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Typology of Urban Sprawl Based on Its Characteristics and Intensity in Mijen Subdistrict, Semarang City, Indonesia

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Abstract. Mijen District has experienced rapid urban expansion driven by population growth and infrastructure development, resulting in the conversion of non-built-up land into built-up areas. While urban sprawl has been widely studied, research integrating sprawl typology assessment with future land-use prediction in peri-urban areas remains limited. This study aims to identify the driving factors of urban sprawl, classify its typologies and intensity, and predict land-use changes in 2032. A quantitative approach was employed using descriptive, spatial, and inferential analyses supported by ArcMap and the Land Change Modeler in TerrSet 2020. The results indicate three levels of urban sprawl: low (Jatisari), moderate (Wonoplumbon and Cangkiran), and high (Bubakan and Karangmalang). The main driving factors include infrastructure expansion, population growth, and uncontrolled migration. Land-use prediction for 2032 indicates the continued expansion of built-up areas, particularly in zones with high urban sprawl intensity. This study contributes to urban sprawl research by integrating spatial typology analysis with future land-use modeling and provides a basis for spatial planning policies aimed at controlling urban expansion and promoting sustainable peri-urban development.

Keywords: *urban sprawl; peri-urban development; land-use change; Land Change Modeler; GIS; Mijen Subdistrict*

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Introduction

Urban expansion has become a central issue in contemporary spatial planning because the growth of built-up land often exceeds the rate of population growth and produces fragmented metropolitan regions (Angel et al., 2011; Seto et al., 2012). In many developing urban regions, the fringe area is where land conversion occurs most rapidly because it provides cheaper land, new infrastructure, and easier access to emerging employment centers. When this outward expansion is weakly coordinated with spatial plans, it can generate urban sprawl, a pattern generally associated with low density, discontinuity, land-use separation, weak centrality, and fragmented accessibility (Ewing et al., 2002; Galster et al., 2001; Jaeger et al., 2010).

Although the term urban sprawl has been defined differently across planning, geography, and environmental studies, most definitions emphasize unplanned outward expansion and the conversion of non-urban land into urban uses (Bhatta et al., 2010; Frenkel & Ashkenazi, 2008). Galster et al. (2001) argue that sprawl is better understood through multiple dimensions such as density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. Similarly, Ewing and Hamidi (2015) conceptualize sprawl as a spatial form that reduces accessibility and increases dependence on private mobility. These conceptual debates are important because urban sprawl is not merely a physical expansion of buildings; it also reflects the interaction between population pressure, infrastructure provision, market forces, planning control, and household location preferences.

The consequences of urban sprawl are significant for urban sustainability. Uncontrolled conversion of agricultural land, shrubland, and open land can reduce ecological functions, increase infrastructure costs, intensify commuting, and create spatial inefficiency (Angel et al., 2011; Lambin & Geist, 2006; Seto et al., 2012). At the same time, peri-urban expansion may be attractive for households because it provides a more comfortable living environment and access to new economic opportunities. This duality makes sprawl a complex planning issue: it can support residential and economic growth, but it can also undermine spatial order and environmental resilience when the expansion is scattered or poorly regulated (Bhatta, 2010; McGee, 1991).

Remote sensing and Geographic Information Systems (GIS) have become essential tools for observing land-use and land-cover change because they enable consistent spatial comparison across time (Bhatta et al., 2010; Jensen, 2015). Multi-temporal satellite imagery can identify the conversion of non-built-up land into settlement, commercial, industrial, and infrastructure uses, while spatial models can project future land-use scenarios to support policy decisions (Pontius et al., 2004; Wu et al., 2006). TerrSet Land Change Modeler (LCM), for example, is designed to analyze historical land-cover change, model relationships with explanatory variables, and simulate future land-change scenarios (Clark Labs, 2024). Such tools are especially relevant for peri-urban areas where growth trajectories are rapid and spatial planning requires anticipatory evidence.

Semarang City, the capital of Central Java Province, Indonesia, has experienced population growth, infrastructure development, and outward urban expansion. The pressure of development is not concentrated only in the inner city; it has increasingly shifted toward peripheral areas, including Mijen Subdistrict. Mijen is strategically located in the southwestern part of Semarang City and covers approximately 57.55 km^2. Its position as a peri-urban area, combined with planned low-density housing, industrial activity, and accessibility improvements, makes it vulnerable to land conversion from non-built-up to built-up uses. The Semarang spatial plan also places Mijen within a development framework that includes public-service reserves, low-density housing, industrial and commercial functions, and green/open-space roles (Badan Pusat Statistik Kota Semarang, 2012, 2017, 2022; Pemerintah Kota Semarang, 2011).

Previous studies on sprawl and peri-urban change in Semarang and other Indonesian cities have examined land-use change, urban fringe typology, and spatial policy conformity. However, the specific typology of sprawl based on both physical characteristics and causal factors in Mijen remains important to investigate because the area combines settlement growth, industrial attraction, and ecological planning functions. This study therefore asks: (1) how did land use in Mijen change between 2012, 2017, and 2022; (2) how is land use projected to change by 2032; (3) what is the level and typology of urban sprawl in selected peri-urban villages; and (4) what factors most strongly explain urban sprawl in Mijen? By integrating land-use classification, LCM projection, sprawl scoring, and factor analysis, this article contributes an empirical case for understanding peri-urban expansion in Indonesian secondary metropolitan contexts.

Methods

This study used a quantitative research design with descriptive, spatial, and inferential analytical techniques. Quantitative design was appropriate because the study relied on measurable indicators of land-use area, population density, building density, spatial distance, leapfrog index, and survey-based factor scores (Creswell & Creswell, 2018). The spatial analysis was used to identify and project land-use change, while inferential analysis was used to reduce several causal indicators into dominant sprawl-driving factors.

The study area was Mijen Subdistrict, Semarang City, Central Java Province, Indonesia. Mijen is located in the southwestern part of Semarang City and has an area of approximately 57.55 km^2. The sprawl-level analysis focused on five peri-urban villages: Wonoplumbon, Jatisari, Cangkiran, Bubakan, and Karangmalang. These villages were selected because they represent the fringe dynamics of Mijen, where the transition between rural and urban land-use characteristics is most visible.

The data consisted of primary and secondary sources. Primary data were collected through field observation and questionnaires. The questionnaire was used to identify factors causing urban sprawl and was distributed to 100 respondents. The sample size was calculated using the Slovin formula based on a population of approximately 76,000 and a 10% error tolerance. Secondary data included population data from BPS Kota Semarang, spatial planning documents, Landsat 9 Operational Land Imager imagery, Google Earth time-series imagery, and spatial layers required for GIS analysis. Land-use classes were grouped into built-up land and non-built-up land. Built-up land consisted of residential/settlement and commercial/service uses; non-built-up land consisted of shrubland, vacant land, and water bodies.

Land-use classification for 2012, 2017, and 2022 was conducted using ArcMap 10.6. Satellite images and Google Earth interpretation were processed through image correction, cropping, raster preparation, and interactive supervised classification. The classification accuracy was estimated at approximately 85%, which was considered acceptable for identifying broad land-use classes at the subdistrict scale. Accuracy assessment is important in remote-sensing-based land classification because classification error may influence subsequent change detection and modelling results (Congalton & Green, 2019; Jensen, 2015).

Future land-use change for 2032 was projected using TerrSet 2020 Land Change Modeler. The LCM workflow involved preparing land-cover maps from 2012 as the earlier land-cover layer and 2022 as the later land-cover layer, synchronizing class legends, analyzing land-cover gains and losses, identifying transition potentials, and producing a change prediction map. The transition submodels included shrubland to residential/settlement, shrubland to commercial/service, shrubland to vacant land, shrubland to water, and vacant land to residential/settlement. These transitions were selected because they represented the most plausible and dominant conversion pathways observed in Mijen.

The level of urban sprawl was calculated through a scoring method based on four characteristics: population density, building density, distance to the city center, and leapfrog development pattern. Population density was calculated by dividing population by administrative area; building density was calculated by dividing the number of building units by land area; distance to the city center was measured from each village office to Simpang Lima, the central point of Semarang City; and the leapfrog development index was calculated by dividing the total distance between new buildings and old settlement centers by the number of new buildings. Low population and building density were scored as indicators of higher sprawl, whereas greater distance and higher leapfrog index were also scored as indicators of higher sprawl. Total scores were then classified into three typologies: Typology I (low sprawl), Typology II (moderate sprawl), and Typology III (high sprawl).

The causal factors of sprawl were analyzed using Principal Component Analysis (PCA) with varimax rotation in SPSS 26. The original questionnaire contained ten variables, but the analysis retained eight variables after the screening process. Factor loading greater than 0.50 was used as the minimum threshold for interpretation, following common multivariate analysis practice (Hair et al., 2019). The rotated solution produced three interpretable factor groups: infrastructure improvement, population growth, and uncontrolled migration.

Table 1.
Research objectives, variables, and analytical techniques

Analytical objective	Main variables/indicators	Analytical technique
Land-use change, 2012-2022	Residential/settlement, commercial/service, shrubland, vacant land, water bodies	Supervised classification and GIS overlay
Land-use projection, 2032	Dominant land-use transition pathways	TerrSet Land Change Modeler
Urban sprawl level	Population density, building density, distance to city center, leapfrog index	Scoring and typology classification
Drivers of sprawl	Questionnaire indicators related to infrastructure, planning, population, migration, accessibility, and economic activity	PCA factor analysis with varimax rotation

Results

Land-use change from 2012 to 2022

The land-use analysis shows a substantial increase in built-up land during the 2012-2022 period. Residential and settlement land increased from 3.62 km^2 in 2012 to 18.20 km^2 in 2017 and 21.83 km^2 in 2022. Commercial and service land increased more gradually from 0.52 km^2 in 2012 to 0.61 km^2 in 2017 and 1.24 km^2 in 2022. In contrast, vacant land decreased sharply from 18.93 km^2 in 2012 to 3.21 km^2 in 2017 and only 0.12 km^2 in 2022. This indicates that the first phase of growth, particularly between 2012 and 2017, was dominated by the conversion of vacant land into residential and settlement areas. Shrubland remained high in 2017 but declined considerably by 2022, showing that later expansion also affected vegetated or semi-natural land.

Table 2.
Land-use change in Mijen Subdistrict, 2012-2022

Land-use class	2012 (km²)	2017 (km²)	2022 (km²)	Change 2012-2022 (km²)
Residential and settlement	3.62	18.20	21.83	+18.21
Commercial and service	0.52	0.61	1.24	+0.72
Shrubland	34.08	35.03	23.94	-10.14
Vacant land	18.93	3.21	0.12	-18.81
Water bodies	0.40	0.50	0.75	+0.35
Total	57.55	57.55	57.55	0.00

In aggregate, built-up land increased from 4.14 km² in 2012 to 23.07 km² in 2022, representing an increase of 18.93 km². The proportion of built-up land therefore expanded from approximately 7.2% to 40.1% of the subdistrict area. This pattern confirms that Mijen experienced a rapid physical transformation from a predominantly non-built-up peri-urban landscape toward a more urbanized settlement and service landscape.

Projected land-use change in 2032

The LCM projection suggests that built-up expansion will continue by 2032. Residential and settlement land is projected to increase from 21.83 km² in 2022 to 30.86 km² in 2032, while commercial and service land is projected to increase from 1.24 km² to 6.66 km². Shrubland is projected to decline from 23.94 km² to 18.45 km². The projected built-up area, combining residential/settlement and commercial/service land, reaches 37.52 km² or approximately 65.2% of the total subdistrict area. The model reported an RMS error of 0.2691, indicating acceptable model performance for a broad land-use projection.

Table 3.
Projected land-use change in Mijen Subdistrict, 2022-2032

Land-use class	2022 (km²)	2032 projection (km²)	Projected change (km²)
Residential and settlement	21.83	30.86	+9.03
Commercial and service	1.24	6.66	+5.42
Shrubland	23.94	18.45	-5.49

Table 3.
Projected land-use change in Mijen Subdistrict, 2022-2032

Land-use class	2022 (km²)	2032 projection (km²)	Projected change (km²)
Vacant land	0.12	0.34	+0.22
Water bodies	0.75	1.24	+0.49
Total	57.55	57.55	0.00

The projection also suggests that future land-use change will not only involve residential expansion but also a substantial increase in commercial and service uses. This pattern is consistent with Mijen's role in the city spatial plan as an area of low-density residential development, public-service reserve, industrial activity, and urban support functions. However, the expansion of built-up land also implies stronger pressure on shrubland and remaining open spaces.

Urban sprawl typology in the peri-urban villages

The sprawl-level analysis used four indicators. Jatisari had the lowest total score, indicating low sprawl, because it had the highest population and building density and a relatively consolidated settlement pattern. Wonoplumbon and Cangkiran were classified as moderate sprawl areas. Bubakan and Karangmalang were classified as high sprawl areas because their total scores were highest, reflecting lower density and/or more fragmented expansion characteristics.

Table 4.
Urban sprawl score and typology of peri-urban villages in Mijen

Village	Population density score	Building density score	Distance score	Leapfrog score	Total score	Sprawl typology
Wonoplumbon	3	3	1	1	8	Moderate
Jatisari	1	1	2	1	5	Low
Cangkiran	2	2	3	1	8	Moderate
Bubakan	3	3	2	2	10	High
Karangmalang	3	3	1	3	10	High

The classification ranges were 5.0-6.6 for low sprawl, 6.7-8.3 for moderate sprawl, and 8.4-10.0 for high sprawl. The results indicate that sprawl is not evenly distributed across Mijen. Some villages have experienced more consolidated urban growth, whereas others show stronger signs of discontinuous or low-density expansion.

Factors causing urban sprawl

The factor analysis reduced eight questionnaire variables into three major components. The first component, infrastructure improvement, explained 19.716% of variance and included variables related to settlement attractiveness, the suitability of peri-urban areas for settlement development, and the relationship between irregular settlement expansion and infrastructure needs. The second component, population growth, explained 16.209% of variance and was associated with increasing settlement demand and occupational shifts toward industrial employment. The third component, uncontrolled migration, explained 16.149% of variance and included limited housing availability in the urban core, wider transportation access, and industrial employment attraction. Together, the three components explained 52.071% of total variance.

Table 5.
Factor analysis results for drivers of urban sprawl

Factor	Interpreted driver	Variance explained (%)	Main loading variables
1	Infrastructure improvement	19.716	X1, X3, X10
2	Population growth	16.209	X2, X5
3	Uncontrolled migration	16.149	X4, X7, X9
Total	Three-factor solution	52.071	Eight retained variables

The rotated component matrix indicates that X3 had the strongest loading on the infrastructure factor (0.742), X5 had the strongest loading on the population-growth factor (0.693), and X4 had the strongest loading on the uncontrolled-migration factor (0.743). These results suggest that sprawl in Mijen is not driven by a single cause. It is produced by the interaction between infrastructure-led attractiveness, demographic pressure, and migration or relocation toward peripheral areas.

Discussion

The findings demonstrate that Mijen's peri-urban transformation follows a typical sprawl pathway: non-built-up land is gradually converted into residential, commercial, and service uses as infrastructure and accessibility improve. The most striking change occurred in residential and settlement land, which increased by 18.21 km^2 between 2012 and 2022. This confirms that the demand for housing has become a dominant force in the spatial transformation of Mijen. In the broader literature, residential expansion is one of the most common forms of peri-urban sprawl because households often seek lower land prices, larger plots, and better environmental comfort outside the dense urban core (Bhatta, 2010; Ewing et al., 2002; Galster et al., 2001).

The sharp decline of vacant land from 18.93 km^2 to 0.12 km^2 indicates that land reserves suitable for immediate development have largely been absorbed by urban uses. This is an important planning signal. Once easily convertible vacant land becomes scarce, future expansion tends to move toward shrubland, agricultural land, or more environmentally sensitive areas. The 2032 projection supports this concern because shrubland is expected to decline by 5.49 km^2 while built-up land continues to grow. This pattern is consistent with global evidence that urban land-cover change can place pressure on ecosystems, open spaces, and land resources if not managed through clear spatial regulations (Angel et al., 2011; Lambin & Geist, 2006; Seto et al., 2012).

The projected growth of commercial and service land is particularly important. While residential land remains the largest built-up class, commercial and service land is projected to increase from 1.24 km^2 to 6.66 km^2 between 2022 and 2032. This indicates a shift from purely residential suburbanization toward a more complex peri-urban economy. Such growth may improve access to services and local employment, but it can also accelerate land conversion and traffic generation when development is not coordinated with transport, green space, and public-service capacity. Sprawl is therefore not only a land-cover issue; it is also a governance issue involving the timing and location of infrastructure, permits, and economic activities (Ewing & Hamidi, 2015; Jaeger et al., 2010).

The sprawl typology reveals spatial differentiation within Mijen. Jatisari was classified as low sprawl because it has higher population and building density, suggesting a more consolidated form of development. By contrast, Bubakan and Karangmalang were classified as high sprawl areas. Their characteristics align with the classic indicators of sprawl, including lower density and fragmented or leapfrog patterns of development. Leapfrog development is particularly relevant because it produces discontinuity between old and new settlement areas, increases infrastructure extension costs, and may create inefficient land-use patterns (Frenkel & Ashkenazi, 2008; Galster et al., 2001; Hasse & Lathrop, 2003).

The factor analysis adds an explanatory dimension to the spatial results. Infrastructure improvement emerged as the strongest factor, reflecting the role of accessibility, public facilities, and planned development functions in attracting settlement expansion. In many peri-urban settings, infrastructure both follows and induces growth. Roads, public services, and transport access can reduce travel friction and make fringe land more attractive to developers and households. However, when infrastructure provision is not synchronized with compact development control, it can unintentionally stimulate scattered settlement expansion (Bhatta et al., 2010; Wu et al., 2006).

Population growth was the second major factor. The increasing need for housing reflects both natural population growth and household relocation. As the urban core becomes denser and land prices increase, peri-urban areas become attractive alternatives. In Mijen, this process is reinforced by industrial and employment opportunities. The shift in livelihood from farming toward factory-related work also indicates that the land-use transition is connected to economic restructuring. This is consistent with peri-urban theory, which describes fringe areas as hybrid spaces where rural land uses, urban employment, and new settlement forms coexist and compete (McGee, 1991).

Uncontrolled migration was the third factor. This factor captures the movement of residents from outside or from more central areas into Mijen due to comfort, security, accessibility, and proximity to work. The issue is not migration itself, but the absence of effective spatial control to guide where and how new residents settle. If migration-driven demand is absorbed through scattered low-density development, the result is likely to be greater sprawl. Therefore, policy responses should focus on managing settlement location, limiting unnecessary land conversion, requiring adequate infrastructure and utilities, and preserving green/open-space functions in accordance with the Semarang spatial plan (Pemerintah Kota Semarang, 2011).

From a planning perspective, the results suggest three priorities. First, land-use permits should be aligned more strictly with the spatial plan, especially because Mijen is also expected to function as an urban green lung. Second, infrastructure development should be used as a tool for compact and planned growth rather than as a trigger for scattered development. Third, residential and commercial growth should be directed toward areas with existing service capacity while maintaining minimum green-space requirements. Without such control, the projected 2032 expansion may reduce non-built-up land and intensify spatial inefficiency.

Conclusion

This study examined the typology of urban sprawl based on land-use characteristics and causal factors in Mijen Subdistrict, Semarang City. The results show that Mijen experienced rapid land conversion between 2012 and 2022. Residential and settlement land increased from 3.62 km^2 to 21.83 km^2, while vacant land decreased from 18.93 km^2 to 0.12 km^2. The 2032 LCM projection indicates continued built-up expansion, with residential and settlement land expected to reach 30.86 km^2 and commercial/service land expected to reach 6.66 km^2. The sprawl typology shows that Jatisari is classified as low sprawl, Wonoplumbon and Cangkiran as moderate sprawl, and Bubakan and Karangmalang as high sprawl. These differences indicate that peri-urban expansion in Mijen is spatially uneven and that some villages require stronger control over fragmented or low-density development. The factor analysis identifies three dominant drivers of sprawl: infrastructure improvement, population growth, and uncontrolled migration. These factors explain 52.071% of the variance in the retained variables. The main implication is that

Mijen's future growth should be managed through stricter land-use regulation, infrastructure synchronization, compact development, and protection of non-built-up and green-space functions. The study is limited by the spatial resolution of imagery and the use of broad land-use classes. Future research should apply higher-resolution imagery, validate classification through more extensive field checks, and develop scenario-based simulations that compare compact-growth, business-as-usual, and conservation-oriented planning alternatives.

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