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Urban Sprawl Symptoms in Ngaliyan and Mijen Sub-Districts of Semarang City in 2015, 2019, and 2023

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Abstract Rapid population growth and urban expansion have become critical issues in achieving sustainable spatial planning, particularly in urban fringe areas where uncontrolled settlement development is increasingly prevalent. This research focuses on the Mijen and Ngaliyan Sub-districts in Semarang City, which represent peri-urban zones. The objective of this study is to map the extent and typology of urban sprawl through a spatially explicit approach using Geographic Information Systems (GIS). GIS analyzed urban sprawl utilizing the ratio of population distribution to built-up area at the subdistrict level in 2015 and 2023. A weighted scoring method was applied using five parameters: population density, building density, network-based distance to the city center, buffer-based highway strip index, and leapfrog development index derived from settlement distribution. The results show that no low-level sprawl classification is present in the identified villages. The medium level includes Ngaliyan, Tambakaji, Kedungpane, Bubakan, and Pesantren. Meanwhile, the high classification includes Jatibarang Village and Bambankerep Village, characterized by rapid, unplanned growth and limited infrastructure connectivity. Additionally, Grid-based spatial analysis was employed to classify sprawl typologies, and ribbon development that emerged as the dominant typology, concentrated along major road corridors. This research offers spatial evidence to support urban development policies and promote more sustainable growth in peri-urban areas of emerging cities.

Keywords Urban Sprawl, Urban Sprawl Typology, Geographic Information System, Leapfrog, Ribbon Development

1. Introduction

Population growth and urban expansion have long been the leading drivers of urban sprawl [1], [2], [3], characterized by the uncontrolled spread of built-up areas and social inequalities across peripheral regions [4]. Urban sprawl has a significant impact on spatial sustainability, including spatial fragmentation, high resource consumption, and inequality of access to infrastructure and public services. Identified five key indicators of urban sprawl included: population density, building density, leapfrog development, development along major roads, and inaccessibility of nodes to the city center, which were also carried out in research by Hasse and Lathrop [5]. The city of Semarang has experienced a significant increase in built-up areas, particularly in the districts of Ngaliyan and Mijen, a trend also observed in Putri Ayu Az Zahra's research [6]. This reflects the rapid dynamics of urban sprawl in the city's outskirts. To understand and map the impacts of this phenomenon, Geographic Information Systems (GIS) approaches are a relevant method. GIS can analyze spatial and historical changes in land use patterns and support the formulation of sustainable spatial planning policies. Therefore, this research is crucial in providing accurate data on urban sprawl patterns and promoting the use of the latest mapping technology to support more effective regional planning.

2. Literature Review

2.1. Urban Sprawl

Urban sprawl refers to the uncontrolled outward expansion of urban development into peripheral or peri-urban areas, typically marked by fragmented spatial patterns and low-density settlements [7]. This phenomenon is often associated with irregular urban growth and the expansion of urban activities beyond designated planning zones, resulting in spatial inconsistencies and challenges in service provision [8]. Key factors contributing to urban sprawl include rapid population growth, expansion of transportation infrastructure, weak land-use regulations, and economic pressures that drive development towards the city's outskirts [6].

The impacts of urban sprawl are both environmental and socio-economic. These include the conversion of peripheral agricultural land into built-up areas [9], [10], which threatens food security and ecological balance [11], as well as an increased reliance on private vehicles, resulting in traffic congestion, air pollution, and higher energy consumption [12]. To mitigate these effects, scholars and planners have proposed integrated spatial planning such as the concept of a more compact city [13], [14] to improved public transportation systems, and compact urban development models that promote more controlled and sustainable city growth trhough the principle of crhono urban mexhanism, 15 minutes cities [15], [16], [17].

2.2. Urban Sprawl Typology

Urban sprawl can be classified into several typologies based on the proportions and patterns of built-up areas at a neighborhood scale. There are four main types of urban sprawl — secondary urban core, urban fringe, ribbon development, and scatter development —that are also explored in Chettry's [18] research. These categories are classified using a 1 km ²spatial unit. Secondary urban cores have 50–80% built-up coverage, while urban fringes contain 30–50% built-up areas. Scatter and ribbon development each involve less than 30% of the built-up area, but ribbon development is specifically located within 100 meters of major transportation routes.

These typologies help reflect the fragmented nature of urban expansion, often shaped by topography, infrastructure, socio-economic factors, and environmental risks. Grid-based spatial analysis, such as hexagonal or square meshes, enables objective classification and comparison across urban landscapes [19]. Understanding these spatial patterns is essential for evaluating the sustainability and structure of urban growth. **Table 1** details the urban sprawl typology according to V. Chettry [18].

Table 1. Urban Sprawl Typology

NO	Urban Sprawl Typology	Threshold Value	Description
1	*Secondary Urban Core*	50-80% built-up area in km^2	Discontinuous dense
2	*Urban Fringe*	30-50% built-up area in km^2	Discontinuous Medium dense
3	*Scatter Development*	<30% built-up area in km^2	Discontinuous low-density
4	*Ribbon Development*	<30% built-up area within 100m proximity to national highways	

2.3. Classification of Urban Sprawl

Urban sprawl intensity is often classified into three levels: low, moderate, and high. To provide spatial precision, this classification is usually enhanced using scoring and overlay analysis, incorporating parameters such as population density, building density, road proximity, and leapfrog patterns [20]. Areas categorized as low sprawl generally show proportional or compact development [21], whereas moderate sprawl areas exhibit mismatches between population and land use [4]. High-sprawl regions, such as Jakarta Megacity, are characterized by a significant imbalance: either high population concentration with limited built-up space or expansive land development with a sparse population, indicating inefficient land conversion and challenges in service provision [22].

3. Methodology

3.1. Study Area

This research focuses on two sub-districts in Semarang City, Indonesia, namely Ngaliyan and Mijen. Both are areas that have experienced significant land-use change and exhibited striking symptoms of urban sprawl in recent years. These two sub-districts are also the most distant from Semarang City's city center; Ngaliyan Sub-district is about 14.43 km from the city center, while Mijen Sub-district is about 17.34 km, making it the most peripheral area in Semarang City's spatial structure.

3.1.1. Ngaliyan Sub-District

Located in the western part of Semarang City, Ngaliyan Sub-district spans 3,181.96 hectares and comprises 10 urban Neighborhoods. This area was previously known as the center of guava production, but is now experiencing massive land conversion into residential areas. **Figure 1** below shows Nagliyan Subdistrict’s geographic location.

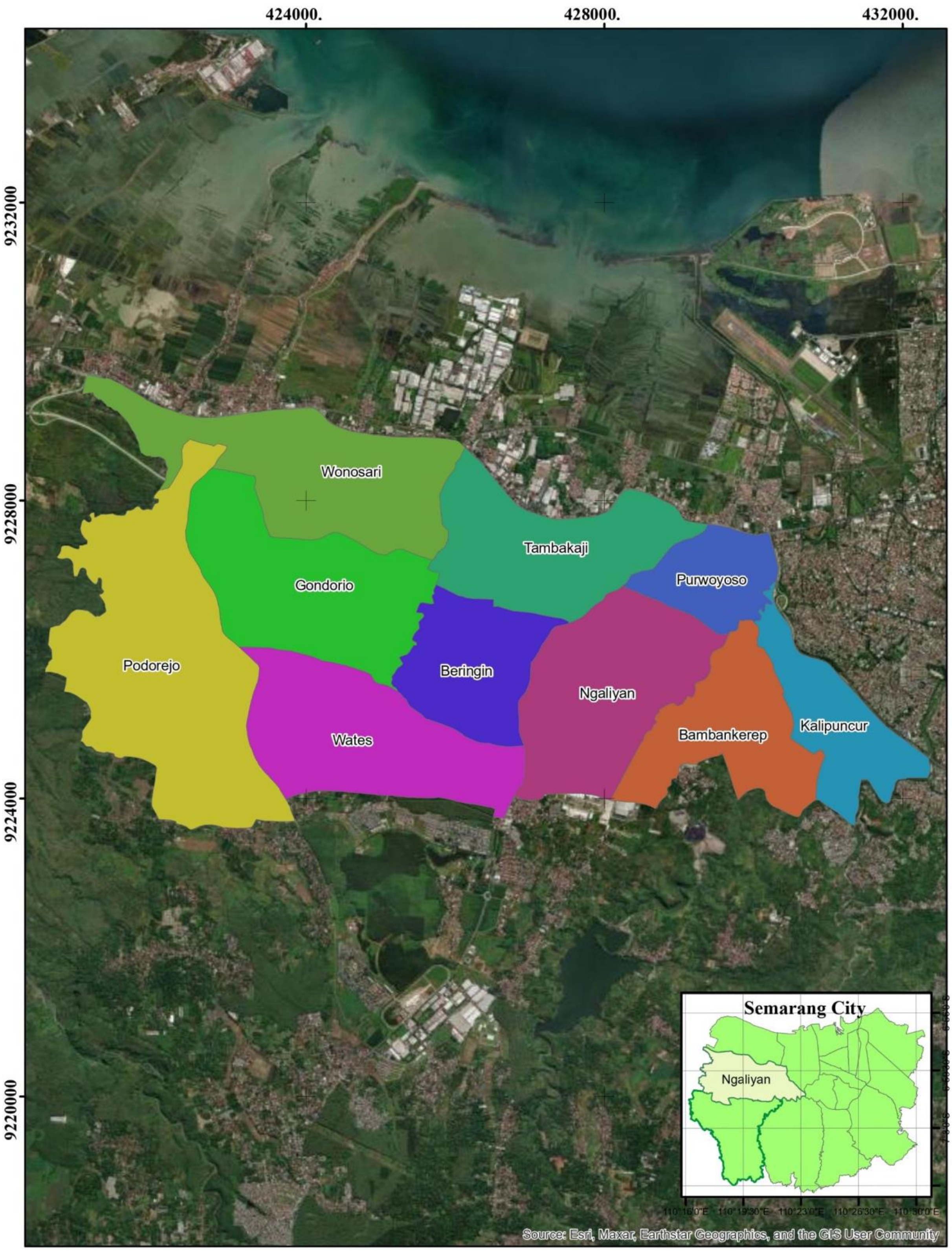

Figure 1. Map of Ngaliyan Subdistrict

Based on Google Earth imagery from 2023, urban sprawl in Ngaliyan is primarily spread along major infrastructure corridors, such as the Semarang-Batang Toll Road, as well as around new industrial and residential areas. The characteristics of urban sprawl in Ngaliyan include fragmented housing development, low density, horizontal pattern, and lack of integration with public facilities and public transportation networks. The most affected areas include Tambakaji, Wonosari, and Podorejo.

3.1.2. Mijen Sub-District

Figure 2 below depicts the Mijen Subdistrict map as the second field study. Mijen is the largest sub-district in Semarang City, covering 57.55 km^2 and located at an altitude of 311 meters above sea level. Mijen is also the most distant sub-district from the city center, at 17.34 km. The area had green coverage and low population density.

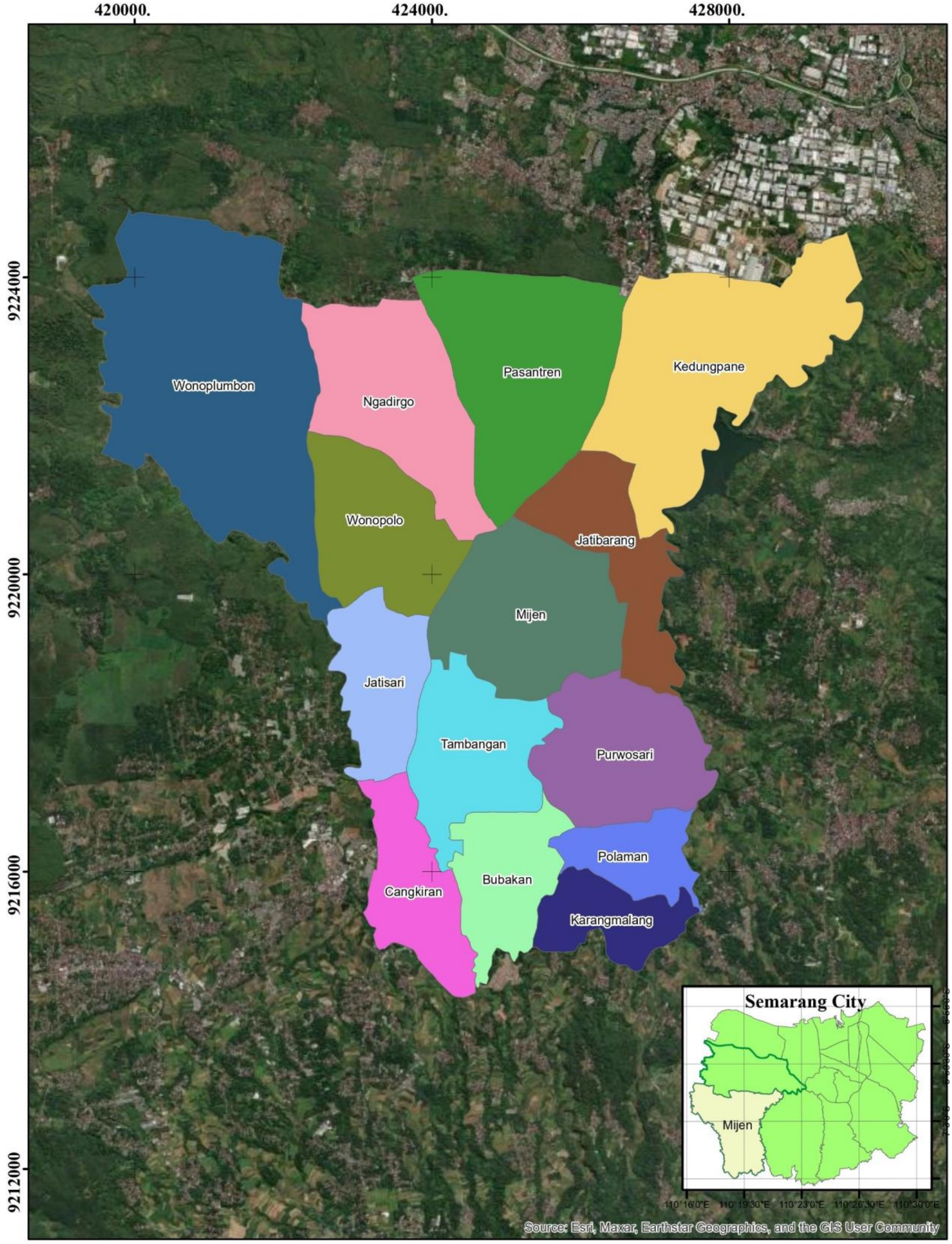

Figure 2. Map of Mijen Subdistrict

Over the last decade, however, Mijen has experienced rapid development, marked by the sporadic emergence of new settlements and industrial areas. Based on the 2023 satellite imagery analysis, the symptoms of urban sprawl are most prevalent in Jatisari, Karangmalang, and Ngadirgo. Development in Mijen is generally characterized as greenfield, carried out on open land or former farms, with low density and limited connectivity to public facilities and public transportation. This leads to an increased reliance on private vehicles, making sustainable spatial integration difficult.

3.2. Tools and Data

3.2.1. Tools

The equipment used in this study consisted of a single laptop unit as the primary hardware. The software used includes ArcGIS, QGIS, and Google Earth Pro for spatial analysis and visualization, as well as Microsoft Word and Microsoft Excel for data processing and report preparation.

3.2.2. Data

This research employs several types of data, such as Administrative Boundaries of Subdistricts in Semarang City, Population data, Building data, and PlanetScope Image (NICFI). **Table 2** contains the list of data elaborated in this research.

3.3. Flow Chart

Figure 3 demonstrates the research flowchart. The figure systematically illustrates the step-by-step allure of the research.

First and foremost, this research began by proposing a specific research problem: the spatio-temporal analysis of Urban Sprawl Symptoms in Ngaliyan and Mijen Sub-Districts of Semarang City across 2015, 2019, and 2023, and by elaborating on the state-of-the-art literature, which constitutes a fundamental part in situating the research within previous similar research topics. Afterwards, various spatial and non-spatial data were combined to answer the research's essential questions.

3.4. Method

3.4.1. Sprawl Identification

The initial stage of the analysis involved identifying urban areas affected by urban sprawl to distinguish between dense urban development and urban sprawl conditions in the subdistricts of Ngaliyan and Mijen. The spatial unit used in this assessment was the Neighborhood, with a focus only on Neighborhoods that showed potential for urban sprawl. This identification was carried out by comparing two ratios: (A) the proportion of the Neighborhood population to total district population, and (B) the proportion of the Neighborhood built-up area to total district built-up area [23].

$$(A) - (B) = -\ \ (Sparwl)$$

$$(A) - (B) = 0\ \ \text{(Normal)}$$

$$(A) - (B) =\ \ +\ (Compact)$$

If the difference between A and B is zero, the area is considered balanced or normal. A positive result indicates compact development (more population per unit of land), while a negative result suggests urban sprawl (more land per unit of population). Neighborhoods with negative values were then selected for further analysis using multiple spatial parameters to better understand the driving factors and typology of urban sprawl in the study area.

Table 2. Research Data

NO	Data	Year	Source
1.	Administrative Boundaries of Subdistricts in Semarang City	Latest	Semarang City Spatial Planning Office
2.	Total Population	2015 and 2023	Semarang Central Statistical Office
3.	Building Data	2023	OpenStreetMap
4.	Road Network	Latest	Semarang Public Works Office
5.	PlanetScope Image (NICFI)	2015, 2019, and 2023	Planet.com

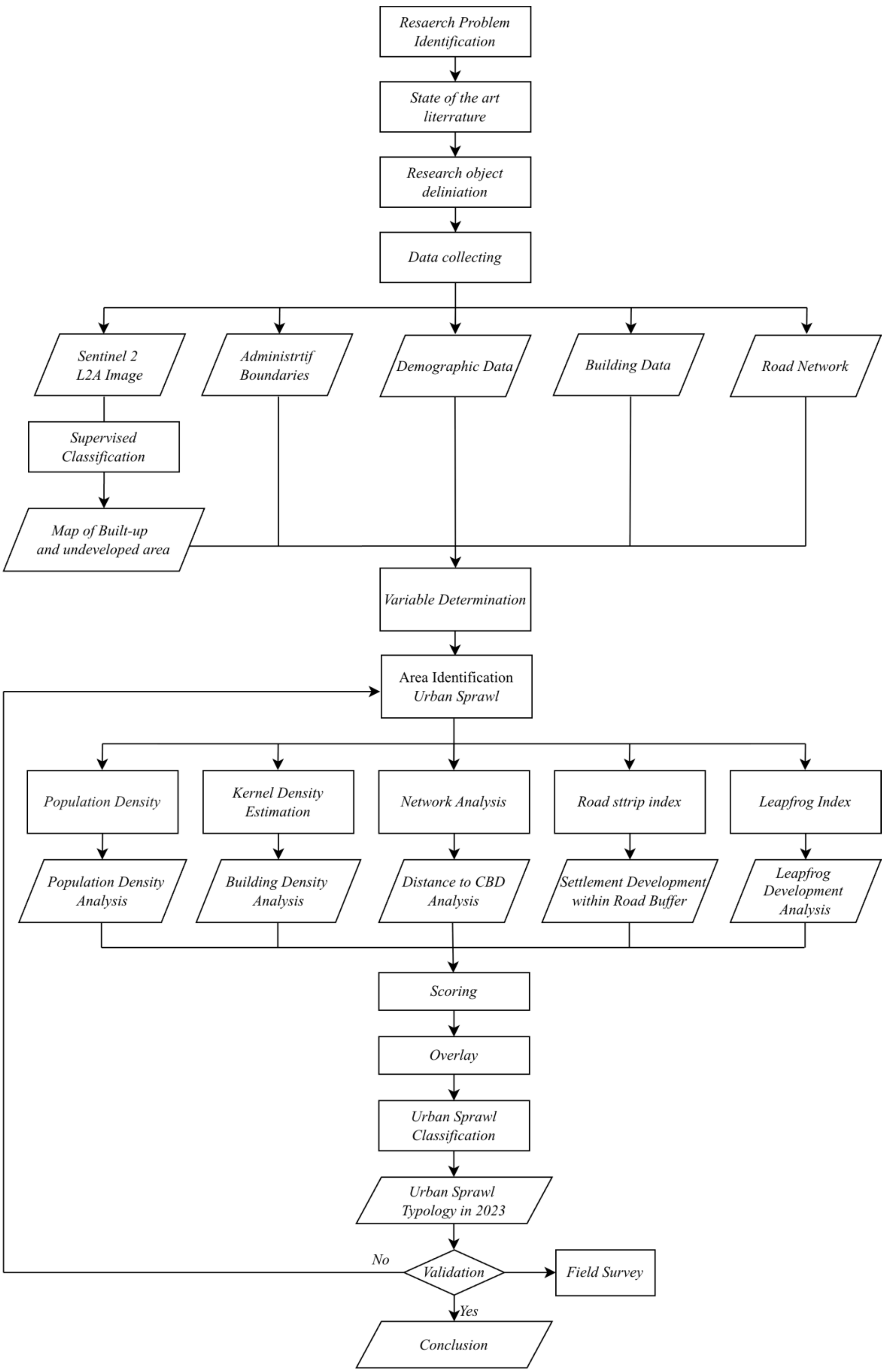

Figure 3. Research Flowchart

3.4.2. Urban Sprawl Parameters

Following the identification of the sprawl-affected Neighborhood, the intensity of urban sprawl within these areas is quantified using five distinct parameters:

1. Population Density

Population density, conceptualized as the increasing concentration of human population within a fixed or limited spatial area, is calculated by dividing the total population of each Neighborhood (sourced from BPS Semarang City) by its corresponding built-up land area (derived from OpenStreetMap). A higher population density inherently suggests a reduced extent of urban sprawl. The formula applied is:

$$Population\ Density = \frac{Total\ Population}{Built-up\ Land\ Area}$$

The calculated population densities were then classified into three categories—high, medium, and low—to facilitate the determination of population density levels.

2. Building Density

Building density analysis quantifies the concentration of structures within a given area [24]. This parameter is computed as the ratio of the total number of buildings within each Neighborhood (obtained through OpenStreetMap data and image interpretation) to the built-up area of that respective Neighborhood. A higher building density indicates a lower degree of urban sprawl. The formula employed is:

$$Building\ Density = \frac{Total\ Buildings\ Unit}{Built-up\ Land\ Area}$$

The resulting building densities are then categorized into three classes—high, medium, and low—to establish their respective density levels.

3. Distance to City Center

The distance to the city center is a critical variable for discerning urban sprawl patterns [25]. In this study, Tugu Muda in Semarang City is designated as the central business district (CBD). Theoretically, an increase in distance from the city center correlates with a higher propensity for low-density settlement expansion, thus indicating a greater potential for urban sprawl. This analysis uses network analysis, specifically the Shortest Path Network Analysis Tool in QGIS, to determine the shortest travel distance from the most distant building points in each Neighborhood to the city center. The derived distances are then categorized into three classes —high, medium, and low — to define their respective distance levels.

4. Development within Road Network Reach (Highway Strip Index)

This parameter assesses the extent of development influenced by existing road networks using the Highway Strip Index. This index compares the number of newly constructed buildings situated within a 100-meter buffer zone of the road network against the total count of new buildings within the Neighborhood. New buildings are identified through a comparative analysis of 2023 building shapefiles with 2015 imagery, pinpointing building polygons that were absent in the earlier imagery. A higher Highway Strip Index ratio suggests a lower degree of urban sprawl, indicating more structured, efficient development along established transportation corridors. The methodology for this index, including the 300-feet (approximately 100-meter) buffer for major road networks, is consistent with the approach outlined by Hasse, John, and Richard [26]. The formula for the Highway Strip Index is:

$$Indeks\ Highway\ Strip = \frac{Total\ New\ Buildings\ within\ Road\ Network\ Buffer}{Total\ New\ Buildings}$$

The calculated index values are subsequently classified into three levels—high, medium, and low—to characterize development within the road network's reach.

5. Leapfrog Development Pattern (Leapfrog Index)

The analysis of leapfrog development patterns is conducted using the Leapfrog Index. This index is derived by comparing the distance from the nearest new sprawl settlement center to the established old compact settlement center with the total number of new buildings in the sprawl-affected Neighborhood. Old settlement centers are identified by applying Kernel Density Estimation to 2015 building data. A higher Leapfrog Index value indicates a more pronounced level of sprawl, reflecting fragmented, discontinuous development. The formula for the Leapfrog Index, as conceptualized by Hasse, John, and Richard [26], is:

$$Leapfrog\ Index = \frac{Total\ Distance\ of\ Fragmented\ New\ Buildings}{Total\ New\ Buildings}$$

The resulting index values are then categorized into three classes — high, medium, and low — to define the level of the leapfrog development pattern.

3.4.3. Scoring and Overlay

A scoring mechanism is implemented to ascertain the relative weight of each variable, ranging from the lowest to the highest score. The cumulative total score for each Neighborhood is subsequently utilized to determine its urban sprawl typology. Each variable is assigned a score of 1, 2, or 3, corresponding to its classification (high, medium, or low). The total score for each Neighborhood is computed as the summation of the scores from the five aforementioned parameters:

$$Total\ Scor = [a + b + c + d + e]$$

Where:
a: Population Density
b: Building Density
c: Distance to City Center
d: Development within Road Network Reach
e: Leapfrog Development Pattern

The overlay technique in this research involves superimposing the classification maps of individual variables to generate new spatial information. This integrated information is then used to calculate the total score. The total scores are subsequently categorized into three distinct urban sprawl levels—low, medium, and high—by defining appropriate class ranges.

3.4.4. Grid Method

The grid approach is strategically employed in this research to spatially identify and characterize the level and typology of urban sprawl. The study area is systematically partitioned into uniform 1 km x 1 km grid cells using the Grid Index Feature tool in ArcGIS, thereby facilitating structured, quantifiable spatial analysis. For a more granular examination, these 1 km^2 grids are further subdivided into four 0.25 km^2 sub-grids.

Based on the percentage of built-up area and proximity to major roads, each 0.25 km^2 grid is assigned to one of three urban sprawl typologies: Ribbon Development, Scatter Development, or Urban Fringe. This classification adheres to the typological thresholds presented in **Table 1** [18].

The application of the grid method facilitates precise mapping and in-depth analysis of urban sprawl typologies, effectively revealing temporal shifts in development patterns, including the emergence and growth of ribbon development, scatter development, and urban fringe areas.

4. Result and Analysis

4.1. Identification of Urban Sprawl Sub-Districts

The first stage of the analysis involved identifying the sub-districts in Semarang City that showed strong indications of urban sprawl. This was done by calculating the distance of each sub-district from the city center, defined as Tugu Muda, using network analysis.

The results show that Ngaliyan and Mijen sub-districts are located at a considerable distance from the city center, approximately 14.4 km and 17.3 km respectively. This geographical location classifies them as peri-urban areas, typically transitional zones that experience development pressure due to land scarcity in the core city. One of the main drivers of development in these two areas is the presence of the integrated township, BSB City, located in Mijen. In addition, Semarang City's 2011-2031 Regional Spatial Plan (RTRW) designated Mijen Sub-district as a strategic area for new residential development. Outward urban expansion, particularly to the northwest along the Walisongo Road corridor, also contributes significantly to the growth potential of Ngaliyan Sub-district. The availability of arterial road infrastructure and improved inter-regional accessibility has accelerated the growth of new settlements in both Mijen and Ngaliyan.

4.2. Identification of Urban Sprawl Areas

After identifying the subdistrict level, a more detailed analysis was carried out to determine the specific Neighborhoods in Ngaliyan and Mijen affected by urban sprawl. The identification was based on a population-to-built-up land area ratio.

Based on **Table 3**, Sprawl Calculation in 2015, eight Neighborhoods were identified as urban sprawl areas: Bubakan, Jatibarang, Kedungpane, and Pesantren (Mijen), as well as Bambankerep, Ngaliyan, Wates, and Wonosari (Ngaliyan). **Figure 4** presents a spatial map of urban sprawl in 2015, in which several sub-districts, such as Bubakan, Jatibarang, Pesantren, Kedungpane, Ngaliyan, Bambankerep, Wates, and Wonosari, appeared to be experiencing sprawl.

Table 3. Sprawl Calculation 2015

Subdistrict	Neighborhoods	A	B	A-B	Description
Mijen	Bubakan	0.036105	0.040800	-0.004695	*Sprawl*
	Cangkiran	0.058741	0.057441	0.001300	*Compact*
	Jati Barang	0.046869	0.104691	-0.057822	*Sprawl*
	Jatisari	0.161078	0.137855	0.023223	*Compact*
	Karangmalang	0.037082	0.028299	0.008783	*Compact*
	Kedungpane	0.084830	0.120462	-0.035632	*Sprawl*
	Mijen	0.101897	0.084429	0.017468	*Compact*
	Ngadirgo	0.090595	0.073821	0.016774	*Compact*
	Pesantren	0.021839	0.050997	-0.029158	*Sprawl*
	Polaman	0.029232	0.024332	0.004900	*Compact*
	Purwosari	0.073251	0.062098	0.011153	*Compact*
	Tambangan	0.067079	0.057441	0.009638	*Compact*
	Wonolopo	0.122205	0.114725	0.007480	*Compact*
	Wonoplumbon	0.067568	0.042609	0.024959	*Compact*
Ngaliyan	Banbankerep	0.041223	0.104879	-0.063656	*Sprawl*
	Bringin	0.117692	0.094711	0.022981	*Compact*
	Gondoriyo	0.053708	0.044320	0.009388	*Compact*
	Kalipancur	0.147574	0.105121	0.042454	*Compact*
	Ngaliyan	0.103824	0.159463	-0.055638	*Sprawl*
	Podorejo	0.055862	0.044364	0.011498	*Compact*
	Purwoyoso	0.123621	0.092003	0.031618	*Compact*
	Tambakaji	0.172601	0.164796	0.007805	*Compact*
	Wates	0.036057	0.037805	-0.001748	*Sprawl*
	Wonosari	0.147837	0.152539	-0.004702	*Sprawl*

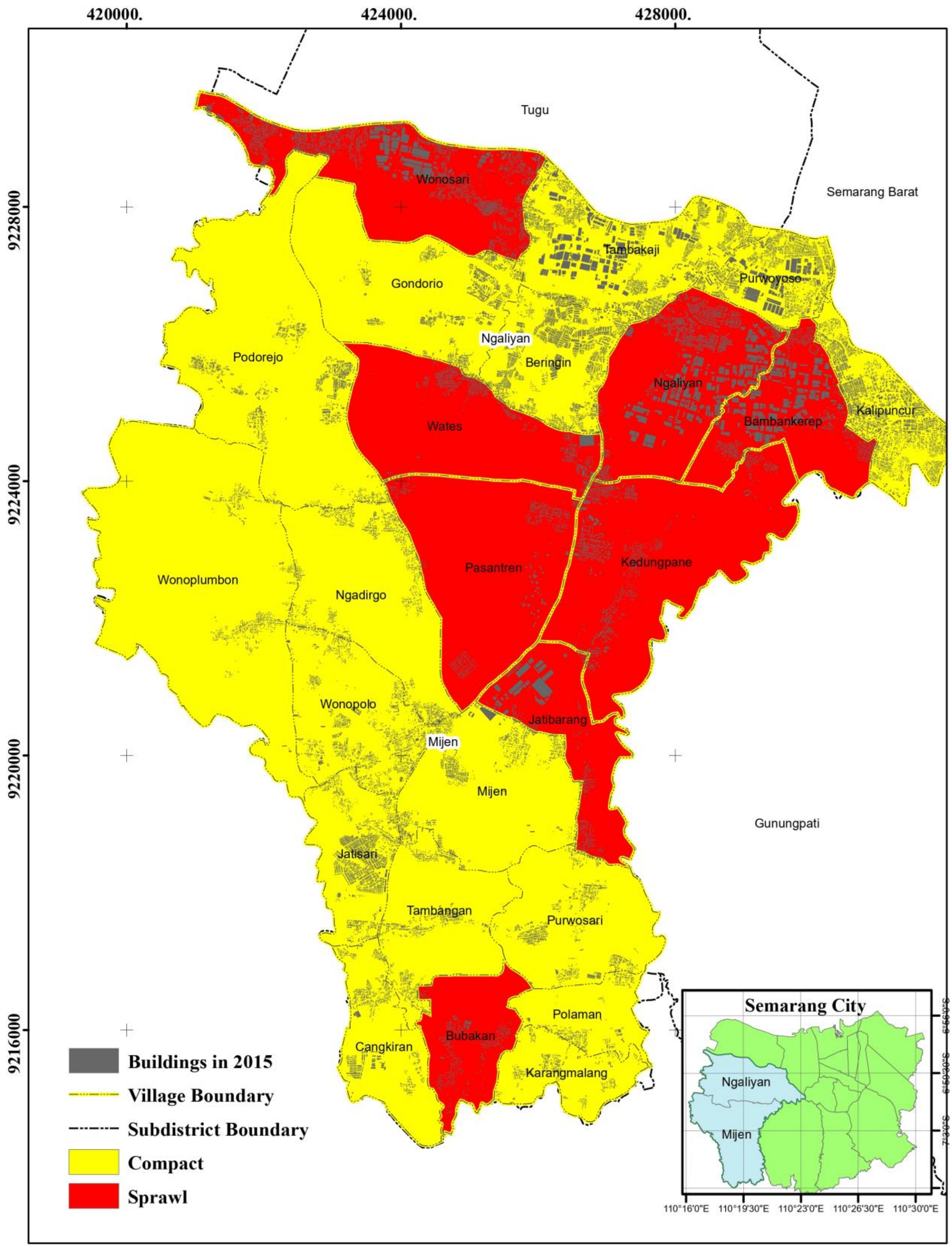

Figure 4. Map of Urban Sprawl Identification in 2015

Table 4. Sprawl Calculation 2023

Subdistrict	Neighborhoods	A	B	A-B	Description
Mijen	Bubakan	0.044954	0.068807	-0.023853	*Sprawl*
	Cangkiran	0.061697	0.050111	0.011585	*Compact*
	Jati Barang	0.043534	0.135759	-0.092225	*Sprawl*
	Jatisari	0.154236	0.124063	0.030173	*Compact*
	Karangmalang	0.033718	0.024688	0.009031	*Compact*
	Kedungpane	0.102318	0.139344	-0.037026	*Sprawl*
	Mijen	0.096725	0.081295	0.015430	*Compact*
	Ngadirgo	0.087105	0.070335	0.016770	*Compact*
	Pesantren	0.035836	0.097645	-0.061809	*Sprawl*
	Polaman	0.024086	0.021227	0.002860	*Compact*
	Purwosari	0.061893	0.054174	0.007719	*Compact*
	Tambangan	0.065454	0.052661	0.012793	*Compact*
	Wonolopo	0.135792	0.100795	0.034997	*Compact*
	Wonoplumbon	0.052652	0.049431	0.003221	*Compact*
Ngaliyan	Banbankerep	0.044004	0.116160	-0.072156	*Sprawl*
	Bringin	0.126593	0.083572	0.043021	*Compact*
	Gondoriyo	0.056413	0.040242	0.016170	*Compact*
	Kalipancur	0.145889	0.092060	0.053830	*Compact*
	Ngaliyan	0.091928	0.197252	-0.105325	*Sprawl*
	Podorejo	0.069943	0.039295	0.030648	*Compact*
	Purwoyoso	0.108320	0.103624	0.004697	*Compact*
	Tambakaji	0.147150	0.149161	-0.002011	*Sprawl*
	Wates	0.041998	0.036331	0.005667	*Compact*
	Wonosari	0.167762	0.142303	0.025459	*Compact*

By 2023, **Table 4** explains the Sprawl Calculation, which decreased to seven, with Wates and Wonosari no longer classified as sprawl areas due to increased population density without significant land expansion. Meanwhile, Tambakaji, which was not classified in 2015, became a sprawl area in 2023, following a 3.54% increase in built-up area despite a slight population decline, indicating inefficient land use and low-density development.

Figure 5 displays the Map of Urban Sprawl Identification in 2023. In this figure, based on quantitative analysis of the population and building densities, the sprawl zone shifted significantly relative to the 2015 map. Sub-districts Bubakan and Wates are no longer identified as sprawl. These findings demonstrate that urban sprawl is a dynamic and evolving process influenced by population shifts, land-use patterns, and the intensity of development over time.

4.3. Urban Sprawl Parameters

4.3.1. Population Density

The population density analysis in **Table 5**, shows a range from a minimum of 84.44 people/ha in Neighborhood Bambankerep to a maximum of 219.90 people/ha in Neighborhood Tambakaji. Based on these values, the neighborhoods were classified into two categories: low-density and high-density, as the medium-density category did not appear in the results. Low population density is a strong indicator of high levels of urban sprawl, as it indicates a population spread over a large area.

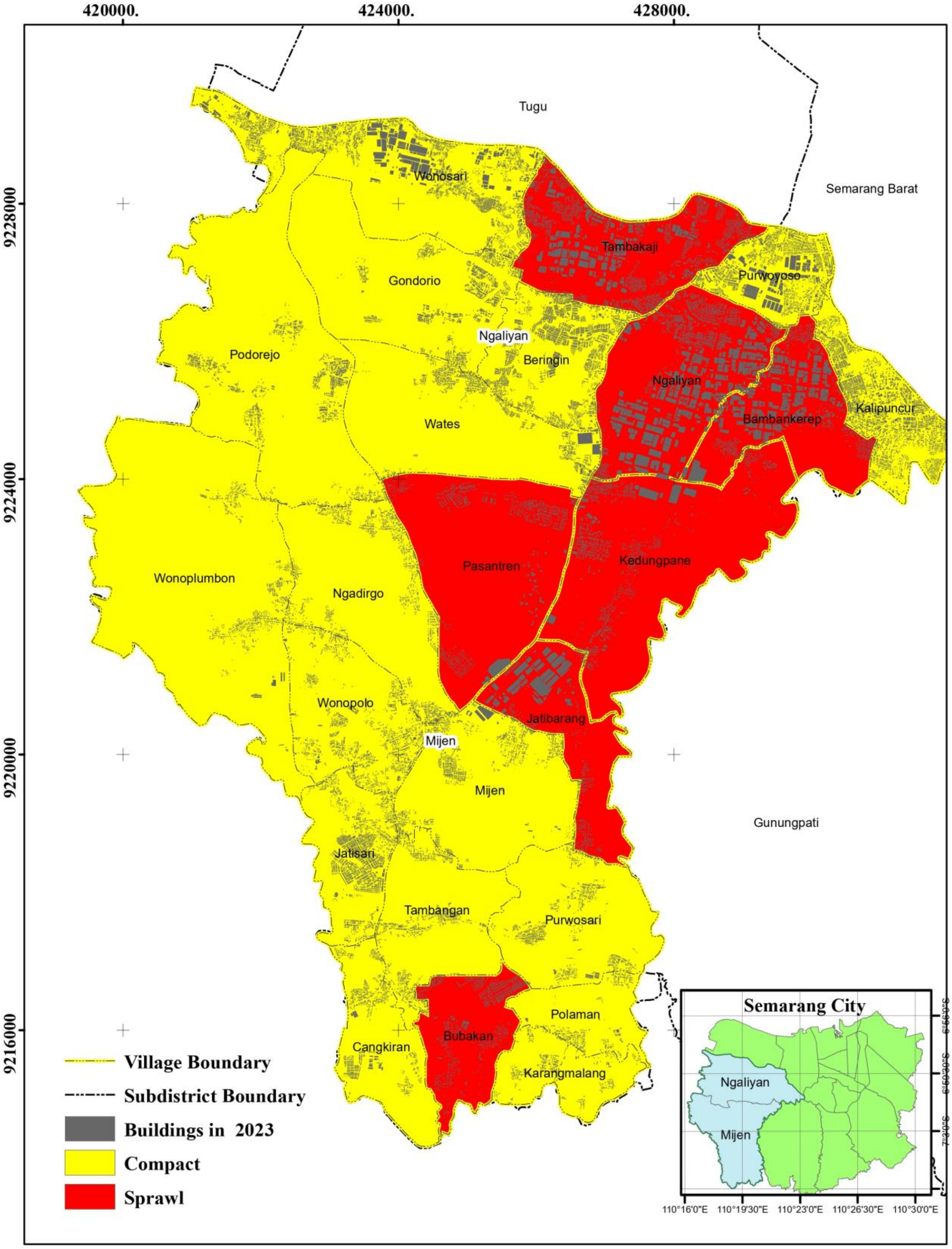

Figure 5. Map of Urban Sprawl Identification in 2023

Table 5. Population Density Calculation

Neighborhood	Total Population	Built-up Area (Ha)	Population Density	Description
Tambakaji	21131	96.091818	219.9042587	High
Bambankerep	6319	74.832188	84.442272	Low
Ngaliyan	13201	127.073177	103.885024	Low
Bubakan	3673	20.297153	180.961340	High
Kedungpane	8360	41.104735	203.382895	High
Jati Barang	3557	40.047206	88.820179	Low
Pesantren	2928	28.803909	101.652869	Low

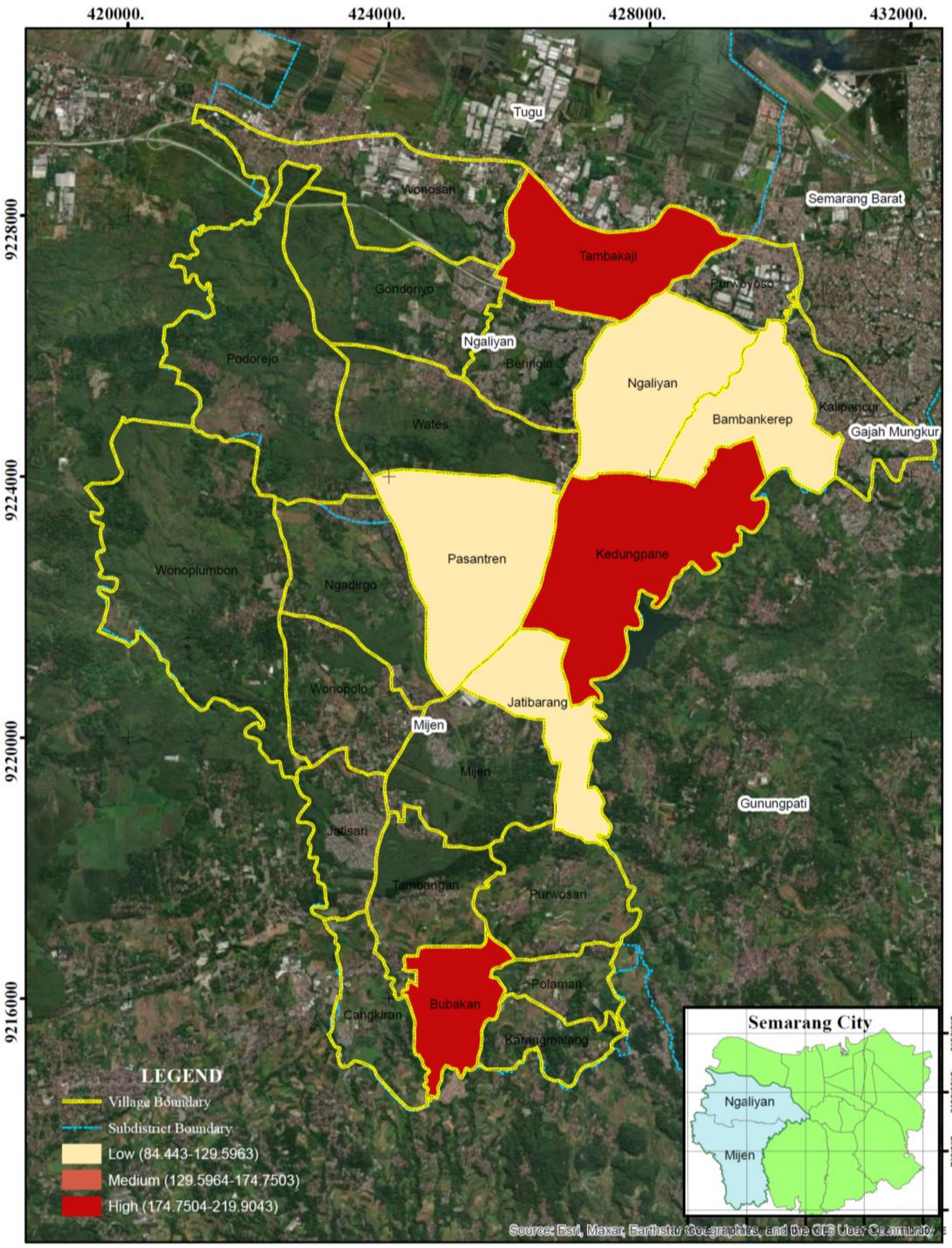

Figure 6. Map of Population Density Classification in 2023

Four urban Neighborhoods (Bambankerep, Ngaliyan, Jatibarang, and Pesantren) exhibit low population density, indicating a high level of urban sprawl due to uneven population distribution. In contrast, three Neighborhoods (Tambakaji, Bubakan, and Kedungpane) exhibit high population density, indicating denser development with efficient land use. This inverse relationship suggests that higher population density correlates with lower levels of urban sprawl, and vice versa—the visualization of population density in **Figure 6 below Table 5**.

4.3.2. Building Density

The analysis of building density in **Table 6** shows a minimum value of 25,791 units/ha in Neighborhood Bambankerep and a maximum of 116,716 units/ha in Neighborhood Bubakan. These values result in classifications of low, medium, and high building density. Low building density is associated with high levels of urban sprawl, reflecting a pattern of development that is scattered rather than concentrated.

While **Figure 7** conveyed the spatial information regarding the Map of Building Density Classification in 2023, three urban Neighborhoods (Bambankerep, Ngaliyan, and Jatibarang) were categorized as having low building density, indicating high levels of urban sprawl due to dispersed and concentrated development. Kedungpane and Pesantren are classified as medium density. Neighborhood Bubakan shows a high building density, indicating denser development and efficient space utilization. This parameter, like population density, is crucial to understanding the dynamics of urban sprawl, where lower density often implies greater horizontal sprawl and increased pressure on infrastructure.

4.3.3. Distance to City Center

An analysis of the distance to the city center based on **Table 7**, measured from the furthest building in each Neighborhood to Tugu Muda, yielded distances ranging from 8.939 km (Neighborhood Bambankerep) to 20.353 km (Neighborhood Bubakan). These distances were classified into low, medium, and high categories. A short distance to the city center generally correlates with low urban sprawl, while a long distance indicates high urban sprawl.

Bambankerep, Ngaliyan, Kedungpane, and Tambakaji are classified as having a short distance to the city center, indicating low levels of urban sprawl. Jatibarang and Pesantren fall into the medium distance category. Neighborhood Bubakan is far from the city center, placing it in a peri-urban area prone to greater urban sprawl, driven by lower land prices and low-density development. This parameter is crucial for evaluating the influence of accessibility on urban growth patterns. Further, **Figure 8** identified the spatial condition of Distance Classification to the City Center in 2023.

Table 6. Building Density Calculation

Neighborhood	Building Number	Built-up Area (Ha)	Building Density	Description
Tambakaji	5515	96.091818	57.393024	Medium
Bambankerep	1930	74.832188	25.791041	Low
Ngaliyan	4338	127.073177	34.137810	Low
Bubakan	2369	20.297153	116.715876	High
Kedungpane	2955	41.104735	71.889528	Medium
Jati Barang	1075	40.047206	26.843321	Low
Pesantren	2265	28.803909	78.635160	Medium

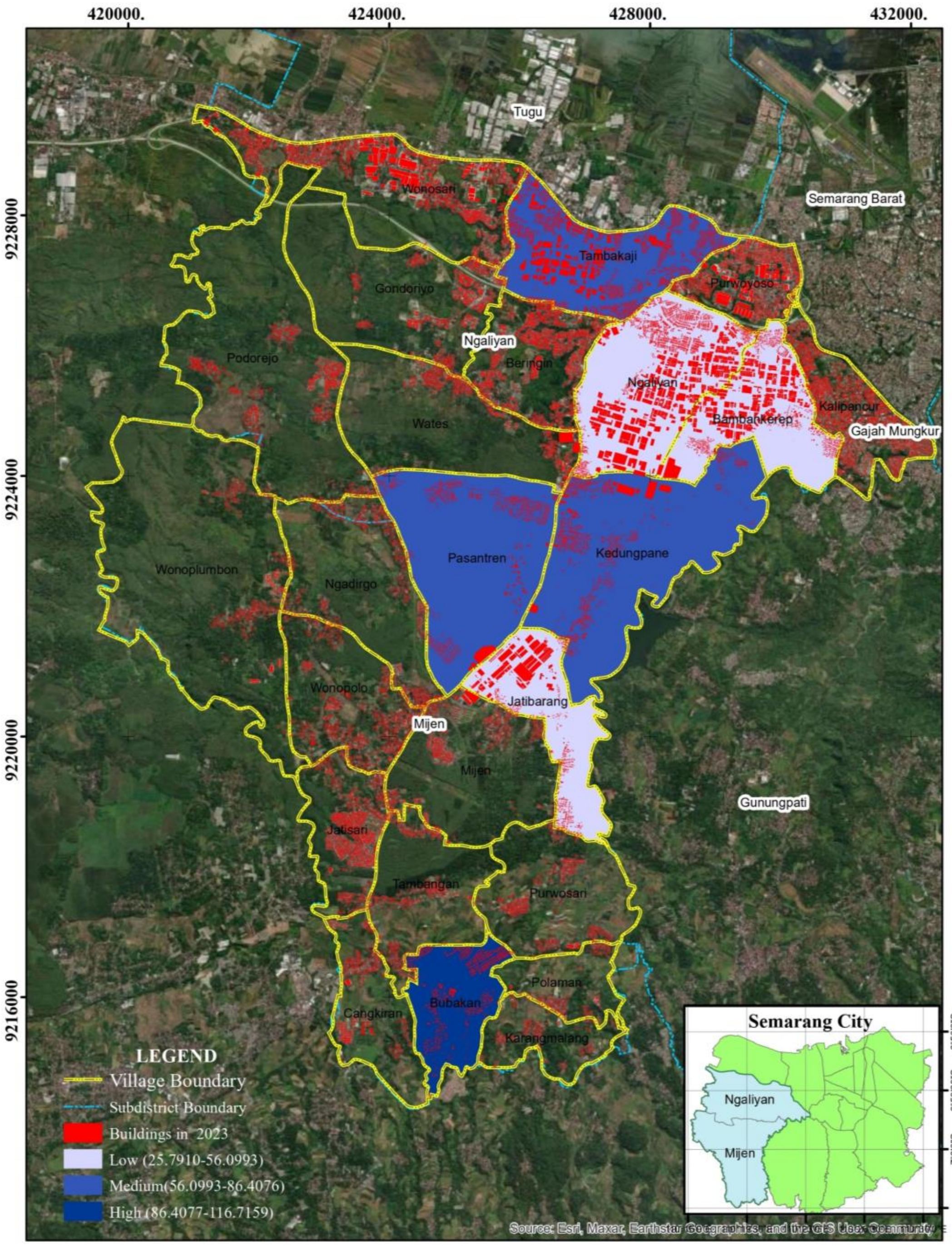

Figure 7. Map of Building Density Classification in 2023

Table 7. Calculation of Distance to City Center

Neighborhood	Distance to City Center	Description
Tambakaji	10.532964	Low
Bambankerep	8.939122	Low
Ngaliyan	10.728591	Low
Bubakan	20.352856	High
Kedungpane	12.569039	Low
Jati Barang	15.726156	Medium
Pesantren	14.852705	Medium

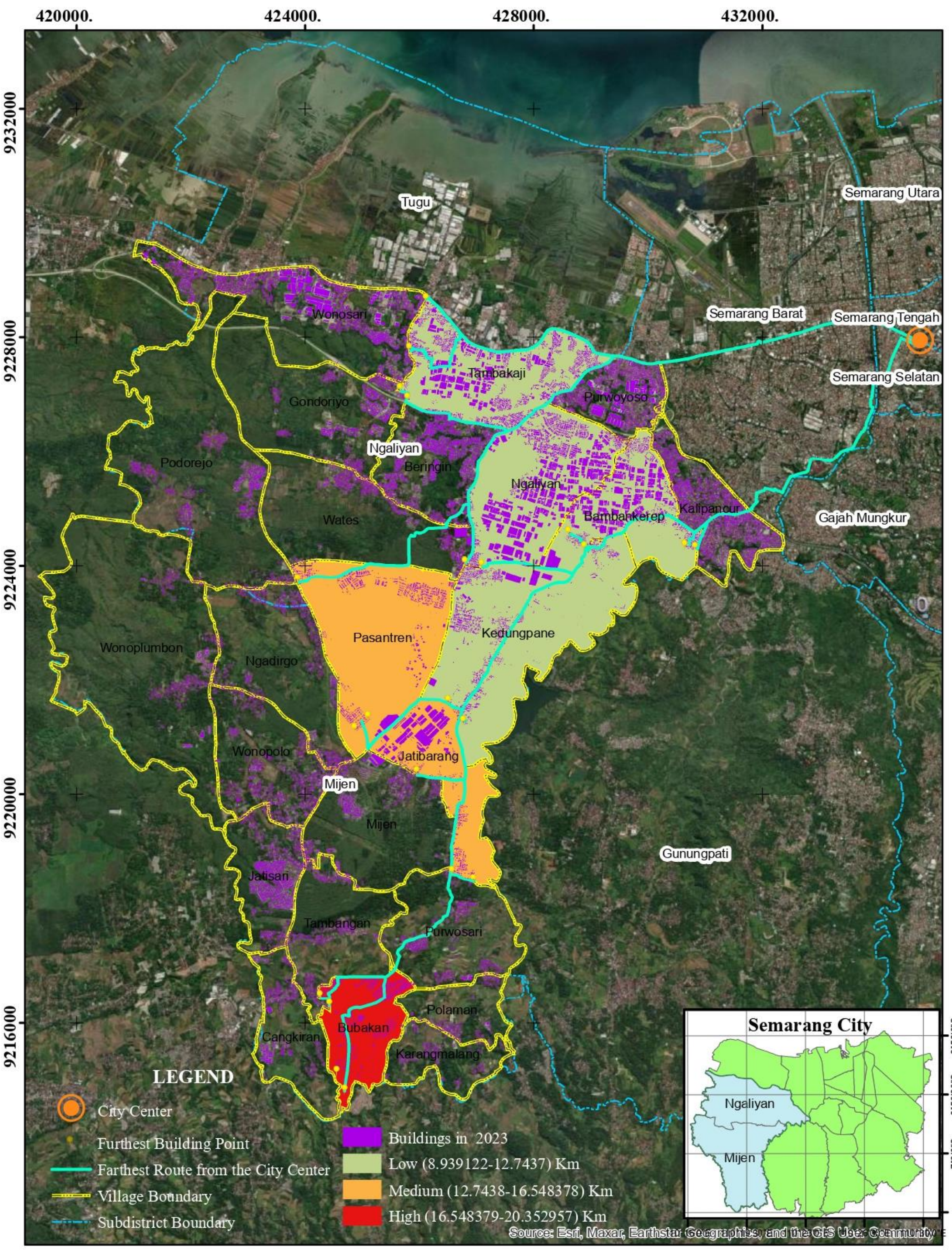

Figure 8. Map of Distance Classification to City Center in 2023

Table 8. Highway Strip Index Calculation

Neighborhood	Number of Buffer Buildings	Number of New Buildings	*Indeks Highway Strip*	Description
Tambakaji	13	81	0.160494	Low
Bambankerep	36	86	0.418605	Medium
Ngaliyan	56	180	0.311111	Low
Bubakan	146	1166	0.125214	Low
Kedungpane	36	116	0.310345	Low
Jati Barang	20	61	0.327869	Low
Pesantren	138	1111	0.124212	Low

4.3.4. Development within Road Network Reach (Highway Strip Index)

The index classification is divided into three classes, with values ranging from 0-1 on the index or 0%-100% for the percentage of new buildings located within the road buffer. Based on **Table 8**, there are only two classes (Low and Medium), with the lowest highway strip index being 0.124. This indicates that 12.4% of new buildings in Pesantren Village were within the buffer zone. In contrast, the highest highway strip index was 0.419, indicating that 41.9% of new buildings in Bambankerep Village were within the buffer zone.

The higher the Highway Strip Index ratio, the lower the level of urban sprawl occurring in the village. Conversely, a smaller Highway Strip Index ratio may indicate a more dispersed, less structured development pattern. In other words, the level of urban sprawl is also higher. **Figure 9** visualizes the Development Classification Within Road Network Reach in 2023.

4.3.5. Patterns of Leapfrog Development

The Leapfrog Index, based on **Table 9**, measures fragmented development and ranges from a minimum value of 0.001827 in Neighborhood Bubakan to a maximum of 0.053443 in Neighborhood Jatibarang. These values are classified into low, medium, and high categories. A higher Leapfrog Index indicates greater urban sprawl, characterized by discontinuous, dispersed development.

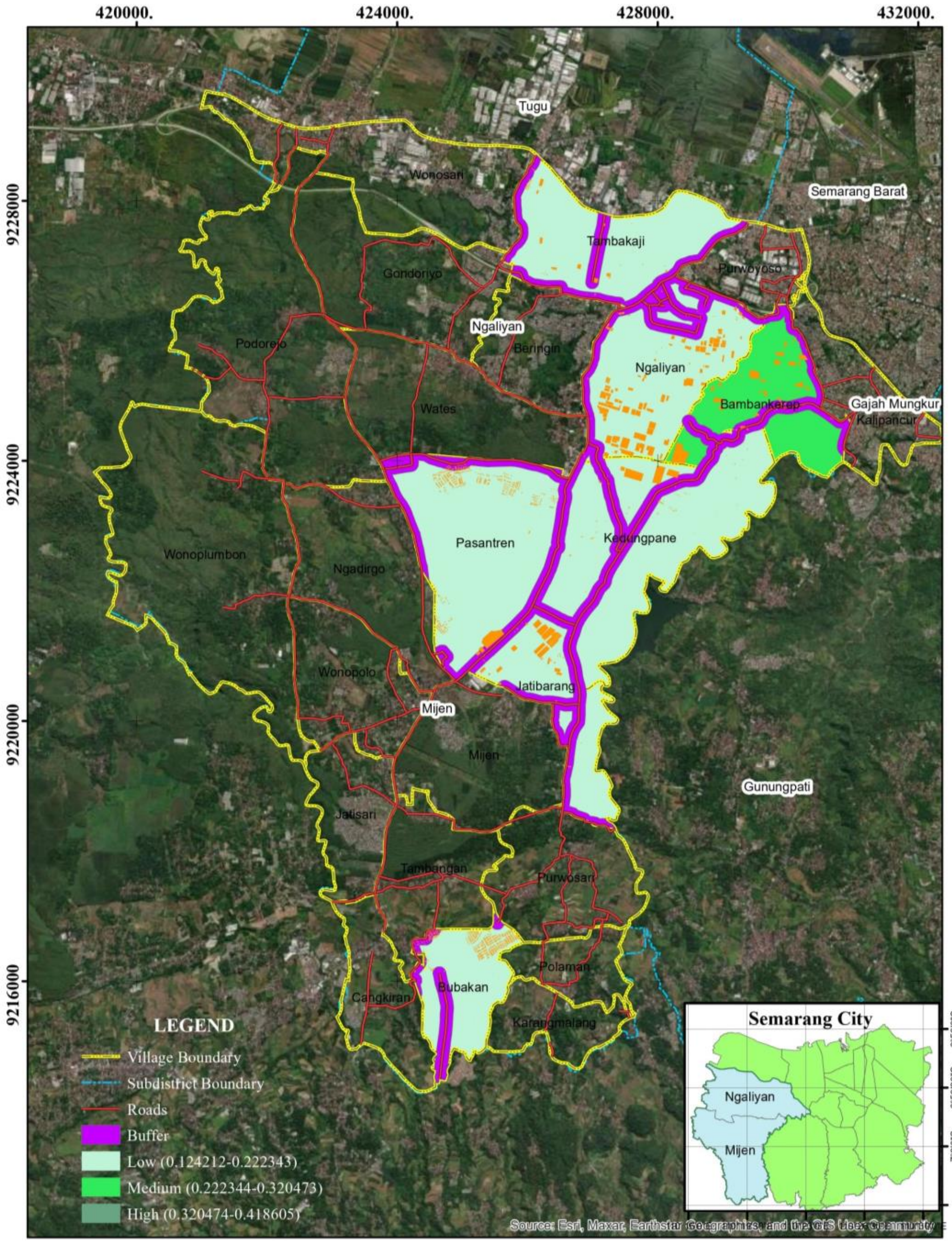

Figure 9. Map of Development Classification Within Road Network Reach in 2023

Table 9. Leapfrog Index Calculation

Neighborhood	Distance	Number of New Buildings	*Indeks Leapfrog*	Description
Tambakaji	0.55	81	0.00679	Medium
Bambankerep	3.38	86	0.039302	High
Ngaliyan	2.25	180	0.0125	Low
Bubakan	2.13	1166	0.001827	Low
Kedungpane	2.73	116	0.023534	Medium
Jati Barang	3.26	61	0.053443	High
Pesantren	2.78	1111	0.002502	Low

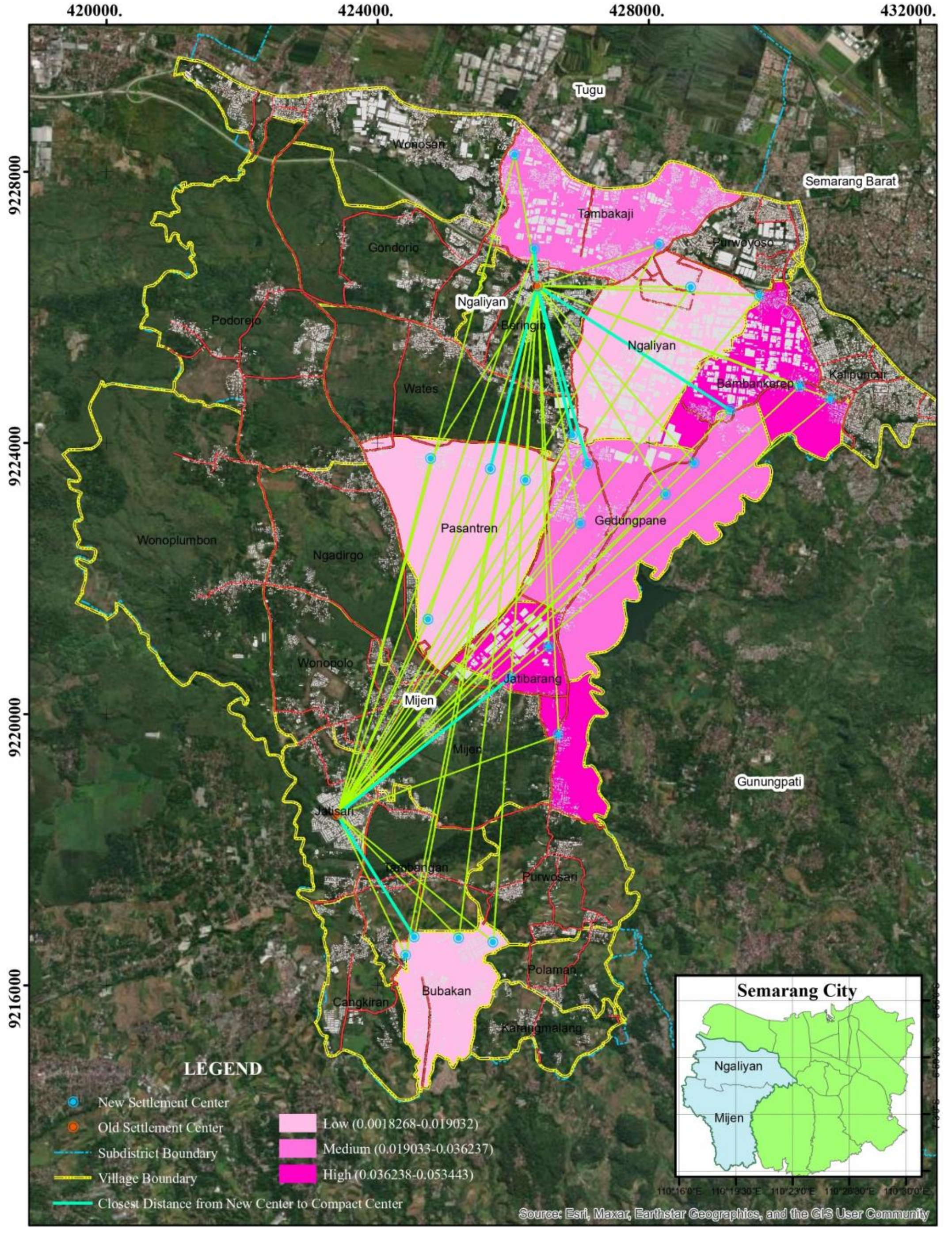

Figure 10. Map of Leap Frog Development Pattern Classification in 2023

The Neighborhoods of Pesantren, Ngaliyan, and Bubakan exhibit a low Leapfrog Index, indicating lower levels of urban sprawl due to more concentrated, integrated development. Tambakaji and Kedungpane are in the medium category, indicating scattered development but still connected to the main area. Neighborhoods Bambankerep and Jatibarang exhibit a high Leapfrog Index, indicating significant urban sprawl driven by highly dispersed, disconnected development, limited infrastructure, and unplanned land conversion. This parameter is critical to understanding the spatial efficiency and sustainability of urban growth. Meanwhile, **Figure 10** develops the spatial understanding of the Leap Frog Development Pattern Classification in 2023.

4.4. Urban Sprawl Classification

Based on **Table 10**, the urban sprawl classification is divided into three levels: low (scores 5-8.33), medium (scores 8.34-11.67), and high (scores 11.68-15). There is no low-level sprawl classification in the identified villages. The medium-level areas include Ngaliyan Village, Tambakaji Village, Kedungpane Village, Bubakan Village, and Pesantren Village. Meanwhile, the high classification includes Jatibarang Village and Bambankerep Village, characterized by rapid, unplanned growth and limited infrastructure connectivity. **Figure 11** suggests the Urban Sprawl Classification in 2023.

4.5. Urban Sprawl Typology

The information in **Table 11** is a per-grid urban sprawl typology that has changed from 2019 to 2023.

Table 12 expresses the per-grid urban sprawl typology that has changed from 2015 to 2019.

Based on the analysis of changes in urban sprawl typology in **Tables 11** and **12**, changes were examined across 184 grids of 0.25 km ². Between 2015 and 2023, the built-up area increased, as indicated by a decrease in unclassified grids (from 51 to 36). Scatter development increased (44 to 48 grids), and urban fringe grew significantly (0 to 12 grids), while ribbon development decreased slightly (89 to 88 grids). This shift reflects an increasingly dispersed, decentralized, and less concentrated development pattern, indicating a change in the spatial character of urban areas. Consequently, **Figures 12, 13,** and **14** aim to visualize the Typology Map of Urban Sprawl for 2015, 2019, and 2023.

Table 10. Total Score for each Neighborhood

Neighborhood	Score					
	Population Density	Building Density	Distance to City Center	Development in the Road Network	Development Pattern (Leapfrog)	Total Score
Tambakaji	1	2	1	3	2	9
Bambankerep	3	3	1	2	3	12
Ngaliyan	3	3	1	3	1	11
Bubakan	1	1	3	3	1	9
Kedungpane	1	2	1	3	2	9
Jati Barang	3	3	2	3	3	14
Pesantren	3	2	2	3	1	11

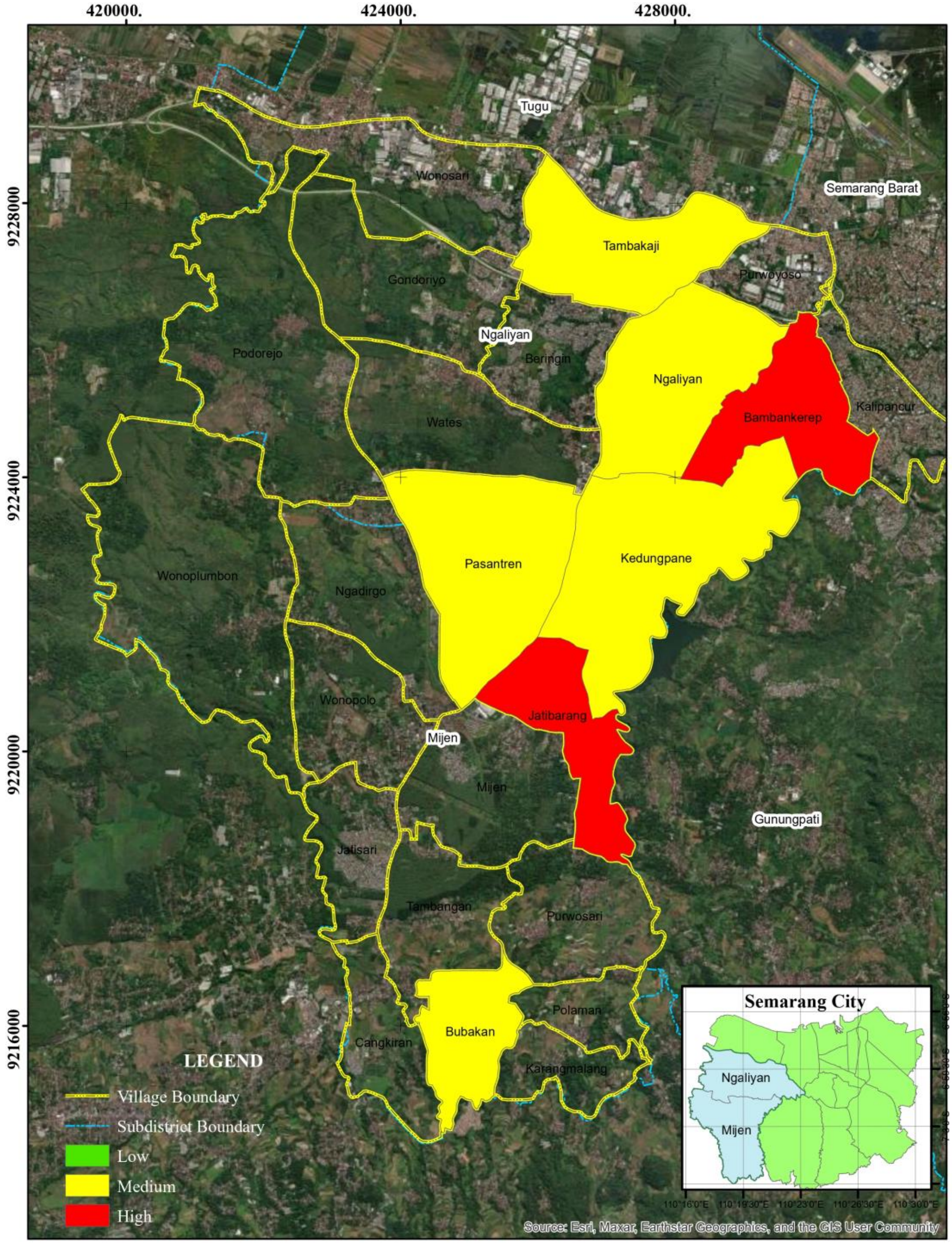

Figure 11. Urban Sprawl Classification in 2023

Table 11. Changes in Urban Sprawl Typology in 2019-2023

Subdistrict	Neighborhoods	No Grid	Changes	
			2019	2023
Mijen	Kedungpane	L10	Unclassified	Scatter Development
		L11	Unclassified	Scatter Development
		M9	Unclassified	Scatter Development
	Pesantren	N2	Unclassified	Ribbon Development
		J4	Unclassified	Ribbon Development
		N3	Unclassified	Scatter Development
Ngaliyan	Bambankerep	J10	Unclassified	Scatter Development
		H11	Scatter Development	Urban Fringe
		H12	Scatter Development	Urban Fringe
		I11	Ribbon Development	Urban Fringe
		I12	Ribbon Development	Urban Fringe
	Ngaliyan	E12	Unclassified	Ribbon Development
		J8	Ribbon Development	Scatter Development
		H9	Scatter Development	Urban Fringe
		N10	Scatter Development	Urban Fringe
		I9	Scatter Development	Urban Fringe
		I10	Ribbon Development	Urban Fringe

Table 12. Changes in Urban Sprawl Typology in 2015-2019

Subdistrict	Neighborhoods	No Grid	Changes	
			2015	2019
Mijen	Pesantren	J3	Unclassified	Scatter Development
		O2	Unclassified	Ribbon Development
		K3	Unclassified	Scatter Development
		K4	Unclassified	Scatter Development
	Bubakan	Y3	Unclassified	Scatter Development
		Y5	Unclassified	Scatter Development
Ngaliyan	Ngaliyan	J9	Unclassified	Scatter Development
		F11	Ribbon Development	Urban Fringe
		F12	Ribbon Development	Urban Fringe
		G11	Scatter Development	Urban Fringe
	Bambankerep	G12	Scatter Development	Urban Fringe
	Jatibarang	P6	Ribbon Development	Scatter Development

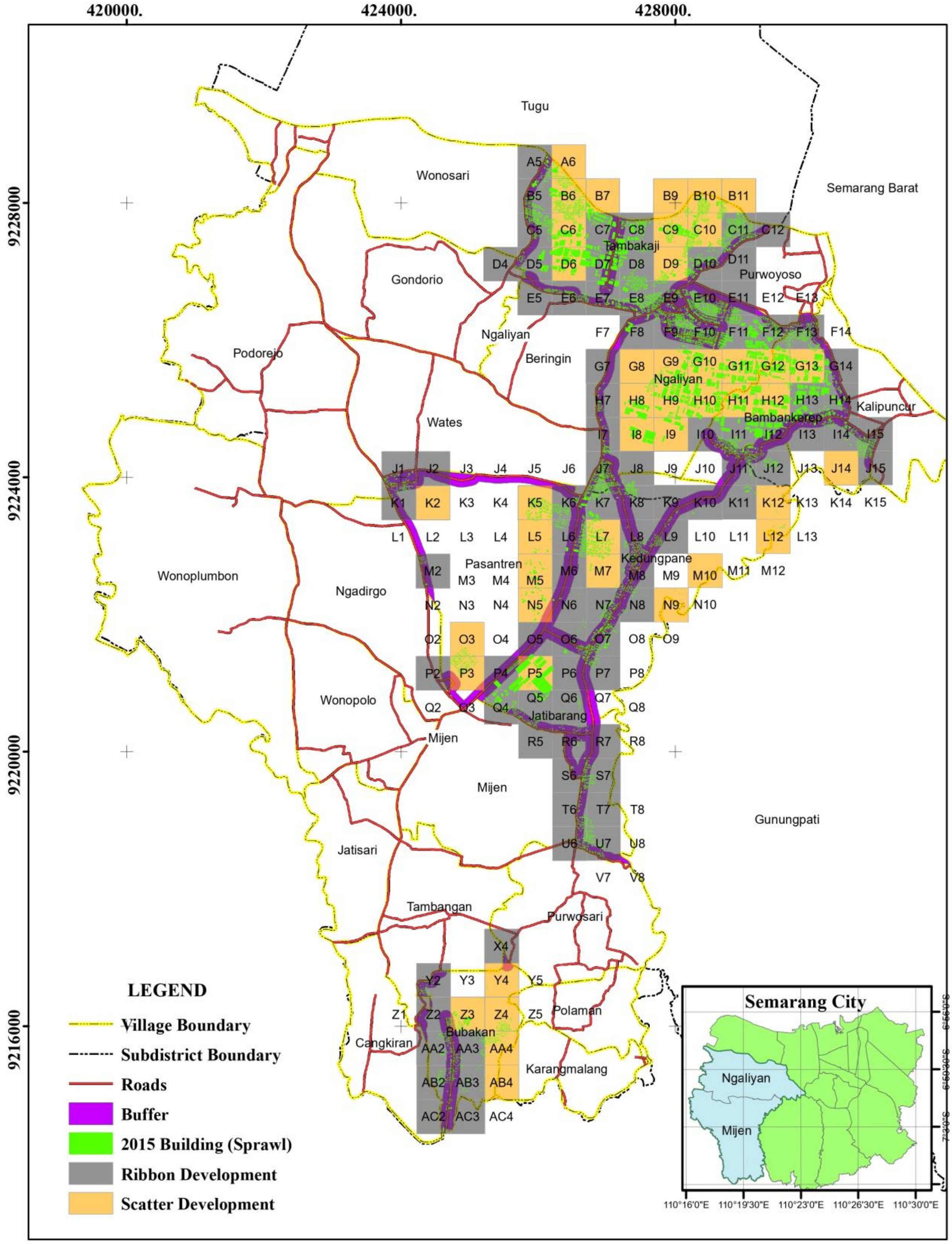

Figure 12. Typology Map of Urban Sprawl in 2015

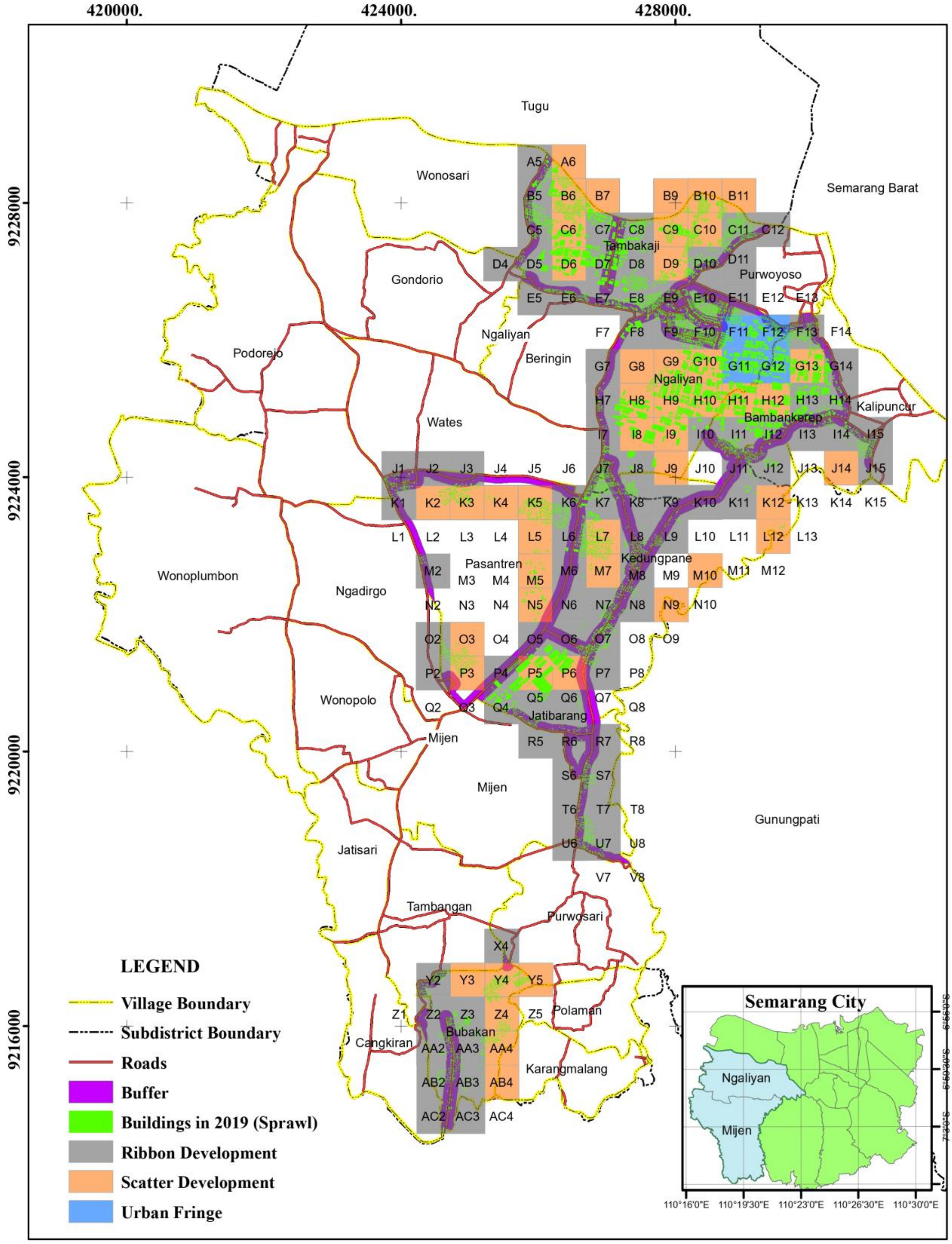

Figure 13. Typology Map of Urban Sprawl in 2019

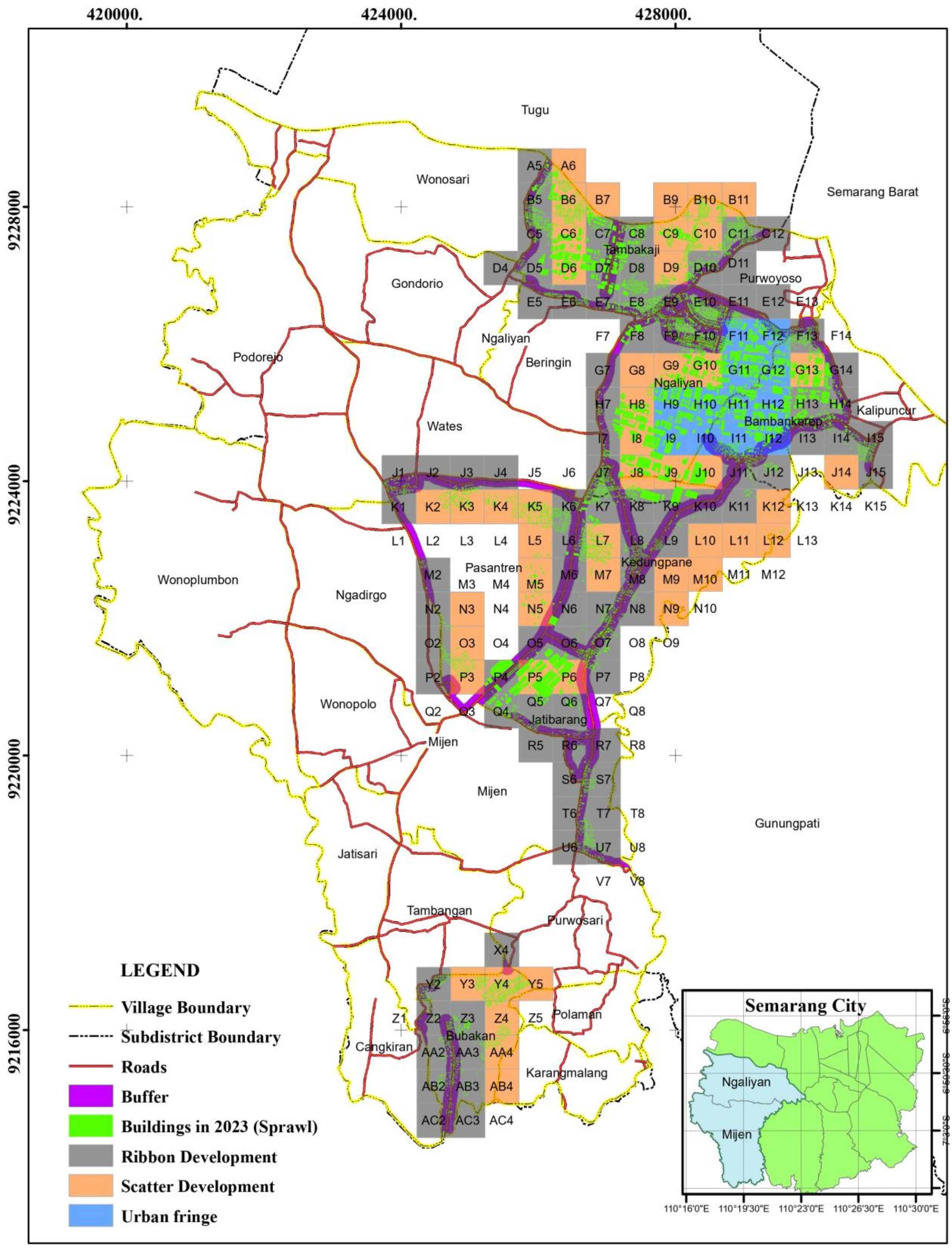

Figure 14. Typology Map of Urban Sprawl in 2023

5. Conclusions

The following are the conclusions of this research:

1. The grid method (0.25 km²) effectively mapped urban sprawl changes in Ngaliyan and Mijen Sub-districts (2015, 2019, 2023), revealing a significant increase in built-up areas and a shift in development patterns from concentrated along roads to more dispersed and decentralized forms, providing accurate and in-depth spatial analysis of land use changes.

2. Spatial grid analysis (184 units of 0.25 km²) indicated significant changes in urban sprawl typologies (2015-2023) in Ngaliyan and Mijen Sub-districts. An increase in scatter development and urban fringe grids reflects a dispersed and unconcentrated development pattern, particularly in the metropolitan fringe, which expanded from 0 to 12 grids, indicating that development is increasingly detached from the leading urban network. Conversely, a slight decrease in ribbon development suggests expansion beyond primary road corridors. Overall, scatter development dominated the 2023 sprawl typology, followed by ribbon development and the urban fringe, indicating increasingly widespread, unconcentrated development.
3. Uncontrolled urban development in the subdistricts of Ngaliyan and Mijen has caused environmental degradation, including reduced water catchment areas, increased flooding risk, and habitat fragmentation. Uncontrolled urban development has also increased the use of personal two-wheeled, fossil-fueled vehicles, which are inconsistent with Indonesia's new wave of ecological policies aimed at reducing emissions. It is suggested that the Spatial Planning Policy (RTRW) address this matter by prohibiting the expansion of Settlements and Residential Areas and by promoting more sustainable housing models, such as the Vertical Housing Policy. We noted the failure of the "RTRW" as a spatial planning document to serve as a control tool for suburban extension. In this article, we also lamented the Semarang government's pro-investment program, which supports the role of private housing developers who have consistently sought to develop new satellite cities beyond the city's outskirts since the emergence of the new culture in Indonesia. The middle-income citizen opted to live farther from the city center because of the perception of the city center as an unhealthy, crowded place.

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