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Urban Sprawl Evolution in a River-Split City: A 20-Year Analysis of Palembang

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ABSTRACT

Rapid urbanization in developing countries often triggers uncontrolled urban sprawl. Palembang, the capital of South Sumatra, presents a unique case as a split city bisected by the Musi River, creating complex spatial dynamics. This research aims to uncover the spatiotemporal patterns of urban sprawl in Palembang over the last two decades (2003–2023) and analyze the direction of its physical development. The study employs a multitemporal remote sensing approach using Landsat 5, 8, and 9 satellite imagery at five-year intervals. Spatial analysis was conducted using the Normalized Difference Built-up Index (NDBI) and Modified Normalized Difference Water Index (MNDWI) to extract built-up land cover. The direction of expansion was quantified using rose diagrams to determine spatial distribution tendencies relative to the Central Business District (CBD). The results reveal a massive conversion of non-built-up land, with built-up areas increasing from 8,434.34 ha in 2003 to 15,542.36 ha in 2023. A key finding is the morphological shift from a traditional radial-centrifugal pattern to an asymmetric polycentric model. Urban growth exhibits a dominant directional bias toward the North and Northwest (Sukarami and Alang-Alang Lebar), primarily driven by infrastructure accessibility. Conversely, the Southern region (Ulu) remains stagnant due to physical wetland constraints, hydro-spatial friction, and limited connectivity. This study contributes to urban geography by establishing hydro-spatial friction as a critical determinant in urban evolution, demonstrating how natural barriers can override conventional growth models. The findings recommend Integrated Corridor Management, strict zoning policies, and transit-oriented development to mitigate the environmental impacts of low-density sprawl and promote balanced urban growth.

INTRODUCTION

Urbanization has emerged as one of the most significant demographic and spatial trends of the 21st century, with over half of the global population now residing in urban areas (James, 2024; Ying, 2025). Cities, particularly in developing countries like Indonesia, are experiencing rapid population growth rates, often triggering the physical expansion of cities, commonly a phenomenon known as urban sprawl (Brasika et al., 2025; Civelli et al., 2023). This expansion is not merely an increase in built-up areas; it involves complex changes in land cover, infrastructure, and socio-economic dynamics (Jing et al., 2022; Miah et al., 2024). In Indonesia, a nation with a high urbanization rate, urban expansion is a pressing issue that demands serious attention from planners and policymakers.

Uncontrolled urban expansion can lead to multidimensional impacts, including the loss of fertile agricultural land, fragmentation of natural habitats, increased carbon footprints, and alterations to hydrological systems (Diaconu et al., 2025; Y. Li et al., 2025). From a social perspective, it can lengthen commuter distances, increase living costs, and create spatial segregation between city centers and peripheral areas (Chai, 2024; Escolano-Utrilla et al., 2024). Furthermore, the need for adequate infrastructure, such as roads, clean water, sanitation, and energy, poses a significant challenge for local governments, who often struggle to keep pace with the rapid pace of urban development.

The city of Palembang, as the capital of South Sumatra Province, presents a compelling and significant research site for examining urban sprawl. Geographically, Palembang is known as a "split city" because the mighty Musi River bisects it. The morphology of a split city is inherently more complex than that of a compact land-based city, as the river acts as a primary determinant of spatial configuration (Adiyanto & Atyanta, 2020; Heldayani et al., 2024; Wicaksono et al., 2022). This fragmentation necessitates a deeper analysis of urban morphology, which examines the physical form and evolution of urban structures over time. In river-split contexts, urban development is often characterized by hydro-spatial friction, in which the water body serves as both a central identity and a physical barrier that constrains uniform expansion (Mobaraki et al., 2025; Noaime & Alnaim, 2025).

Beyond its geographical distinctiveness, Palembang is an ancient city with a rich history rooted in the Srivijayan civilization, a crucial element in formulating a livable city concept grounded in its local context and sense of place. As cities reach their carrying capacity in the central core, they often transition toward a polycentric urban form, in which new sub-centers emerge on the periphery to accommodate growth (Jing et al., 2022; Ondoš et al., 2025; Wang & Liu, 2025). This process is governed by the principle of spatial refinement, where capital and infrastructure development gravitate toward areas with the least physical resistance and highest accessibility (Zhou & Liu, 2022).

In Palembang, this leads to an asymmetric expansion where the North-Northwest corridor, supported by airport access and arterial roads, evolves more rapidly than the swamp-dominated Southern region. Data indicate a continuous population increase, reaching 1,772,492 inhabitants in 2023, with an average growth rate of 1.44% (Palembang City Health Service, 2023). Given the complexity, monitoring urban sprawl using remote sensing offers an effective approach for assessing changes in built-up land cover as an indicator of expansion (Yu & Fang, 2023; Zhu et al., 2022).

Despite the abundance of literature on urban sprawl, a significant research gap remains in understanding how hydro-geomorphological barriers, such as major river systems and extensive riparian wetlands, interact with infrastructure policies to determine the long-term directionality of sprawl. Most existing models are derived from terrestrial cities and fail to capture the morphological inertia found in split cities, where natural barriers and wetland ecosystems dictate the direction of urban sprawl, even when countered by modern infrastructure (M. Li et al., 2025; Miah et al., 2024). Previous research on split cities such as Budapest (Hungary) and Louisville (United States) often indicates that urban development tends to be more rapid on one side due to historical factors or accessibility (Padawangi et al., 2025; Tolnai, 2018). However, specific analysis of the patterns of urban sprawl and its development direction in Palembang using multi-temporal imagery over the past two decades remains limited.

This study contributes to the literature by providing a nuanced 20-year analysis of how hydro-spatial friction creates an asymmetric polycentric model, offering a new perspective on urban evolution in tropical riverine environments. The strength of this research lies in its integrated use of multi-index spectral analysis (NDBI and MNDWI) to achieve higher precision in differentiating built-up areas from complex wetland backgrounds, a technical challenge often encountered in riverfront studies (Zhang et al., 2025). Unlike previous studies that treat urban growth as a generic increase in area, this research identifies the specific morphological shift toward an asymmetric polycentric model, providing a more nuanced understanding of urban evolution in tropical riverine settings (Gao et al., 2025).

Furthermore, the practical benefit of this study lies in its application for Integrated Corridor Management in Palembang. By identifying the dominant growth bias toward the North-Northwest, this research provides an empirical basis for local governments to establish Green Belts to protect remaining wetlands and to promote Transit-Oriented Development (TOD) to encourage sustainable densification.

Scientifically, this study enhances understanding of urban evolution by demonstrating how natural landscapes and hydro-spatial friction act as primary determinants that can override conventional ones. Therefore, this research aims to uncover the spatiotemporal patterns of urban sprawl in Palembang from 2003 to 2023, providing a specialized framework and strategic recommendations for managing future settlements and infrastructure expansion in tropical riverine environments.

RESEARCH METHODS

Study Area

This research employs a rationalistic approach, grounded in empirical facts and relevant theories. Palembang was selected as the study location due to several unique physical characteristics. It is a non-compact, split city, meaning its physical appearance is seemingly divided into two parts by the large Musi River. Additionally, Palembang is an ancient city with a strong historical connection to the Srivijayan Kingdom, reflected in its cultural landscape, architecture, traditions, and community identity. Its high urbanization rate, high development intensity, and role as a regional economic hub all contribute to its ongoing urban development (Fig. 1).

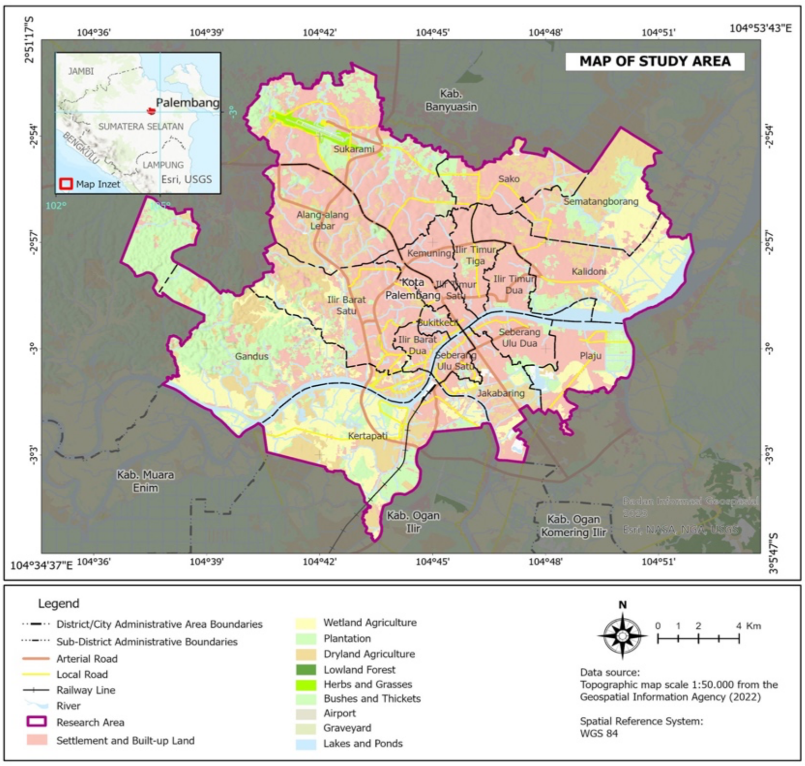

Figure 1. Map of Study Area in Palembang, South Sumatra, Indonesia
(Source: Data Processing, 2024)

Sources of Data

Urban expansion was analyzed based on observed changes in land cover (Linh et al., 2024; Rana & Sarkar, 2021). The proxy variable used to study these dynamics was built-up land cover. A multi-temporal remote sensing approach was applied for interpretation, with the analysis spanning 5-year intervals from 2003 to 2023. The procedure for conducting spatial-temporal analysis is illustrated in Figure 2. The foundational data utilized were LANDSAT 5, 8, and 9 imagery, with specifications as presented in Table 1.

Table 1. Specifications of Satellite Imagery Used in Urban Expansion Analysis

Specification	Landsat 5	Landsat 8	Landsat 9
Launch Year	1984	2013	2021
Sensor	Thematic Mapper	OLI TIRS	OLI-2 TIRS-2
Number of Bands	7	11 (9 OLI + 2 TIRS)	11 (9 OLI-2 + 2 TIRS-2)
Spatial Resolution	30 m (Band 1-5,7) 120 m (Band 6)	30 m (OLI) 100 m (TIRS)	30 m (OLI) 100 m (TIRS)
Spectral Resolution	0.45 - 2.35 μm	0.43 - 2.29 μm (OLI) 10.6 - 12.5 μm (TIRS)	0.43 - 2.29 μm (OLI) 10.6 - 12.5 μm (TIRS)
Temporal Resolution	16 Days	16 Days	16 Days
Swath Width	185 km	185 km	185 km

(Source: Compiled from U.S. Geological Survey (USGS) Landsat Mission Technical Specifications (USGS, 2024). Available online: https://www.usgs.gov/landsat-missions)

Each image was accessed and processed through Google Earth Engine (GEE). Data harmonization across the three Landsat missions was achieved through two measures. First, all images were sourced from surface reflectance products (Collection 2, Level-2), which have undergone standard atmospheric and radiometric correction by USGS prior to distribution, ensuring spectral consistency across sensors and acquisition dates. Second, a median image reducer was applied within each observation year to generate a single representative composite image, reducing the influence of seasonal variation, cloud contamination, and residual atmospheric effects. The next stage involved interpreting built-up land objects using spectral image indices: the Normalized Difference Built-up Index (NDBI) and the Modified Normalized Difference Water Index (MNDWI).

Procedure of the study

The NDBI was used to identify and map built-up areas from satellite imagery by leveraging the spectral differences between the Near-Infrared (NIR) and Mid-Infrared (MIR) bands (Biney et al., 2026; Selka et al., 2024). The two bands have spectral characteristics that are sensitive to differences in the reflectance of mineral-based objects (Table 2).

Table 2. Bands Used in NDBI Analysis

Sensor	**NIR Band**	**SWIR (SWIR 1) Band**
Landsat 5 (TM)	Band 4 (0.76 – 0.90 μm)	Band 5 (1.55 – 1.75 μm)
Landsat 8 (OLI)	Band 5 (0.845 – 0.885 μm)	Band 6 (1.560 – 1.660 μm)
Landsat 9 (OLI-2)	Band 5 (0.845 – 0.885 μm)	Band 6 (1.560 – 1.660 μm)

(Source: Compiled from U.S. Geological Survey (USGS) Landsat Mission Technical Specifications (USGS, 2024). Available online: https://www.usgs.gov/landsat-missions)

These materials, such as soil, concrete, and metals, are the primary components of buildings within the study area. The formula for the NDBI is presented in Equation (1).

$$\text{NDBI} = \frac{\text{SWIR} - \text{NIR}}{\text{SWIR} + \text{NIR}} \quad (1)$$

In contrast to NDBI, the Modified Normalized Difference Water Index (MNDWI) method is used to identify water bodies such as rivers, lakes, reservoirs, and swamps by reducing interference from built-up areas and vegetation (Pan et al., 2020). The MNDWI formula, as shown in (2), utilizes the Green band, which is sensitive to the water content within underlying vegetation. The Shortwave-Infrared (SWIR) band is also included in the formula due to its high absorption levels in objects with water content. The combination of NDBI and MNDWI can strengthen the differentiation of built-up land (Osgouei et al., 2019). The formula for MNDWI is presented as follows:

$$\text{MNDWI} = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}} \quad (2)$$

To determine built-up land cover classes, visual interpretation and experimental thresholding of pixel values were used. Although Landsat 5 (TM), Landsat 8 (OLI), and Landsat 9 (OLI-2) differ in radiometric resolution and signal-to-noise characteristics, the spectral bands required for NDBI and MNDWI computation are consistent across all three sensors. Built-up and non-built-up land were then differentiated using threshold conditions of NDBI > −0.1 and MNDWI ≥ 0 (Chang et al., 2022). The output was a raster map of built-up land for each observation year: 2003, 2008, 2013, 2018, and 2023. Accuracy assessment was performed through visual interpretation of each satellite image, yielding overall accuracy and a Kappa coefficient, given the practical limitations of obtaining ground-truth data for historical acquisition dates.

The built-up land cover for each observation year was analyzed using the overlay method to illustrate urban expansion. Sub-district administrative maps were used as the spatial base for calculating urban development. The area of change in built-up land cover was subsequently calculated for each sub-district (Fig. 2).

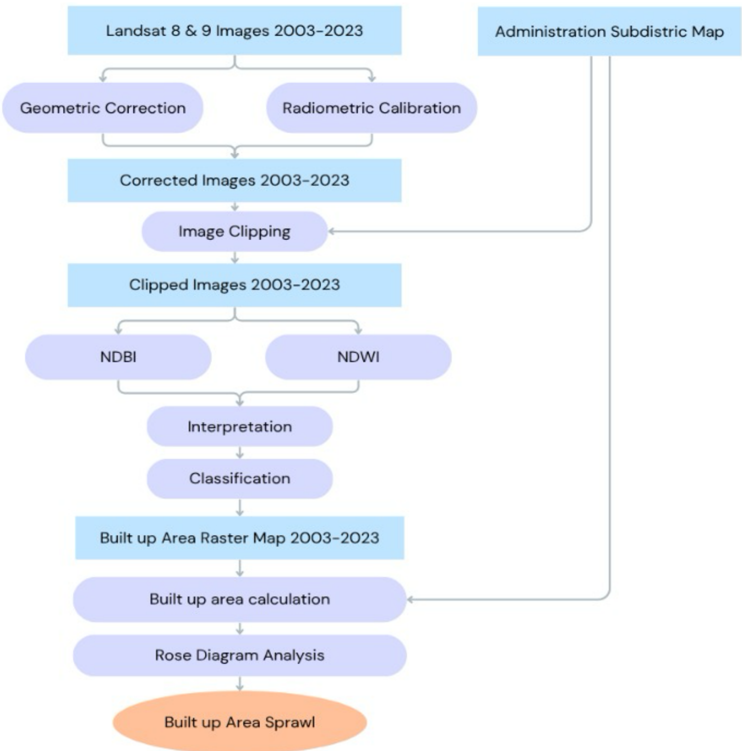

Figure 2. Research Flow Diagram (Source: Data Processing, 2026)

Urban development is not solely about the quantitative increase of built-up land; it also has a directional aspect. We analyzed the direction of development using a rose diagram. This method was chosen for its effectiveness in presenting multidimensional and distributional information (Chi et al., 2022). The direction of development was classified into eight quadrants, with the Central Business District (CBD) of Palembang City defined as the central point. The development value (lt) was quantified as the proportion of the increase in built-up land area relative to the total built-up area, expressed as a percentage (%). The calculation formula is as follows:

$$\% \, lt = \frac{\Delta \, lt}{\Sigma \, A \, lt} \times 100 \, \% \, \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where:
$\Delta \, lt$: increase in built-up land
$\Sigma \, A \, lt$: total built-up area

Taken together, this research employs a systematic and multi-faceted methodology, integrating a distinct case study (Palembang), reliable multi-temporal satellite data (Landsat), and proven spectral analysis techniques (NDBI and MNDWI). This rigorous approach is instrumental in accurately quantifying the magnitude, extent, and directional bias of urban growth, thereby ensuring the generation of highly robust and validated findings.

RESULTS AND DISCUSSION

Palembang City continues to experience physical urban development annually. A conversion of land from previously non-built-up to built-up areas has occurred, driven by population growth and an increasing urbanization rate. Data from the Palembang City Central Bureau of Statistics indicate that the total population in 2023 was 1,772,492 inhabitants, with an average annual population growth rate of 1.44% from 2013 to 2023, as shown in Figure 3. The highest growth rate occurred during the 2021–2022 period, reaching 2.58%, while the lowest rate was observed during the 2020–2021 period, at 0.28% (Fig. 3).

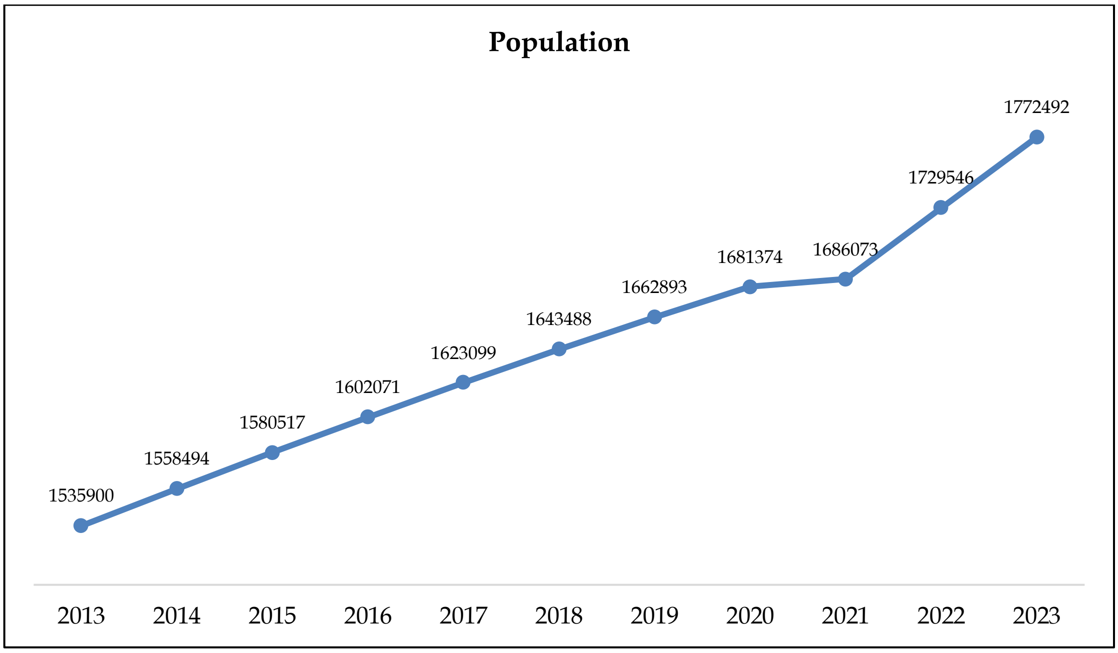

Figure 3. Population growth chart of Palembang City from 2013 to 2023 (Source: BPS, 2024)

Based on data from the Palembang City Central Bureau of Statistics (BPS) in its 2023 "Palembang in Figures" publication, the sub-district with the lowest population is Bukit Kecil (38,704 inhabitants), while Sukarami has the highest (196,752 inhabitants). The sub-districts, ranked from the lowest to highest population among the 18 sub-districts, are as follows: Bukit Kecil, Sematang Borang, Ilir Timur Satu, Ilir Barat

Dua, Ilir Timur Tiga, Gandus, Kemuning, Ilir Timur Dua, Jakabaring, Seberang Ulu Satu, Kertapati, Plaju, Seberang Ulu Dua, Alang-alang Lebar, Sako, Kalidoni, Ilir Barat Satu, and Sukarami. This distribution is illustrated in Figure 4. This pattern indicates a dispersed, rather than a city-center-concentrated, population distribution.

Further insights into Palembang's demographics reveal that the lowest population density is 16 persons/hectare in the Gandus sub-district. In comparison, the highest density is 237 persons/hectare in Seberang Ulu Satu sub-district. Analysis of population density reveals a clustering of residents in areas surrounding the city center, specifically Ilir Timur Satu, Bukit Kecil, Ilir Barat Dua, and Seberang Ulu Satu. This observation aligns with Burgess's Concentric Zone Theory.

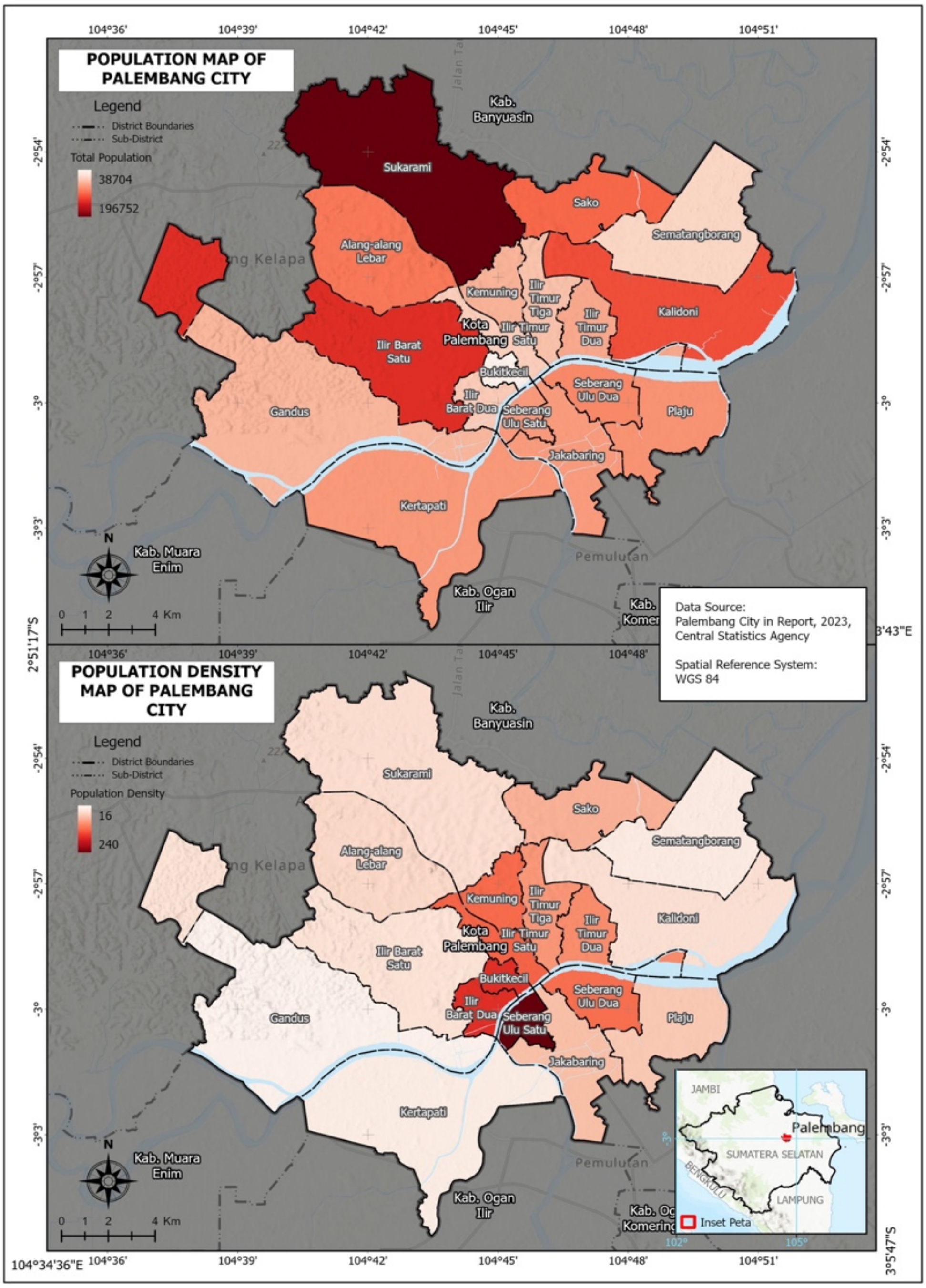

Figure 4. Population and population density of Palembang City in 2023
(Source: Data Processing, 2026)

Population growth can trigger the physical expansion of a city, a phenomenon known as urban sprawl. In this research, urban physical growth was monitored using multi-temporal Landsat (5, 8, and 9) remote sensing data. The processing of Normalized Difference Built-up Index (NDBI) and Modified Normalized Difference Water Index (MNDWI) transformations on Landsat data aimed to facilitate the extraction of built-up area boundaries, two spectral indices were calculated: the Normalized Difference Built-up Index (NDBI) and the Modified Normalized Difference Water Index (MNDWI). NDBI is computed from the shortwave infrared (SWIR) and near-infrared (NIR) bands and yields positive values over impervious surfaces (e.g., rooftops, roads) and negative values over vegetation and water. MNDWI, derived from the green and SWIR bands, yields positive values over water bodies and negative values over built-up land. By combining both indices, the ambiguity in classifying mixed pixels, particularly in distinguishing built-up areas from bare soil, can be reduced.

Threshold values were determined through an iterative process involving histogram analysis, descriptive statistics, and visual interpretation of the index images against high-resolution reference data. Areas with NDBI > -0.1 were considered built-up, as values above this threshold consistently corresponded to impervious surface signatures in the study area. A complementary condition of MNDWI ≥ 0 was applied to exclude water bodies, which can exhibit spectral responses similar to built-up land in NDBI alone. These thresholds were validated across multiple acquisition dates to ensure temporal consistency.

The results of monitoring built-up land cover in Palembang City from 2003 to 2023 are presented in Figure 5. A visible reduction in non-built-up land area and an increase in built-up land area are observable. The built-up land area, which was 8,434.34 ha in 2003, increased to 15,542.36 ha in 2023. Conversely, the non-built-up land area, which was 26,817.96 ha in 2003, decreased to 19,709.94 ha in 2023. This indicates a 84.3% conversion of non-built-up land to built-up land within 10 years in Palembang City. The highest conversion occurred in the 2013-2018 period, reaching 26.61%

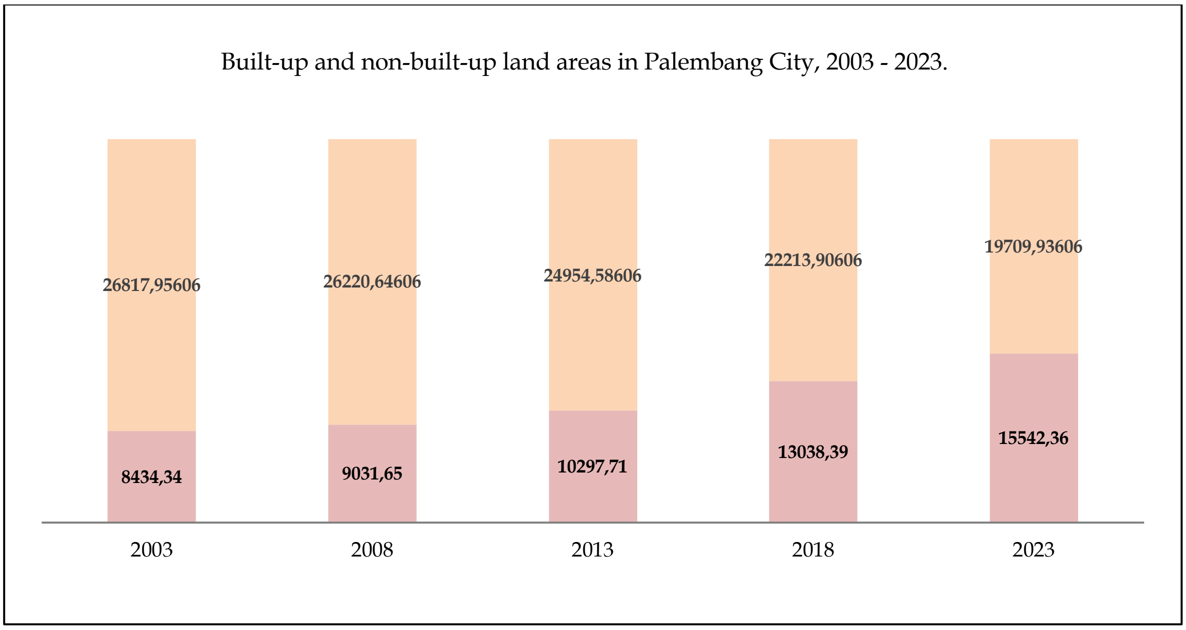

Figure 5. Comparison of built-up and non-built-up land areas in Palembang City, 2003 – 2023 (Source: Analysis Results, 2024)

The phenomenon of converting non-built-up land into built-up land in each sub-district of Palembang City can be observed and analyzed, as presented in Figure 6. The area values have been converted to percentages of built-up land cover relative to each sub-district's total area to avoid bias in the analysis. As a result, in 2023, the sub-districts with more than 80% built-up land cover were Ilir Timur Satu, Bukit Kecil, and Kemuning. These three areas are located within the Central Business District (CBD) zone of Palembang City. Conversely, the sub-districts with less than 30% built-up land cover in 2023 were Gandus, Kertapati, and Sematang Borang, all of which are peripheral areas of Palembang City

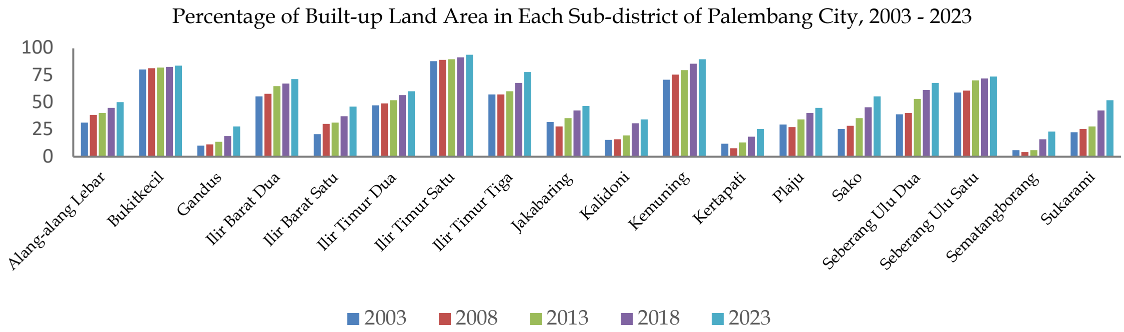

Figure 6. Graph of percentage change in built-up land area relative to total area per sub-district in Palembang City, 2003 – 2023 (Source: Analysis Results, 2024)

It is evident that over a decade (2003-2023), significant development dynamics have occurred, with the built-up land area increasing continuously and the non-built-up land area decreasing. Spatially, or in terms of footprint, the distribution of built-up land in 2003 was more concentrated in the center. In contrast, by 2023, built-up land had spread more widely across all areas of Palembang City, as presented in Figure 7. Furthermore, in 2003, the city's physical development was concentrated in the Ilir region, the area north of the Musi River. Starting in 2008, the city's physical development began to spread more evenly, including into the Ulu region, or the area south of the Musi River.

Accuracy assessment was conducted using 72 sample points obtained through stratified purposive sampling, with 4 sample points allocated to each of the 18 sub-districts in Palembang City. Reference data were obtained through visual interpretation of each Landsat satellite image for each observation year, given the practical limitations of acquiring ground-truth data for historical acquisition dates. The classification results were evaluated using a confusion matrix, from which Overall Accuracy (OA) and Kappa coefficient (κ) were derived for each observation year. The OA values ranged from 90.28% (2003) to 94.44% (2018), with Kappa coefficients ranging from 0.7925 (2023) to 0.8691 (2018), indicating substantial to almost perfect agreement between the classification results and the reference data (Dash et al., 2023), refer to table 3. The slight variation in accuracy across observation years is attributable to differences in atmospheric conditions, image acquisition complexity, and the increasing proportion of built-up land in later years, which introduces greater spectral ambiguity at urban fringe boundaries. Nevertheless, all accuracy values exceeded the commonly accepted threshold of 85% OA and 0.75 κ for remote sensing-based land cover classification (Congalton & Green, 2019), confirming that the multi-temporal built-up land cover maps produced in this study are reliable for urban expansion analysis.

Table 3. Accuracy and Kappa

Year	Overal Accuracy	Kappa Coefficient
2003	90.28%	0.8056
2008	93.06%	0.8607
2013	91.67%	0.8195
2018	94.44%	0.8691
2023	91.67%	0.7925

(Source: Analysis Results, 2024)

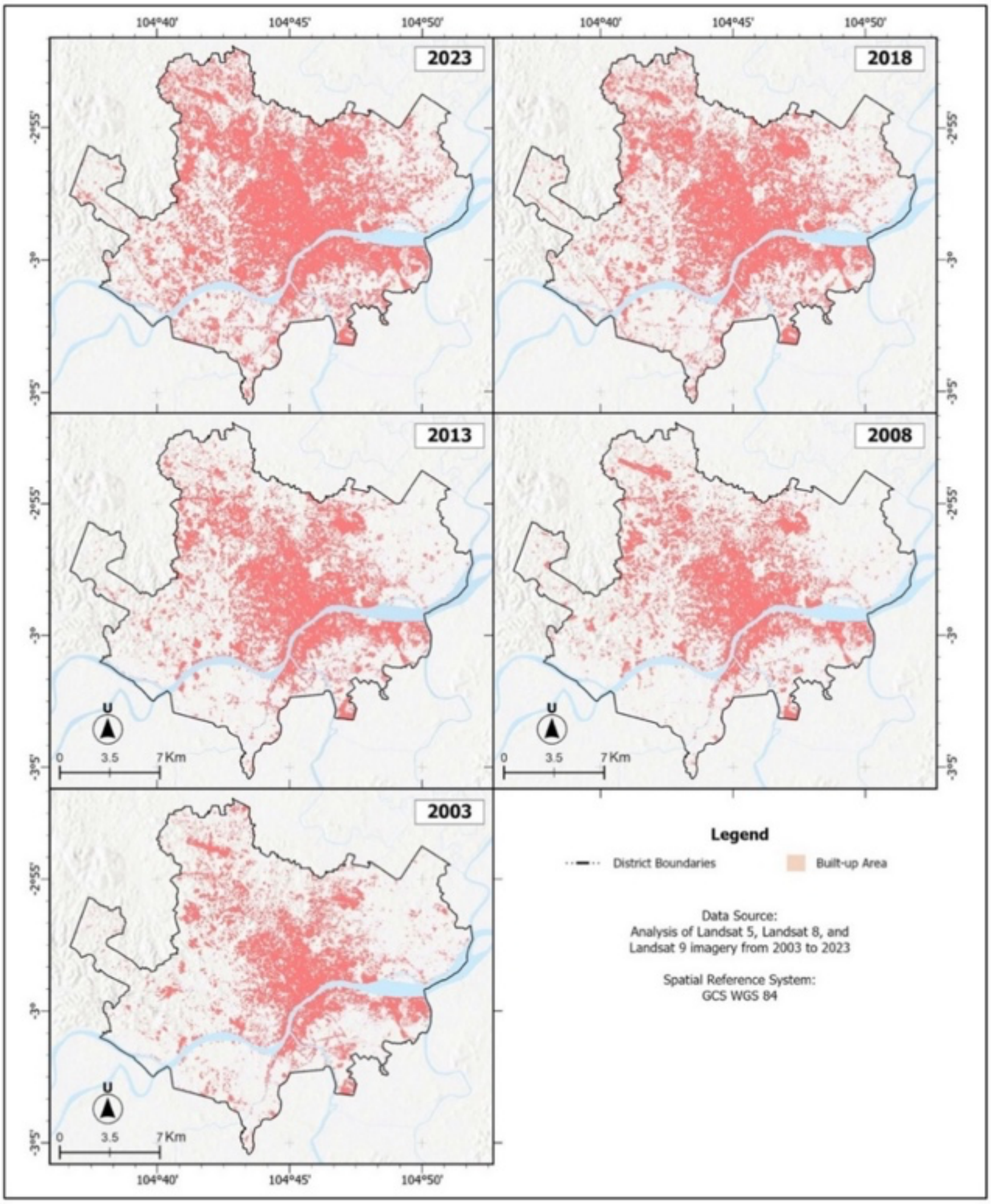

Figure 7. Built-up land cover of Palembang City, 2003-202
(Source: Analysis Results, 2024)

Regarding the dynamics of physical urban growth, known as urban sprawl, in Palembang City, there are notable differences across administrative sub-districts. Between 2003 and 2008, the first five years of the study, the highest growth in built-up land was concentrated in sub-districts north of the Musi River, specifically Ilir Barat Satu, Alang-alang Lebar, and Sako. These areas represent extensions of central urban development hubs such as Ilir Timur Dua, Bukit Kecil, and Kemuning. This trend shifted between 2008 and 2013, with urban characteristics extending farther eastward into sub-districts such as Sematang Borang, which accounted for 40% of the district's area. Concurrently, sub-districts in the southwest also experienced rapid development. Kertapati and Seberang Ulu Dua recorded the highest increases during this period, at 60% and 40% respectively. Further details on these urban changes can be observed in Figure 8.

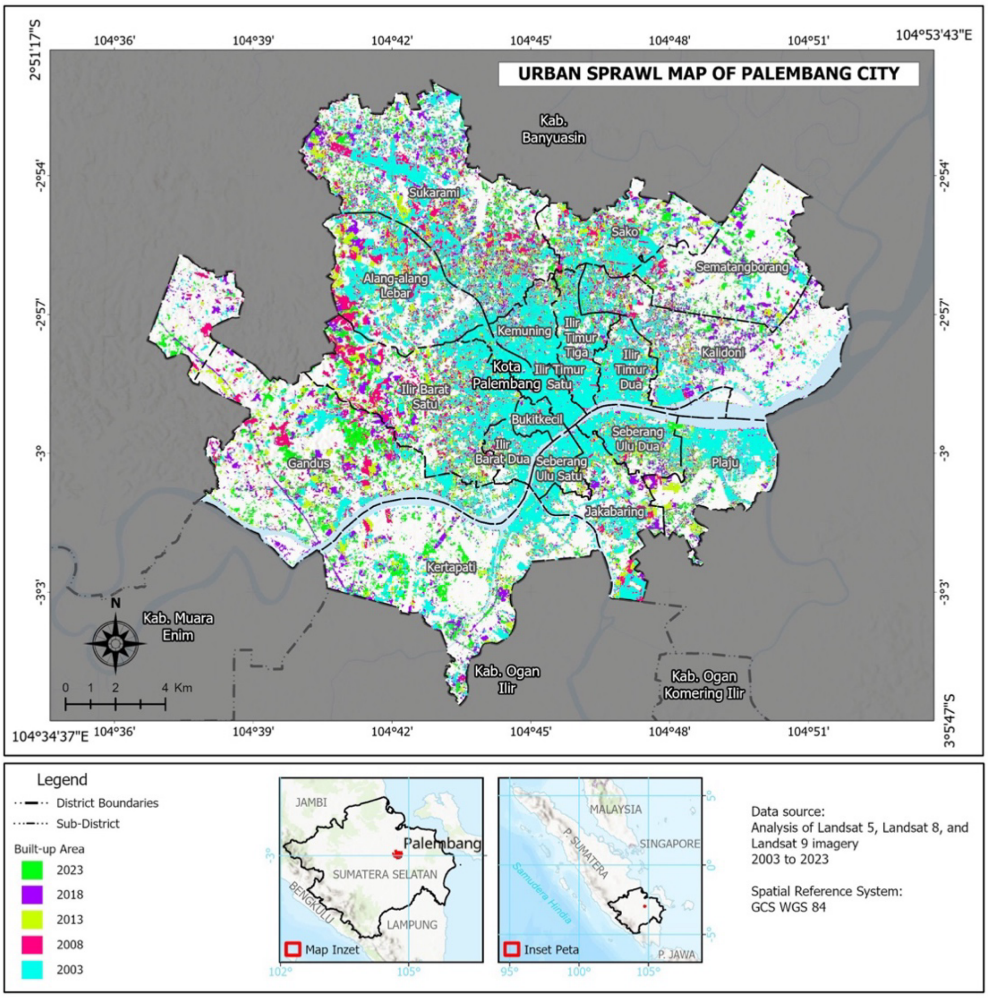

Figure 8. Urban expansion map of Palembang City, 2003 – 2023
(Source: Analysis Results, 2024)

Relatively minor changes occurred across all sub-districts between 2013 and 2018, except in Sematang Borang. This sub-district experienced a striking 70% increase in built-up land expansion, while other areas averaged less than 10%. During the 2013-2018 period, Gandus had the highest development rate, at 40%, followed by Kertapati at 45%. This indicates a trend of urban development shifting westward, with the Gandus sub-district tending to have relatively open land cover and access to national roads. By the end of the observation period (2023), Sematang Borang continued to expand its built-up area significantly, making it the sub-district with the highest consistency in regional development. The multi-temporal dynamics of built-up land cover change from 2003 to 2023 in Palembang City are illustrated in Figure 9.

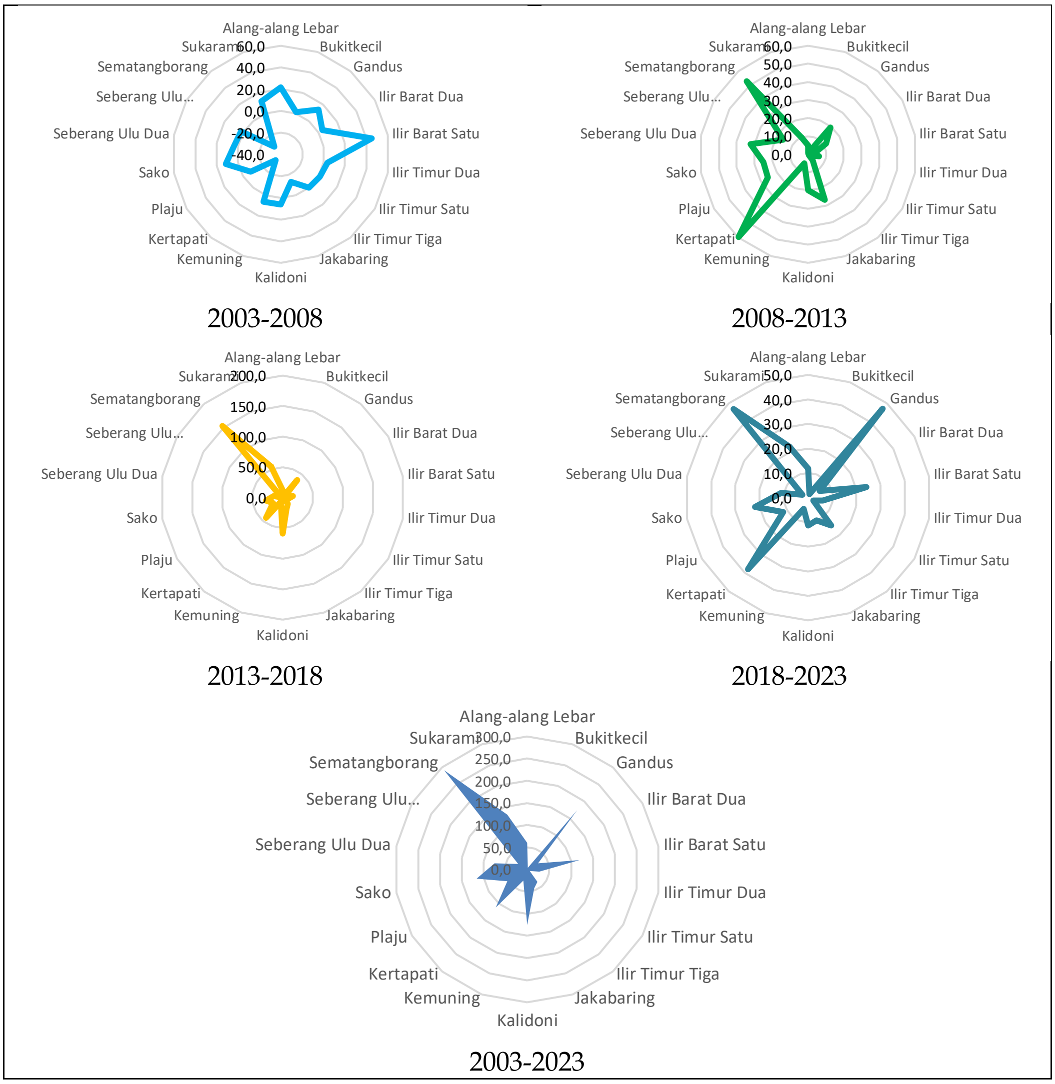

Figure 9. Percentage of built-up land area change per sub-district in Palembang City every 5 years from 2003 to 2023 (Source: Analysis Results, 2024)

Urban activity centers concentrated in and around the Kemuning sub-district have experienced stagnation in growth due to their generally high settlement density, resulting from the concentration of public service facilities, such as offices, and economic activities. Land clearing for settlements has altered the landscape of surrounding areas with good accessibility, as observed in Sematang Borang and Gandus. The tendency for urban development is less pronounced in sub-districts located south of the Musi River, such as Jakabaring and Plaju. This is attributed to the limited economic activities within these areas. Nevertheless, Kertapati managed to grow and establish a new activity center, with significant land additions, particularly from 2008 to 2013. This analysis indicates that urban sprawl in Palembang City exhibits non-uniform and unbalanced dynamics, primarily due to regional physical factors, particularly natural barriers such as the Musi River. Despite this, regional planning and development policies undoubtedly contribute to the diffusion of this urban characteristic. Figure 9 illustrates the trend of urban sprawl direction in Palembang City over the last two decades.

The phenomenon of urban development, as indicated by changes in built-up land, exhibits a radial-centrifugal pattern relative to the CBD. Densely built-up land around the CBD constitutes more than 66% (high) of the land cover in the northwest and northeast quadrants. Medium-class built-up land cover, occupying 33.3% to 66.6% of the area, tends to be located in the east, north, and northwest directions. The low class, where land cover is less than 33.3%, dominates in every directional quadrant.

This pattern shifted in 2008, with urban development predominantly moving towards the north and northwest quadrants. Conversely, the northeast quadrant experienced an increase in built-up land cover density, reaching the medium class. This dynamic was maintained over the subsequent five years, with only a slight increase in the area of high built-up land cover in the northwest quadrant. This indicates that the region northwest of the CBD has become a potential area for development. The increase in built-up land cover intensified in 2018, with the development of high- and medium-density areas tending to dominate in the northwest and north directions. Nevertheless, the eastern quadrant stood out with a fairly significant development in the medium class. By the final year of observation (2023), a significant change occurred: the northern quadrant experienced a surge in high-class built-up land cover, even as other quadrants experienced stagnation. The west and northwest quadrants also showed development in the medium class. In contrast to these facts, low-class built-up land cover was corrected (decreased or stabilized) in the eastern quadrant of the city.

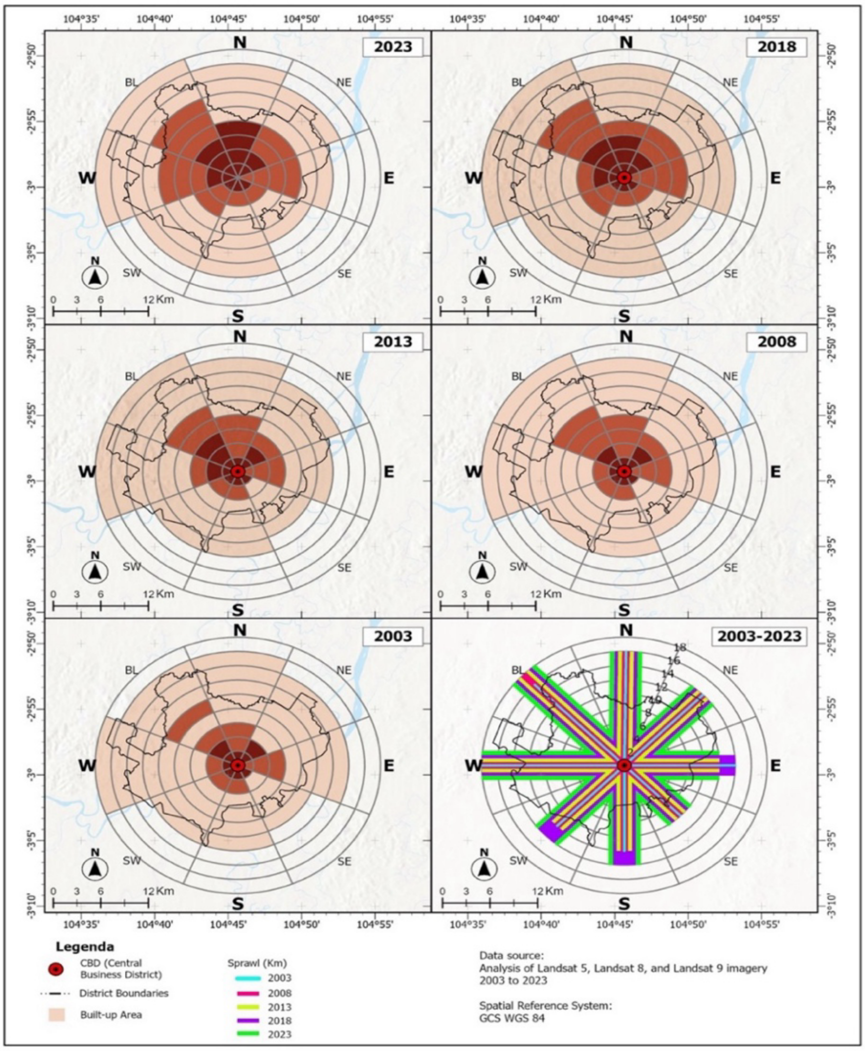

Figure 10. Urban Sprawl of Palembang City, 2003-2023 (Source: Analysis Results, 2024)

As presented in Figure 10, Palembang City experienced significant development towards the west, northwest, and north. Over the five-year periods between 2003 and 2023, development towards the north and west remained consistent. Development in the northwest region surged after 2008. In contrast to these findings, urban development in the southeast has been relatively minor over the past two decades. Nevertheless, the development trend towards the east, south, and southwest began to increase in 2018. This likely occurred because development outside the CBD was prioritized in the western, northwestern, and northern regions. Once these areas became dense and near saturation, urban development extended to the opposite quadrants, particularly the east, south, and southwest.

Cities and urban life are inherently complex systems characterized by self-organization and adaptation (Abujder Ochoa et al., 2024). Understanding the spatial evolution of Palembang requires analyzing how these complex forces manifest physically over time. The findings of this study confirm a fundamental spatial reconfiguration in Palembang over the last two decades (2003–2023). Initially, the city exhibited a classic radial-centrifugal pattern, with expansion radiating uniformly outward from the historic Central Business District (CBD) in Ilir Timur and Bukit Kecil. However, our multi-temporal analysis reveals a decisive break from this pattern, beginning around 2008, shifting towards a distinctly asymmetric polycentric model. This morphological shift is characterized by a dominant directional bias towards the North and Northwest quadrants (specifically Sukarami, Alang-Alang Lebar, and Sematang Borang).

In terms of comparative analysis, our findings reveal that Palembang's expansion is heavily shaped by 'hydro-spatial friction' from the Musi River, creating a starker developmental dichotomy than in other river-split cities like Louisville or Budapest. While expansion in many global cities is driven by proximity to the CBD, Palembang's morphology is uniquely restricted by its riparian geomorphology. Furthermore, while sprawl in delta cities like Ho Chi Minh City is largely steered by canal networks and water-based transportation (Downes et al., 2024; Linh et al., 2024). Palembang's growth follows an infrastructure-led 'ribbon development' primarily toward the North-Northwest quadrants. This confirms that in tropical riverine environments, natural barriers and wetland ecosystems can act as 'morphological inertia' that overrides conventional land-based growth models, forcing a transition into an asymmetric polycentric form.

This phenomenon aligns with the theory of infrastructure-led urban growth, where the expansion of built-up land is not merely a function of population pressure but is heavily dictated by accessibility (Zhou & Liu, 2022). The Northwest corridor, supported by strategic access to Sultan Mahmud Badaruddin II Airport and the development of major arterial roads, has reduced transportation costs and increased land values, thereby serving as a magnet for residential and commercial developers. This confirms the trends observed by Franco (2020) and Kong & Fu (2022), who argue that in developing metropolitan areas, urban form follows the path of least resistance provided by state-funded infrastructure. Unlike the saturated city center, where land prices are prohibitive and space is scarce, the peri-urban North offers a "spatial fix" for capital accumulation, triggering a leap-frog development pattern that extends the urban footprint far beyond the original administrative core.

. However, this expansion highlights a critical geographical constraint: the persistence of the Split City phenomenon. Despite the high demand for land, the Musi River continues to function as a significant developmental threshold, creating a stark dichotomy between the Northern (Ilir) and Southern (Ulu) regions. While the North has transformed into a sprawling, modern urban landscape, the South remains largely stagnant, with the notable exception of the Kertapati node. This disparity can be explained by the Boom-Diffuse-Saturate growth cycle. The Northern region has passed through the acceleration phase and is reaching saturation in its core, forcing diffusion to the Northwest periphery.

In contrast, the Southern region faces a geographical lock-in. The dominance of wetlands and low-lying swamp areas in Seberang Ulu significantly increases the cost of land reclamation and infrastructure construction. Although there was a brief surge in growth in the Southeast (Jakabaring) between 2003 and 2013, driven by government-led sports infrastructure projects, this did not trigger a sustained, widespread market-driven sprawl comparable to that in the North. This reinforces the argument by Wicaksono et al. (2022) that without massive engineering interventions or a denser network of bridges to close the connectivity gap, the natural landscape will continue to constrain urban expansion, perpetuating socio-economic segregation between the two riverbanks.

Consequently, this rapid conversion of non-built-up land to built-up areas, which nearly doubled during the observation period, presents profound environmental trade-offs. The observed expansion pattern indicates ribbon development or low-density sprawl, which is known to be the most land-intensive form of urbanization. This trajectory disproportionately consumes agricultural lands and wetland ecosystems in the peri-urban fringe. These wetlands are crucial for Palembang's ecological resilience, serving as natural retention basins for flood mitigation and carbon sinks. The loss of these ecological buffers aligns with the concerns raised by Chai (2024) regarding the conflict between economic development and environmental sustainability.

As the city expands horizontally rather than vertically, the impervious surface area increases drastically, exacerbating surface runoff and elevating the risk of hydro-meteorological disasters. Furthermore, this dispersed morphology increases the dependency on private motorized vehicles, as the low-density residential pockets in the Northwest are difficult to serve efficiently with public mass transport. This creates a vicious cycle of increased carbon emissions and traffic congestion, undermining the quality of urban life.

To mitigate these adverse effects and guide future growth towards sustainability, a business-as-usual approach is no longer viable. The transformation of Palembang requires a strategic policy shift from reactive zoning to proactive Integrated Corridor Management. As suggested by Civelli (2023) and Yu & Fang (2023), the North-Northwest corridor should be treated as a specific planning domain. First, strict zoning regulations must be enforced to protect the remaining wetlands in the expanding periphery, implementing a "green belt" strategy to contain unlimited sprawl. Second, the government should promote Targeted Densification or Transit-Oriented Development (TOD) around the Light Rail Transit (LRT) stations and main corridors, encouraging vertical growth rather than horizontal expansion. Finally, to address the Ilir-Ulu inequality, incentivized development policies are needed for the Southern region.

This does not mean replicating the sprawl of the North, but rather fostering compact, self-sufficient sub-centers in the South that are compatible with its wetland topography (e.g., amphibious architecture or eco-districts). If managed effectively, the emerging polycentric pattern offers a strategic opportunity to reduce pressure on the old CBD; however, if left uncoordinated, it risks cementing long-term environmental degradation and inefficiencies.

CONCLUSION

Based on the spatiotemporal analysis of urban dynamics over the last two decades, this study draws three fundamental conclusions. First, regarding the shift in urban morphology, Palembang has transitioned from a traditional radial-concentric expansion pattern to an asymmetric polycentric urban form. Urban growth is no longer spatially uniform but exhibits a dominant directional bias toward the North and Northwest quadrants (Sukarami and Alang-Alang Lebar), driven primarily by infrastructure accessibility and regional connectivity rather than purely demographic pressure.

Second, regarding the Split City Phenomenon, the Musi River remains a significant physical barrier, perpetuating a developmental dichotomy. The marked contrast between the rapidly densifying Northern region (Ilir) and the stagnant Southern region (Ulu) confirms that physical geography and hydro-spatial friction continue to override the potential for urban expansion in the South, despite increasing demand for urban land.

Third, the observed expansion is characterized by low-density sprawl that disproportionately consumes vital wetland ecosystems and agricultural lands in the peri-urban fringe, following ribbon development patterns along major transport corridors. This trajectory poses a long-term threat to the city's ecological resilience and hydrological balance.

To address these environmental trade-offs and promote balanced urban growth, this study offers two strategic recommendations for urban policy. First, the local government should implement 'Integrated Corridor Management' by establishing restrictive 'Green Belts' in the North-Northwest periphery to protect remaining riparian wetlands from uncontrolled horizontal sprawl. Second, a shift toward Transit-Oriented Development (TOD) is essential, particularly by optimizing land use around LRT stations, to encourage vertical densification and reduce carbon-intensive dependency on private vehicles.

These findings emphasize that sustainable urban planning in a river-split city like Palembang requires a paradigm shift from reactive zoning to proactive, landscape-based interventions that synchronize physical expansion with ecological resilience. Ultimately, this study contributes significantly to the field of urban geography by establishing 'hydro-spatial friction' as a critical determinant in urban evolution. It provides an original 'asymmetric polycentric model' that challenges conventional land-based growth theories and offers a robust framework for managing urbanization in tropical riverine environments worldwide.

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