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Built-Up Area Changes, Spatial Pattern and Urban Sprawling in Kedungsepur Metropolitan Area

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ABSTRACT

Kedungsepur is a metropolitan city in Indonesia designated as a national strategic area. With the increasing population, the demand for land for urban activities has also risen, leading to the conversion of undeveloped land into built-up areas. However, few studies have measured land use changes in developing countries, especially in metropolitan areas. This article delves deeper into this subject. While the development of big cities in Indonesia has led to physical expansion, uncontrolled growth has caused urban sprawl in the urban fringe of the core city and suburban areas, as well as in the metropolitan context comprising core and satellite cities. Planning the city's physical growth is crucial to prevent uncontrolled and sporadic urban sprawl. Urban sprawl studies in Indonesian metropolitan areas, particularly those using high-resolution satellite images, are still uncommon. This article uses Sentinel 2A imagery to qualitatively interpret urban sprawl patterns and quantitatively analyze spatial patterns using the nearest neighborhood analysis technique in ArcGIS software. The results reveal that the Kedungsepur Metropolitan Area is experiencing a sprawling leapfrog type of urban sprawl. These findings are crucial for monitoring and improving urban spatial planning in the future.

1. INTRODUCTION

The Kedungsepur Metropolitan Area is one of Indonesia's ten metropolitan development priorities and national strategic areas determined by economic interests. Kedungsepur is an acronym for Kendal-Demak-Ungaran-Semarang-Salatiga-Purwodadi. Kedungsepur is a top priority for several reasons, including the relatively secure slope of the land and connectivity in all directions. Regarding income, Kedungsepur contributes one-quarter of Central Java's Gross Regional Domestic Product (PDRB). In addition, President Regulation (Perpres) Number 78 of 2017 has also been issued to establish Kedungsepur as a Metropolitan Area.

Semarang City, the capital of Central Java Province, is the core city of the Kedungsepur Metropolitan Area. Functionally, Semarang City is interconnected with the surrounding areas Kendal, Demak, Semarang (Ungaran), Salatiga City and parts of Grobogan (Purwodadi). The Kedungsepur area was formed along with the population increase in cities due to urbanization, in-migration, and natural population growth. According to Central Java's Statistics, in 2015, Semarang City had the highest population, population growth rate, and population density in Kedungsepur [1].

The rapid growth of the city's population coincides with an increase in required to meet basic needs, directly impacting urban development. As an area that will continue to expand, Kedungsepur must be able to accommodate a rapid increase in socio-economic activity which can stimulate the growth of the area's function. Based on Indonesia's spatial plan, Kedungsepur is a strategic economic area, so the major development activities are settlements, trade and services. The need for land for housing and supporting facilities also competes with the need for business land, while the land area must remain the same. The land condition resulted in symptoms of non-urban land, with the previously vegetated land cover being converted to urban land use in core and metropolitan satellite cities. The problem also occurs in Kedungsepur, which developed naturally and was designated a metropolitan urban area in 2017. As a result, it is intriguing to determine whether there is a difference between the area developed in 2016, the year preceding the determination, and 2020, four years after the establishment.

The urban population and activities have raised the demand for expansive urban spaces. On the other hand, space availability in the city is fixed and constrained; the growing need for housing and the location of activities tends to consume space in the urban fringe. Expanding suburbanization in the urban fringe, which in the metropolitan context leads to satellite cities, frequently occurs randomly (urban sprawl) and is uncontrollable [2].

The development of major cities in Indonesia shows a swift movement from time to time. The physical development of cities usually differs from the city plans drafted [3]. As city functions expanded, urban characteristics spread to the surrounding areas, giving rise to spatial integration between regions. The city's physical boundaries are constantly changing, resulting in the city's physical boundaries not always being within the city's administrative boundaries.

Urbanisation is the physical development of a region characterised by the emergence of swiftly expanding new buildings. Urbanisation occurs more intensively in areas that are administratively adjacent to cities [4]. The process of

spreading physical appearance to the outside resulted in incorporating satellite cities into the core city. As a consequence, there is a spatial transformation in the city

In contrast, Soetomo [5] defines urbanisation as transitioning from rural to urban life. Soetomo was more concerned with the social lives of city dwellers. Thus, the universal definition of urbanisation and urban sprawl has yet to become a standard agreement among urban study experts [6], so mapping built-up areas are required to initiate research in this discipline. Mapping can be accomplished by interpreting high-resolution satellite images to identify physical changes in the city [7]. Therefore, it is possible to determine whether there has been an increase in a built-up area in Kedungsepur in different years.

From 2016 to 2020, a portion of vegetated land in Kedungsepur was converted into a built-up area. It is recognised that this is inseparable from the sprawling process, which also occurs in development in developed countries and has become an interesting study [8]. However, only some studies on this process have been conducted in developing countries. This research aims to fill the gap in the need for more research focusing on spatial urban sprawling patterns in developing countries, especially in Indonesia.

In theory, there are three patterns of urban sprawl in general: concentric development, linear or ribbon development, and leapfrog development. The concentric development is the slowest pattern. The ribbon development is a pattern that develops following the main transportation corridors; the strategic value of roads as transportation infrastructure strongly influences this phenomenon. Meanwhile, leapfrog development is an urban sprawl pattern that develops sporadically. This phenomenon is strongly influenced by developer initiatives and individual landowner factors [9].

In 2019, Christiawan's research on urban sprawl in Indonesia used a qualitative method by interpreting the ALOS ANVIR-2 imagery to determine the patterns of urban sprawl in Denpasar City, Bali [10]. This research differs from Christiawan's research in two ways: interpretation using Sentinel 2A imagery and quantitative method using nearest neighbourhood analysis techniques. The results of this research can be used as a basis for comprehensive urban planning derived from a more measurable study of urbanisation phenomena.

2. METHODOLOGY

2.1 Location

In this research, the measurement of built-up area change in Kedungsepur is based on the interpretation of two satellite imagery with different recording times. The satellite imagery used was Sentinel 2A in 2016 and 2020. The satellite imagery from 2016 is being used to ascertain the initial scenario prior to the issuance of the presidential regulation establishing the Metropolitan Kedungsepur Area. Meanwhile, satellite imagery in 2020 will be used to assess the state of Kedungsepur four years after it was designated as one of the strategic economic areas known as the Metropolitan Kedungsepur Area.

2.2 Data collecting

Metropolitan Kedungsepur, in this study, refers to Presidential Regulation Number 78 of 2017 concerning Spatial Plans for the Urban Areas of Kendal, Demak, Ungaran, Salatiga, Semarang, and Purwodadi. The data collection methods in this study involve interpreting satellite imagery [11, 12], considering elements of interpretation, i.e., hue or colour, size, shape, texture, pattern, height, shadow, site and association. Sutanto [13] and Somantri [14] stated that interpreting temporal images could identify changes in urban land use. Interpreting these images can provide results for analyzing and comparing urban areas' spatial and temporal dynamics [15]. This research used secondary data from Statistics Indonesia (BPS) and field observations to test the accuracy of interpretation.

2.3 Data analysis

In this study, there are two analytical techniques used. Firstly, image interpretation involves calculating and analyzing the change in the percentage of built-up area. The image used is Sentinel 2A which has a high resolution for mapping regional land use.

The image interpretation results are in the form of land use maps classified based on SNI 7645-1:2014 (Indonesian National Standard), with a comprehensive area coverage consisting of 6 regencies/cities covering an area of 5249.04 km^2. The standard for determining small-scale land cover classification consists of 1) water bodies; 2) open land; 3) built-up areas; 4) forests; and 5) vegetated areas. A descriptive analysis was conducted with statistics to describe the change by calculating the percentage, rate, and average.

Secondly, using the nearest neighbour analysis technique. The nearest neighbour analysis determines a spatial pattern, including the pattern of settlements. Nearest neighbour analysis calculations can determine whether the object pattern is clustered, randomly scattered, or uniform. Nearest neighbour analysis requires data on the distance between one object and the closest object [16].

After the calculation, the index value (T) is obtained, and then the T value is interpreted by Continuum Nearest Neighbor Analysis, which ranges from 0 - 2.15. The closer to the value 0, the pattern formed is clustered. The closer to 1, the pattern is random. While getting closer to the value of 2.15, the pattern formed is uniform. This analysis technique is one of the menus in ArcGIS software.

3. RESULT AND DISCUSSION

The concept of a metropolitan in Indonesia was first raised by NUDS-I (National Urban Development Strategic) period one, in 1985. A Metropolitan combines several cities with links with populations in the core city. The linkage can observe physically, socially, and economically. The core city's population must be more than one million people and characterizes the city's activities.

In 2000 the NUDS-II work resulted in a study on the identification of urban typologies, the interrelationships of cities, and the general principles of urban management according to typologies and their interrelationships. The NUDS-II categorizes Kedungsepur as a metropolitan city. In this period, the standard population of metropolitan cities was still the same as before. The total population in the core city must be more than one million people. Table 1 provides an overview of the population in Semarang City as the core city

of Kedungsepur [17].

Table 1. Total population of Semarang City (core city of Kedungsepur)

No.	Period	Total Population
1	2000	1.350.005
2	2005	1.434.025
3	2010	1.527.443
4	2015	1.595.187
5	2020	1.653.524

Table 1 shows the minimum population requirements for the core city to be classified as a metropolitan city since 2000. The population in Semarang City in 2000 exceeded 1.3 million people. This number continues to grow positively by almost 50 thousand people every five years, so the next two decades have exceeded 1.6 million people by 2020. The second requirement of the metropolitan areas (NUDS-II) is that all regions' total population is at least five million people. If seen based on the data, the total population of Kedungsepur is 5,689,149, so it meets the requirements [1].

3.1 Spatial changes based on built-up area

The results of the 2016 land cover analysis compared to 2020, based on the interpretation of Sentinel 2A imagery regarding the percentage of built-up area, can be seen in Figure 1. In the figure of land cover 2016, most of the Kedungsepur Metropolitan Area is included in the areas with the minimum built-up area, indicating that the percentage of built-up area in each sub-district is still in the range of 10%, qualifying it as slightly rural. The condition happened in the four regencies that support the urban area. The four include Kendal Regency, Demak Regency, Semarang Regency, and Purwodadi in Grobogan Regency. Meanwhile, areas with a greater proportion of built-up area are in Semarang City and Salatiga City.

Studies on built-up area change in Kedungsepur, which are related to changes at the urban level, are also found in publications conducted by Yunus [18], Giyarsih [19], and Mahendra et al. [20]. However, these studies use more detailed urban indicators compared to this study.

The researchers' findings were consistent with the results obtained from measurements of urban change that utilized the built-up area approach with more detailed indicators. Several publications [9, 15, 21-28] have used built-up areas, road networks, and building density as indicators through image interpretation.

Figure 1 shows a red symbol indicating the area dominated by a built-up area. This red symbol is more at the core of Kedungsepur, namely Semarang City and Salatiga City. However, based on observations in Figure 1, land cover in 2020, Salatiga City has started to increase in built-up area compared to 2016. The condition is evidenced by an increase in the urban level category, which has become slightly urban. In contrast, there is a noticeable expansion in the built-up area of Purwodadi City compared to 2016. Simply put, the built-up area in Kedungsepur in 2020 has increased, especially in areas close to arterial and collector roads; new built-up areas have started to grow.

While the urban level based on the built-up area in 2016 and 2020 is primarily classified as slightly rural, specific regions linked with the core city and satellite cities are categorized as highly urban. This creates a spatial distribution pattern that is clustered in Semarang City, following the studies conducted by Christiawan [29], Mulyadi [30], Giyarsih [19], Umam et al. [31], and Mahendra and Pradoto [20].

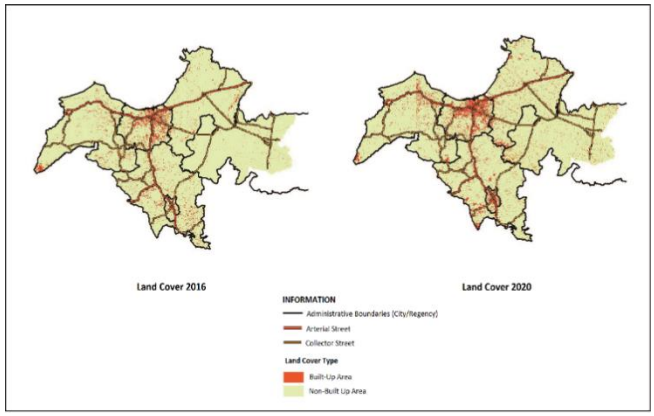

Figure 1. Land cover 2016 and 2020

Based on the analysis of the land cover area in Kedungsepur in 2016 and 2020, the highest percentage of built-up area is in Central Semarang Sub-district, reaching 99.36% in 2016 and becoming 99.42% in 2020. This shows the more intensive activities that convert the vegetated area into the built-up area in the core city.

Furthermore, the qualitative interpretation of the images showed that the transportation infrastructure, particularly the road network, also played a significant role in driving the urbanization process in Kedungsepur. The areas with the highest development of built-up areas are in the Semarang-Ungaran-Salatiga Corridor, followed by areas in the Semarang-Purwodadi Corridor. An explanation of this phenomenon can be found in the research of Pebrian and Rakhmatulloh [32]. As a core city of Kedungsepur, Semarang City influences nearby cities, which puts the surrounding area in the urban category. In line with this opinion, Giyarsih et al. [33], and Kurniawan [34] explain that the stages of spatial transformation start from the rural centre at several points in the road corridor, which are generally transportation connecting nodes.

On the other hand, the area with the highest percentage of non-built-up areas is Karangtengah Sub-district, reaching 88.45% in 2010 and 87.13% in 2015. The condition shows that the areas still vegetated, especially for rice cultivation, are the most extensive in the Semarang-Purwodadi and Semarang-Demak corridors. Areas with natural vegetation (stands) are mostly located in the southern part of Kedungsepur, namely the Semarang-Ungaran-Salatiga Corridor, which has rougher topographic conditions, consisting of hills than the other corridors.

The high development of built-up areas in the Semarang-Ungaran-Salatiga Corridor is influenced by the attractiveness of Salatiga City and the distance factor, which according to Hanafiah [35], Tarigan [36] and Nugroho [37], are one of essential elements in space, which is close to other cities such as the Magelang City, Surakarta City and Yogyakarta. Compared with other corridors, namely the Semarang-Kendal, Semarang-Demak, and Semarang-Purwodadi, which are still slightly rural due to the relatively far distance from other cities.

3.2 Spatial pattern and sprawl type based on built-up area

The Nearest Neighborhood Analysis (NNA) reveals that the

random type predominantly characterizes the spatial distribution in the Kedungsepur Metropolitan Area. This type of random distribution, also known as urban sprawling with a leapfrog pattern, dominated the area in 2016 and 2020. The leapfrog pattern was observed in Kedungsepur before it was designated as a metropolitan area, and it continued to dominate even after the designation.

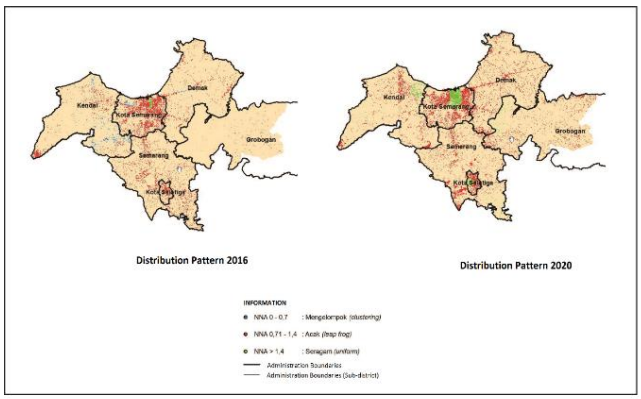

Figure 2. Spatial distribution patterns 2016 and 2020

Land-use changes of built-up land in 2016 and 2010 showed no significant changes. Changes occurred sporadically in Kendal Regency, Semarang City, and Salatiga City regarding their area. It means the urban land area has expanded but needs to be more significant to change the spatial pattern. In other words, even though the area has changed slightly, it has not changed the distribution pattern category of land units, which are built-up or urban areas. These changes can be observed in Figure 2.

Table 2 depicts the number of sub-districts, with each sprawling in each regency or municipality. In general, the dominant type was random both in 2016 and 2020. Slight changes were observed in Kendal Regency, suspected to be in the east of Kendal City or west of Semarang City, due to the establishment of the Kendal Special Economic Zone. The eastern part of Semarang also experienced changes with the growth of industries in the Genuk Sub-district. Likewise, changes occurred in the western city of Salatiga City, particularly in the Sidomukti Sub-district, triggered by the presence of the Salatiga ring road, causing clustered patterns to transform into uniform patterns.

The findings indicate that the spatial pattern distribution is moving from the core city towards the satellite cities, with spread occurring directly adjacent to the core city. This supports the idea that the physical appearance of a city is first seen on its outskirts [38]. The change from a clustering pattern to a uniform one suggests that the presence of industries promotes the growth of more organized settlements, possibly in the form of housing developed by private companies.

The changes observed in Salatiga City are attributed to the construction of new roads as alternative routes to alleviate traffic congestion. This finding supports that government policies in the transportation and housing sectors contribute to sprawl [39]. Such policies are beneficial as they promote the growth of new, spatially organized housing.

The spatial distribution pattern has changed from a clustered pattern to an evenly distributed or spread-out pattern over almost the same distance, indicating a shift towards a more regular pattern. However, the areas that have undergone this change must be more significant. The distribution pattern has remained unchanged in the last five years, dominated by the leapfrog type.

The leapfrog pattern is the sporadic pattern. The leapfrog pattern is aggressive and triggers changes in land use more quickly. Developers building settlements jump from one location to another [40], as each settlement requires infrastructure support and a total land area, making land use inefficient. The development of the leapfrog type is a challenge for regional spatial planning since its direction is difficult to predict and control.

Table 2. Built-up area spatial pattern comparation in Kedungsepur 2016 & 2020

No	Regency/City	Categories and Number of Sub-Districts		Information
		2016	2020	
1	Kendal Regency	*leapfrog (20)* cluster (5) uniform (0)	*leapfrog (20)* cluster (5) uniform (0)	steady
2	Demak Regency	*leapfrog* (12) cluster (2) uniform (0)	*leapfrog* (12) cluster (2) uniform (0)	steady
3	Semarang Regency	*leapfrog* (18) cluster (0) uniform (0)	*leapfrog* (18) cluster (0) uniform (0)	steady
4	Semarang City	*leapfrog* (13) cluster (2) uniform (1)	*leapfrog* (13) cluster (2) uniform (1)	steady
5	Salatiga City	*leapfrog* (4) cluster (0) uniform (0)	*leapfrog* (4) cluster (0) uniform (0)	steady
6	Purwodadi City	*leapfrog* (7) cluster (0) uniform (5)	*leapfrog* (7) cluster (0) uniform (5)	steady

4. CONCLUSIONS

The city's physical development changed with the establishment the Kedungsepur Metropolitan Area as a national strategic area on an economic basis in 2017. From 2016 to 2020, the built-up area increased while the land with vegetation cover decreased. However, this expansion did not result in a significant increase in urbanization. On a regional scale, the area remains dominated by slightly rural, with only the core and secondary cities of Semarang and Salatiga having a higher level of urbanization. Other satellite cities, such as Kendal Regency, Demak Regency, Semarang Regency, and Purwodadi, must develop their urban level further, as the slightly rural category still prevails.

Despite the expansion of the built-up area, the type of urban sprawl in the Kedungsepur Metropolitan Area remained the same. The sprawling type continues to form an irregular

pattern, progressing slowly from the central city towards the satellite cities. The dominant patterns are the cluster type, which turns into a uniform distribution with a more regular nature, and the frog jump type, which is sporadic and tends to trigger changes in land use offensively. The development of industrial areas in the satellite cities of Kendal and Demak has triggered a shift towards more compact and organized spatial arrangements. However, further research is needed to find effective inter-spatial interaction designs that contribute to a more controlled spatial arrangement.

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