	445,89
Total	207,45	879,54	8,33	1095,32

Source: Research Team Analysis Results

The result above shows that regardless of its proportion to the area of each district, the largest growth of built-up land occurred in Mapanget district, followed by Malalayang, Wanea, Tikala, Paal Dua, and Bunaken as the smallest. The high growth in Mapanget district is a logical consequence of the high availability of buildable land compared to other districts. This is also in line with the Manado City spatial planning policy, which designates the district as a prioritized development area. The relatively high growth in Malalayang is a logical consequence of the existence of the primary arterial road corridor which

encourages the development of this district as an extension of Manado City's service center in the Sario-Wenang district, forming a linear service center corridor. The low growth in Bunaken district is a logical consequence of its extreme landscape context with limited buildable land, the relatively long distance to the city's service center and limited infrastructure support.

CONCLUSION

Based on the analysis and interpretation, the following conclusions are drawn:

- 1) SEPI calculations for 2004–2024 show that urban sprawl in the study area is predominantly edge expansion, accounting for 80.30% of total built-up growth. This type occurs through the outward growth of existing built-up clusters, especially residential areas, and often functions as infill sprawl that gradually merges separate clusters into more compact forms. Such a trend indicates increasing land-use efficiency and densification. Therefore, spatial control efforts should prioritize maintaining this pattern by regulating building permits and optimizing ready-to-build areas with adequate infrastructure adjacent to existing clusters, especially in Mapanget Districts.
- 2) Leapfrog sprawl accounts for 18.94% and reflects fragmented development that jumps across open land. It is prominent in districts with large areas of developable land (e.g., Mapanget) or constrained topography (e.g., Bunaken and Malalayang), which limit edge expansion. This pattern should be proportionally reduced through more targeted spatial control mechanisms. In Mapanget, development permits should be directed toward contiguous edge and infill expansion by applying phased growth management, minimum adjacency requirements for new housing estates, and infrastructure provision priorities limited to areas connected with existing built-up clusters. In Bunaken and Malalayang, stricter zoning controls, topographic suitability screening, and selective infrastructure expansion should be implemented to prevent isolated residential enclaves and inefficient land fragmentation. These mechanisms are expected to support more compact and sustainable peri-urban growth in Manado City.
- 3) Ribbon sprawl, characterized by linear growth along main road corridors, represents only 0.76% of total expansion. It occurs in several primary corridors, particularly along the Manado City ring road.

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