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Urban Sprawl Symptoms in Bandar Lampung Suburban Area, Indonesia

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Abstract

This research investigates the phenomenon of urban sprawl in a medium-sized metropolitan area, specifically Bandar Lampung. It identifies the primary characteristics of urban sprawl and its impact on suburban development. The goal is to pinpoint the symptoms of urban sprawl through its spatial patterns, which may form systemically or sporadically, and predict their occurrence. The underlying theory is that urban sprawl symptoms can be observed in the rapid population growth and land use change in suburban areas. Using statistical and spatial analysis (Geographic Information System), we studied the population growth rate and land use alterations in Bandar Lampung and its suburbs over the past decade. Our study reveals that the population in the suburbs is growing faster than in the city. Over a decade, there has been a land use change to 1255 ha of built-up land. This change is strongly associated with the development of public infrastructure and road networks. We recommend implementing smart growth strategies to manage urban sprawl in medium-sized cities in Indonesia. Additionally, we provide a critical review of the causal relationships driving urban sprawl and its widespread impacts

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1. Introduction

Massive urban expansion beyond city boundaries may potentially trigger further informal urban sprawl (Brueckner, 2001; Clawson, 2014; Pendall, 1999). Urban sprawl is a form of unplanned, unstructured, and seemingly random urban expansion in suburban areas (Brueckner, 2001; Clawson, 2014; Kironde, 1997; Pendall, 1999; Tian, Guo, et al., 2017), which have significant effects on several factors. These include physical, economic, and social aspects. This transformation is manifested as a structural change in the spatial economy from agriculture to manufacturing and service industries, an exponential growth of population, and an increase in land prices along with land use dynamics. Combined these may eventually result in potential disasters, such as floods (Winarso et al., 2015). Urban sprawl and urban-rural land conversions have significantly increased in Indonesia since the reformation era in the 90s, particularly in Jakarta and on Java. One of the root causes of this phenomenon is the high population density on Java, which has put enormous pressure on land resources since the early 2000s (Verburg et al., 1999). This is partly due to an active decentralization policy, and more recently, due to increased investments in mega infrastructure both outside of Java as well as on Java itself. Several studies suggest that the most visible effect is the massive land conversion and socioeconomic changes from agriculture to urban settlement, industrial activities, and other activities (Hudalah et al., 2013).

There is a considerable amount of research focusing on urban sprawl characteristics in Indonesia's large cities such as Jakarta, Surabaya, and Medan (Budiyantini & Pratiwi, 2016; Firman, 1998, 1997, 2000; Hudalah et al., 2007; Legates & Hudalah, 2014; Verburg et al., 1999). Despite this, there remains a gap in when it comes to the understanding of urban sprawl in medium-sized metropolitan areas. It's therefore crucial to investigate whether these medium-sized cities share common traits with their larger counterparts or if they possess unique dynamics, growth patterns, and challenges. Since the era of decentralization, these medium-sized cities have experienced significant expansion. Yet, their capacity to manage this growth is limited, making them vulnerable to the negative impacts of urban sprawl, including environmental degradation and congestion. This research aims to generate novel insights to academic literature and planning practice.

According to Dardak et al. (2006), urban areas in Indonesia are considered metropolitan if they have a population of over 1 million people and a population density above 150 people/km², with 75% of the population working in non-agricultural fields. The size of several metropolitan areas in Indonesia varies significantly, with Jakarta being the largest at 10 million people and a density of 16,937 people/km. Bandung, Surabaya, and Medan have a population of around 2,500,000 people, while Makassar, Semarang, and Palembang have approximately 1,500,000 people. Some cities have recently been added to the Metropolitan category with populations of about 1 million, such as Batam, Padang, Bandar Lampung, and Pekanbaru. Moreover, there are several cities expected to be classified as metropolitan soon, as their populations are nearly exceeding 1 million, including Malang, Samarinda, Balikpapan, and Banjarmasin, among others. These cities are commonly known as "medium-sized metropolitan cities."

Urban sprawl is a complex and multifaceted phenomenon that has physical, environmental, and socioeconomic effects. Contemporary urbanization has been characterized by urban sprawl, which is an extensive form of land use for urban purposes that has detrimental environmental effects (Nuissl & Siedentop, 2021). Urban sprawl is characterized by the rapid transformation of land use/land cover into urban built-up areas, which has caused a significant increase in the built-up area (Sahana et al., 2018). The transformation has led to a decrease in urban open space, the transformation of prime agricultural land and wetlands into built-up areas, and changes in densities of resident al housing and buildings, topography, and infrastructure.

Urban sprawl is characterized by low-density, scattered, leapfrog development, strip development, and discontinuous expansion into suburban areas. Low-density housing is a typical characteristic of urban sprawl, often associated with inefficient use of land resources (Guan et al., 2020; Shi et al., 2023). Scattered and leapfrog development is another characteristic of urban sprawl, referring to the lack of a clear pattern in urban development. This type of development leads to spatial inefficiencies and excessive spatial expansion due to pressures to provide land to cater to the rapid growth of the population's need for housing (Frenkel & Ashkenazi, 2008; Nuissl & Siedentop, 2021; Pendall, 1999). Strip development is another characteristic of urban sprawl, referring to the development of long, linear strips of urban development along highways and arterial roads. This type of development tends to be ad hoc and unplanned, leading to spatial inefficiencies and excessive spatial expansion (Ewing, 2008).

Another key characteristic of urban sprawl is the lack of continuity in expansion. This is characterized by the unstructured, random, and unplanned expansion of urban areas, which contributes to changes in land use patterns of various shapes and sizes (Tian, Ge, et al., 2017; Yasin et al., 2021). Rapid land use changes, discontinuous or jumping development patterns, no green open space, following the transportation axis, separation between urban and residential land uses, and low accessibility are additional indicators of urban sprawl (Frenkel & Ashkenazi, 2008; Guastella et al., 2019). The non-spatial characteristics of urban sprawl include absolute population growth, the emergence of a divide between formality and informality, and ineffective property land rights institutions (Wu et al., 2006). Urban sprawl has negative impacts on the environment, economy, and society, including ecological fragmentation and loss of biodiversity, as well as an increase in greenhouse gas emissions, traffic congestion, and air pollution. Moreover, it concentrates wealth in certain areas while cutting off low-income communities from resources, exacerbating social and economic inequality.

The definition of urban sprawl and the differentiation between urban and suburban areas are pivotal. These distinctions can be made through various methods (Mikelbank, 2004; Stokes & Seto, 2019). One approach involves using the administrative boundary to separate the city from the surrounding districts. Another factor is population density, as urban zones typically exhibit higher density, while suburban areas are less densely populated. Land use and economic activities can also create distinctions, with urban areas offering more variety, and suburbs often dominated by housing and minimal economic activities. Finally, the availability of transportation infrastructure and the area's proximity to the city center can be indicative. Suburban zones typically rely more on private transport for accessing jobs and services in the city center. These factors contribute to defining and distinguishing urban and suburban areas.

This study specifically investigates how urban sprawl occurs in medium-sized metropolitan areas, with Bandar Lampung as a sample area. The primary goal is to discern the key drivers, patterns, and areas affected by urban sprawl. Specific objectives encompass assessing the influence of infrastructure development, government policies, and demographic shifts on urban expansion. The research employs Geographic Information Systems (GIS) and remote sensing technologies to map alterations in land use and urban boundaries, aiming to understand the characteristics of urban growth, particularly in suburbs transforming from rural to urban. An additional objective is to formulate evidence-based recommendations for urban planning and policy adjustments to manage and mitigate the impacts of urban growth. The findings can contribute to a sustainable urban growth strategy for Bandar Lampung in particular and similar medium-sized cities in general. To achieve these objectives, the research poses the following research questions: What are the spatial manifestations of urban sprawl in medium-sized metropolitan areas? Are these spatial patterns systematic or sporadic? Is urban sprawl more prevalent in flat topography areas, or does it follow the expansion of roads and infrastructure? How can the observed manifestations of urban sprawl be interpreted and predicted?

Bandar Lampung, situated at the most southern side of Sumatra, is a city characterized by its diverse geography, encompassing beaches, lowlands, and hills. This variety in landscape shapes the trajectory of the city's development, rendering it an ideal subject for studying urban expansion. With a population exceeding one million, the city exhibits rapid urbanization and population growth, mirroring the evolution of medium-sized cities throughout Indonesia. The city's substantial economic growth is primarily attributable to its role as a principal nexus between Java and Sumatra. Infrastructure initiatives such as the Trans Sumatra Toll Road and the establishment of new university campuses on the city's periphery are impelling urban expansion, stimulating land development and real estate investment, and reshaping the city's physical layout.

However, this rapid expansion engenders environmental concerns, including potential damage to biodiversity and habitat alteration. These issues are particularly pertinent in Bandar Lampung, and understanding their implications is critical. With Indonesia's shift towards decentralization, cities like Bandar Lampung now wield greater autonomy in managing their urban development. This grants Bandar Lampung a unique position as a case study for examining the impact of local governance on urban growth. Rapid growth presents urban planning with substantial challenges, particularly in managing urban expansion and its impact on transportation, housing, and public services. Despite its significance, Bandar Lampung has not been as extensively studied as cities like Jakarta or Surabaya. Consequently, this research could contribute valuable new data and insights that could be applied to other cities in Indonesia and elsewhere experiencing similar urbanization patterns. The selection of Bandar Lampung as the research site was influenced by its distinct characteristics and pressing urban expansion issues. Moreover, the potential contributions of these findings to the body of urban planning literature and policy development for similar urban environments globally were also considered.

2. Data and Methods

2.1. Study Area

Bandar Lampung witnessed an annual population increase averaging 18,907 individuals over the past decade, the city's expansion has transcended its administrative boundaries. The Soekarno Hatta highway, bisecting the city, delineates the urban and suburban areas. The city's land area is distinctly divided, with the eastern side, comprising over 50% of the total land, primarily utilized for agricultural purposes, whereas the western side is urbanized. In recent times, Bandar Lampung has seen an influx of land interventions and developmental initiatives. These encompass the construction of infrastructural projects on the city's periphery, the establishment of the trans-Sumatra toll road, and the inception of the New Town development project, which relocated provincial government buildings and spurred the creation of new growth centres. The construction of the Sumatra Institute of Technology (ITERA) campus triggered a surge in land prices in the vicinity.

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Furthermore, the development of Airan Raya Hospital and the elevation of Radin Intan State Islamic Institute to university status contributed to the city's expansion. The Lampung Regional Police Headquarters (Polda Lampung) was also constructed adjacent to the ITERA educational area (Figure 1).

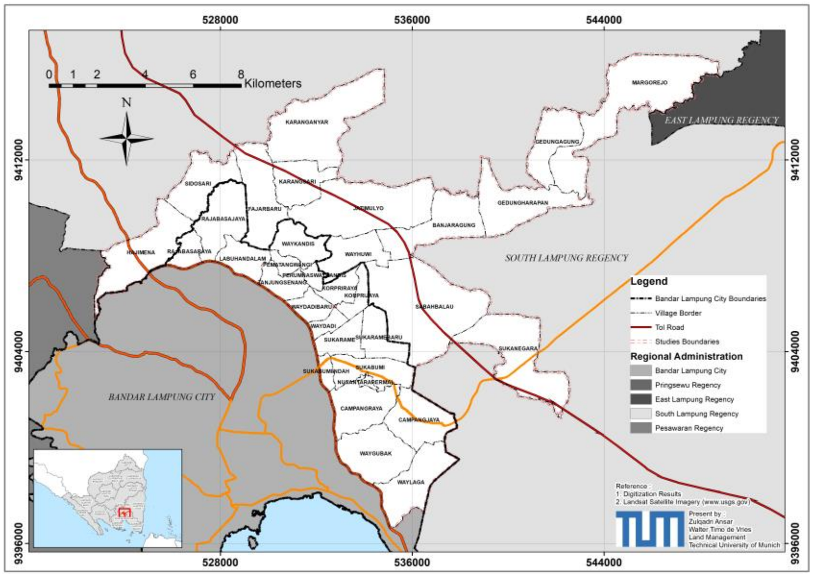

Figure 1. Study Area

2.2. Data

The data referred to in this context is a collection of different types of information that can be used to understand and analyse a particular area. These data types include population data, which indicates the number of people living in a given area, as well as land use data, which reveals how the land is being used and for what purposes. Topographic data is also included, providing a detailed understanding of the physical features of the land, such as elevation and slope. The data is further categorized into three main types: quantitative data, which is numerical in nature and can be easily measured and analysed; qualitative data, which provides a more subjective understanding of the area and can be more difficult to quantify; and spatial data, which provides information on the location and shape of objects and can be represented in the form of a point, a line, or a polygon.

- The first dataset consists of population data for Bandar Lampung and its suburbs, obtained from statistical data released by the Central Bureau of Statistics (Badan Pusat Statistik). This data can be accessed freely at http://www.bps.go.id/. The population data, collected between 2012 and 2022, includes 33 villages or suburbs, 13 of which are in South Lampung Municipality and 20 in Bandar Lampung Municipality.
- The second dataset is land use and land cover data obtained from aerial and satellite imagery of the suburbs of Bandar Lampung. The dataset is available in the open repositories of the United States Geological Survey (USGS, https://www.usgs.gov/) . The USGS publishes aerial photography data with medium-grade quality that is freely accessible by all parties. The satellite used by the USGS is Landsat, and the name of the aerial photo is Landsat Images. The aerial images were collected in 2012 and 2022, enabling us to monitor land cover with medium resolution.
- The third dataset is topographic data, released by the Geospatial Information Agency of the Republic of Indonesia. It can be obtained for free by downloading the data at https://tanahair.indonesia.go.id/. This information is downloaded in Tif format and then changed into Shapefile format by ArcGIS.
- The fourth dataset is infrastructure data, including road development and public facility development in the suburbs of Bandar Lampung. High-resolution aerial photographs collected from the National Institute of Aeronautics and Space of Indonesia (LAPAN) were used to obtain this data. This aerial photo is a Pleiades aerial photo. The data was obtained free of charge for research purposes by requesting data collection from LAPAN. The aerial image was taken in the last year's aerial photo (2022).

2.3. Methodology

The current study utilizes a blend of spatial and quantitative approaches to comprehend the phenomenon of Urban Sprawl. Spatial techniques, including Geographic Information System (GIS) and remote sensing, enable geographic visualization of urban growth and the tracking of urban development over time. GIS is a software designed for storing, managing, and analyzing geospatial data. In this research context, it integrates data such as land use, population, and infrastructure into a single system. It facilitates complex spatial analysis, helping in identifying patterns and trends in the data. Remote sensing is a technique that collects data about the earth's surface using satellites or aircraft. In this study, it has been employed to track land use changes over a decade. Simultaneously, quantitative methods measure population growth rate, land conversion area, and analyze patterns based on variables like topography, public infrastructure, and road network. The findings are then visualized through mapping, infographics, or tables. These two methodologies collectively aid in understanding the process of urban sprawl occurring in Bandar Lampung's suburbs (Figure 2 and Table 1).

There are several causes described in literature. Each of these are addressed hereunder. *Government Policies*. Government policies can inadvertently promote urban sprawl through subsidies for public infrastructure and services, affordable housing, low land prices, and transportation policies. Poorly integrated policies across different dimensions can also contribute to urban sprawl. Adequate transportation policies are crucial in preventing urban sprawl. Settlement development programs and governments' inability to meet housing needs can also be factors. Moreover, local governments often lack experience in managing urban growth (Gómez-Antonio et al., 2016; Habibi & Asadi, 2011; Hosseini & Hajilou, 2019; Majewska et al., 2022; Nazarnia et al., 2019; Taiwo, 2022; Yasin et al., 2021). Urban sprawl is often attributed to weak planning laws and single-use zoning by many experts. Development policies, such as zoning, urban growth boundaries, or development control, are often absent, according to some experts. Several studies have found that incorrect perceptions and policies related to urban growth contribute to urban sprawl. This is often caused by ineffective urban planning and land use policies, accompanied by poor decision-making in a region, particularly with regards to controlling urban growth and land use (Vargas-Hernández & Zdunek-Wielgołaska, 2021; Weilenmann et al., 2017; Xi-Liu & Qing-Xian, 2018; Yasin et al., 2021).

Mobility and Private Vehicle. Population mobility and the use of private vehicles are the primary causes of urban sprawl in cities. Private vehicles are a defining feature of urban sprawl. This type of development is characterized by roads and pathways that prioritize private vehicle use to access shopping and other activity centers. Because of segregated development patterns, residents in peripheral areas become reliant on private vehicles, resulting in high transportation costs and lengthy commutes. As mobility increases, so does private vehicle use, leading to traffic congestion, air pollution, and other negative impacts. This problem is exacerbated by inadequate transportation infrastructure. Private vehicle use encourages low-density development patterns and leads to the expansion of urban areas into surrounding rural areas, resulting in more cars and air pollution. The likelihood of urban sprawl increases with the number of private vehicles owned (Almeida Santos et al., 2018; Ewing & Rong, 2008; Firman, 2002; Gómez-Antonio et al., 2016; Hakim & Parolin, 2009; Hölzl, 2018; Majewska et al., 2022; Manesha et al., 2021; Mehriar et al., 2020; Restivo et al., 2019; Slaev et al., 2018).

Ineffective Urban Planning. Urban planning and control are essential to mitigate urban sprawl. However, several factors contribute to it, including inadequate urban planning policies, weak local governance, and ineffective urban growth control policies. Inadequate policies and weak governance can encourage uncontrolled development, including in rural areas that should be preserved. Government policies that prioritize integration, homeownership, and stability also contribute to urban sprawl. To promote sustainable urban development, it is crucial to understand the needs of both urban and rural land users. Ineffective growth control policies can lead to uneven growth and exclusion of low-income groups and minorities. Policies that encourage development in peri-urban areas are also causes of urban sprawl. Irregular urban land use patterns and a lack of spatial sense can also contribute to sprawl. This is often accompanied by rigid planning (Bidandi & Williams, 2020; Gómez-Antonio et al., 2016; Mustafa & Teller, 2020; Nazarnia et al., 2016; Nuissl & Siedentop, 2021; Xi-Liu & Qing-Xian, 2018).

Land Price. Land prices significantly influence urban sprawl through several mechanisms. Firstly, high land values in city centers often push people to seek cheaper alternatives, typically located in the suburbs. This shift develops pressure for land development, leading to urban sprawl. Secondly, fertile agricultural land in suburban areas is usually less expensive than city-center land. Consequently, it becomes a prime target for developers looking for affordable land for their projects. The resulting conversion of this agricultural land into residential or commercial spaces accelerates urban expansion. Lastly, land in areas affected by urban sprawl often transitions from agricultural to non-agricultural uses. This change is driven by the higher market value of non-agricultural uses, prompting landowners to pursue greater economic returns (Elmanisa et al., 2016; Karakayaci, 2019; Pendall, 1999).

Topography. Topography and landscape features play a crucial role in shaping urban growth patterns. Cities located on plains have an advantage due to the availability of land for urban development, which can increase economic growth. However, areas with higher levels of terrain undulation are less suitable for large-scale spatial expansion. This can encourage denser and more intensive spatial forms within the district. Physical constraints such as terrain undulations and landscape features can influence the direction of urban development and the pattern of urban growth in the region (Herold et al., 2003; Nandi & Dewiyanti, 2019; Yang et al., 2023).

Population Growth. Urban sprawl is characterized by rapid population growth in the suburbs, often caused by people moving from urban centers to more financially affordable suburbs. Population growth has important spatial implications, particularly in terms of economic inequalities. Several studies indicate that urbanization leads to uncontrolled urban sprawl, which poses global challenges, climate change, and urban poverty. Rapid urbanization is a result of an increasing number of urban dwellers, with people migrating to cities for various reasons such as limited land in the city, a desire to be closer to nature, or to avoid the traffic, crime, and noise of the city. However, suburban residents can still access urban areas with their private vehicles. This phenomenon has the potential to disrupt sustainable urban growth due to the expansion of land beyond its availability, characterized by population and employment densities located in city centers and suburbs that are functionally and spatially linked. The expansion of land beyond its availability is a challenge to sustainable urban growth (Bagheri & Tousi, 2018; Carlucci et al., 2018b; Dura-Guimera, 2003; Frenkel & Orenstein, 2012; Guastella et al., 2019; Guite, 2019; Hatab et al., 2022; Liu et al., 2018; Nuissl & Siedentop, 2021; Pendall, 1999; Tian et al., 2017; Yiran et al., 2020; Yue et al., 2016).

In addition to the causes, several authors describe the impacts of urban sprawl. Each of these are dewc4ribed hereunder. *Land Conversion*. Urban sprawl can have both direct and indirect impacts on the environment. These include the loss of agricultural land and its conversion to residential or commercial use. However, building access roads and supporting infrastructure often require tilling and dredging of land, further damaging the environment. The conversion of agricultural land to urban use also comes at the expense of other areas such as forests, wetlands, and grasslands, and can lead to the loss or damage of free ecosystem services such as flood control and water purification. The destruction of wildlife habitats is another obvious environmental impact of widespread building development. Remaining areas of wildlife habitat may be too small to support all the native species that lived there before or may be widely separated from each other. These conditions force wildlife to traverse dangerous, human-dominated landscapes in search of food and mates, which can disrupt ecosystem balance and reduce the availability of natural resources for communities. Another direct impact of such conversion is the loss of agricultural land, resulting in farmers losing their livelihoods and investments in agricultural infrastructure such as irrigation (Bae & Chang, 2019; Cho et al., 2010; Firman, 2000; Hanham & Spiker, 2005; Harrison & Donnelly, 2011; Lennert et al., 2020; Mohammady & Delavar, 2015; Sahana et al., 2018; Schuster Olbrich et al., 2022; Van Metre et al., 2000; Verburg et al., 1999; Yue et al., 2016).

Transportation and Energy Consumption. Urban sprawl leads to negative impacts on transportation, public health, and the environment. This includes increased reliance on private cars, longer commutes, higher costs, traffic congestion, and air pollution. As urban areas expand, they replace open spaces with concrete and asphalt, leading to a decrease in wildlife habitats and biodiversity. Longer distances between destinations also result in higher fuel consumption and increased energy consumption, which contribute to climate change and the depletion of natural resources. Transportation has major impacts on energy consumption and carbon emissions.

More people in an area means more energy is needed, causing increased emissions, energy use, traffic congestion, and destruction of ecosystems. Rapid and sporadic urbanization causes even greater negative impacts (Cartone et al., 2021; Hanif, 2018; Kakar & Prasad, 2020; Mohammady & Delavar, 2016).

Congestion and Pollution. Urban sprawl can lead to traffic congestion and air pollution due to the reliance on private vehicles for commuting, shopping, and schooling. The lack of adequate public transportation exacerbates the problem. This results in longer travel times to work and an increase in private vehicle use for trips to commerce centers, which contributes to traffic congestion and air pollution from vehicle emissions. These negative effects reduce the quality of life in urban areas, as evidenced by studies. To mitigate these effects, it is crucial to improve public transportation options and promote alternative modes of transportation (Bart, 2010; Daniels, 2001; Kakar & Prasad, 2020; Krishnaveni & Anilkumar, 2020; Rubiera-Morollón & Garrido-Yserte, 2020).

2.4. Identifying the Manifestation of Urban Sprawl Symptoms

This study explores urban sprawl by focusing on key indicators like Land Use Change and Population Increase. The former refers to the transformation of non-urban land, such as agricultural or forested areas, into urban spaces, including residential or commercial zones. The latter denotes a higher population growth rate in suburbs compared to urban areas. We employed a quantitative and spatial methodology to discern the indications of urban sprawl in Bandar Lampung's peripheral areas. The quantitative technique scrutinized population growth, and the spatial method inspected shifts in land use. The assessment of population growth served as the primary indicator, facilitating the recognition of urban sprawl symptoms. Our analysis unfolded over three phases. Initially, we assembled data encompassing the population and area of Bandar Lampung City and 12 suburban villages under the administration of the South Lampung Regency for a decade (2012-2022), although the data extended only until 2021. Following this, we conducted a statistical analysis of the population, covering aspects such as growth, density, average growth, and growth rate. Finally, we compared the trend of population growth rates in urban and suburban areas over the previous decade.

In addition to the population analysis, we investigated changes in land use over the last decade. This involved a comparative study of land cover in 2012 and 2022. The data analysis process consisted of three steps. Initially, we digitized 2012 and 2022 satellite images of Bandar Lampung into vector data using ArcGIS mapping software. We then classified the vector data based on land cover criteria. Finally, we overlaid the 2012 and 2022 land cover data to comprehend the changes. This approach produced a map displaying the distribution of land that underwent functional changes over a decade. The spatial method effectively observes changes in land use representing the sprawl phenomenon; however, its success is significantly dependent on the quality of the acquired satellite images.

2.5. Identifying the Variations in and Inter-relations between Independent and Dependent Variables

The focus of this study is the exploration of the nexus between various independent variables and the dependent variable, which is the transformation of land use from 2012 to 2022. Several independent variables are considered in this study, such as topography, roads, public facilities, land price, land type, and regional administrative boundaries. The study seeks to understand how these variables influence land conversion, a process denoting the shift from undeveloped to developed areas, such as residential zones. Data for this study was procured from a previous analysis comparing the landscape of 2012 to that of 2022.

The first independent variable in our study is topography, which relates to the landscape's physical features, including elevation, slope, and terrain type. Topography can influence the pattern and speed of urban sprawl, with areas characterized by gentle slopes and fewer physical barriers often experiencing swift and extensive changes in land use. The examination of topographic variables occurred in three primary stages. The first step was processing DEM/SRTM data in vector format (TIFF) to create topographic maps. The second step was reclassifying this data by elevation class and converting it into polygon format (shapefile). Lastly, we

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overlayed the topographic map with the land use change map from 2012 to 2022. This process is crucial for understanding how topography impacts land use change.

The second independent variable refers to public facilities, such as universities, hospitals, and office parks. The expansion of public infrastructure into suburban regions can act as a catalyst for urban growth and changes in land usage. In order to investigate this variable, the coordinates for each public facility were processed using ArcGIS, a Geographic Information System software. Around these coordinates, a 'buffer' or radius of approximately 1000 meters was created to represent the service area of the public infrastructure. This buffer map was then combined with a map of land that had undergone conversion between 2012 and 2022. The result was a map highlighting areas where land use changes correlated with the type of public infrastructure present. This procedure is key in identifying trends in land use near specific public infrastructure projects.

The third independent variable in this study is road infrastructure. This refers to the primary transportation routes in an urban environment. The construction or expansion of roads can enhance accessibility and result in changes in the function of adjacent land. This variable's value was obtained through three crucial stages: digitizing the road infrastructure lines into ArcGIS, creating a 'buffer' or radius of about 500 meters around the road network map, and superimposing this buffer map with the land use change map. The end product is a map of land use change based on road classification. This procedure is crucial for identifying land use change trends along specific road classes.

Table 1. Research Design

Research Targets	Data Requirements	Data Source	Data Collect	Data Analysis Approach	Analysis Techniques	Output
Identifying the manifestation of Urban Sprawl symptoms	• Population in 2012 • Population in 2022	• Central Bureau of Statistics	Secondary	Quantitative	• Statistic	Urban Population Growth
	• Landsat Imagery in 2012 • Landsat Imagery in 2022 • Pleiades Imagery in 2022	• https://www.usgs.gov/ (Web of U.S Geological Survey) • LAPAN (National Institute of Aeronautics & Space of Indonesia)	Secondary	Spatial Analysis	• GIS Technique (Classified, Overlayed) • Quantitative Analysis	Land Use Change Map
Identifying the variations in and inter-relations between independent and dependent variables	• Topography spatial data • Land use Change 2012 &2022	• BIG (Geospatial Information Agency of Indonesia) • Results of Land Use Change Analysis from 2012 - 2022	Secondary	Spatial Analysis	• GIS Technique (Classified, Overlayed) • Quantitative Analysis	Distribution of land conversion based on Topographic classification
	• Public facilities coordinate • Land use Change 2012 &2022	• BAPPEDA (Regional Development Planning Agency) • Results of Land Use Change Analysis from 2012 - 2022	Secondary	Spatial Analysis	• GIS Technique (Classified, Overlayed) • Quantitative Analysis	Distribution of land conversion based on Public Facilities classification
	• Road Infrastructures • Land use Change 2012 &2022	• BAPPEDA (Regional Development Planning Agency) • Results of Land Use Change Analysis from 2012 - 2022	Secondary	Spatial Analysis	• GIS Technique (Classified, Overlayed) • Quantitative Analysis	Distribution of land conversion based on Road Infrastructure classification

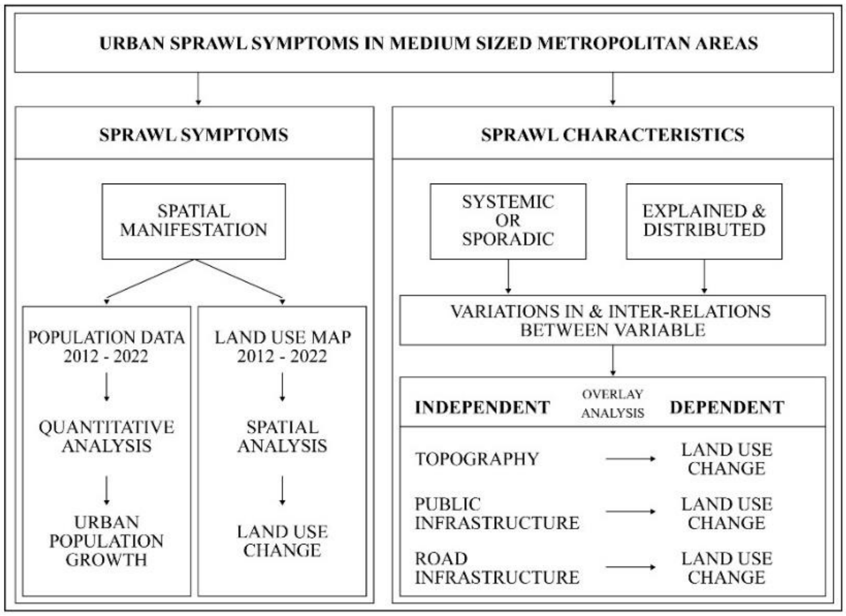

Figure 2. Theoretical Framework Design

3. Results and Discussion

3.1. Population Growth

Bandar Lampung's population statistics indicate an increase of 216,860 people over the past eight years, or an average of 27,107 people per year. The combined population of Bandar Lampung and its suburbs is 1,253,582, with 70% living in urban areas and 30% in suburban areas. As described in the previous chapter, the Soekarno-Hatta bypass highway separates urban and suburban areas: urban areas are located to the west of the bypass highway, while suburban areas are located to the east.

Table 2. Population Growth, Density & Growth Rate 2013 – 2020

	2013	2014	2015	2016	2017	2018	2019	2020	Density (people/km)	Growth Rate
CORE	741.84	756.54	771.23	785.70	800.02	814.11	828.06	877.22	5,913	18.25%
SUBURBAN	294.88	299.23	304.16	309.77	314.87	321.08	325.20	376.36	2,501	27.63%
Subdistricts	200.20	204.15	208.06	212.03	215.89	219.70	223.44	263.35		
Villages	94.68	95.08	96.10	97.74	98.98	101.38	101.76	113.01		

Table 2 shows that the total population in urban areas remains higher than in the suburbs. Table 3 shows that the population density in urban and suburban areas in 2020 is different. Urban areas have a higher population density of 5,913 people/km2, covering 51.63 km2, while suburban areas have a lower population density of 2,501 people/km2, covering 98.86 km2. Despite the lower density, suburban areas have a higher population growth rate than urban areas. From 2013 to 2020, the growth rate trend in the two areas is also different, with urban areas having a growth rate of 18.25% and suburban areas having a growth rate of 27.63%. This indicates that the population increase in suburban areas from 2013 to 2020 has been at a faster rate than in urban areas.

3.2. Land Conversion

The second manifestation of suburban sprawl in Bandar Lampung is land conversion. This has been identified through a spatial approach that observes the conversion of agricultural land into built-up areas in the suburbs. This observation was conducted by comparing two land use maps from 2012 and 2022, which covered a total area of 15,047 hectares.

Table 3. Land Cover in Suburb of Bandar Lampung 2012 - 2022

No	Land Cover in 2012	Area (ha)		Change
		2012	2022	
1	Water Bodies	5.99	5.55	-0.43
2	Open Spaces	178.57	125.26	-53.31
3	Agriculture - Plantation	3,534.06	3,261.46	-272.60
4	Residential	3,013.39	4,268.18	1,254.79
5	Swamp	4.12	4.12	0.00
6	Agriculture - Fields	3,152.17	2,732.70	-419.48
7	Grassland	1,401.43	1,312.37	-89.06
8	Agricultural - Fallow	3,757.49	3,337.57	-419.92
	Total	**15,047.23**	**15.047,22**	**0**

Sources: RTRW of Lampung Province

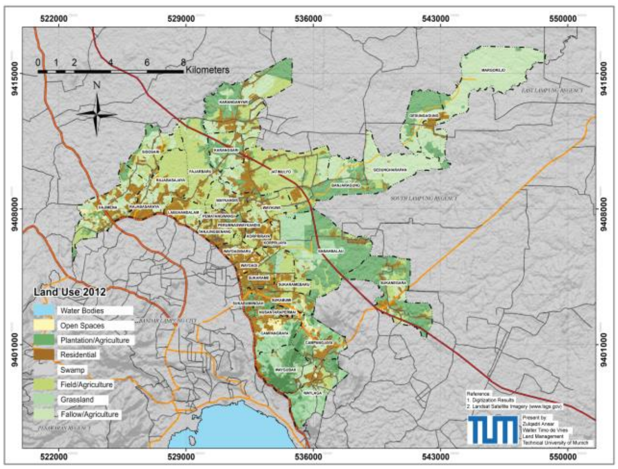

Figure 3. Land Use 2012

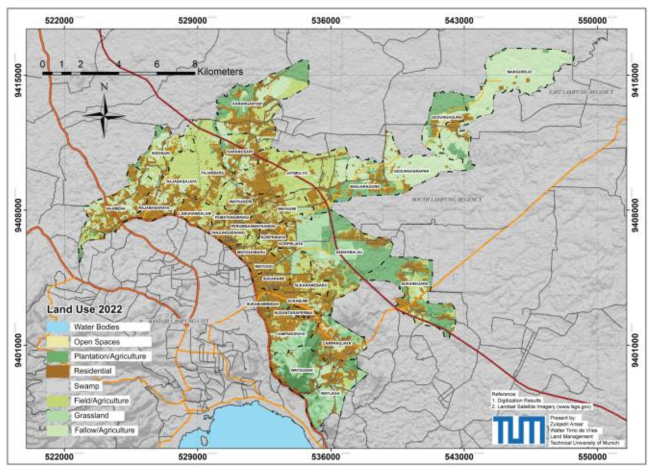

Figure 4. Land Use 2022

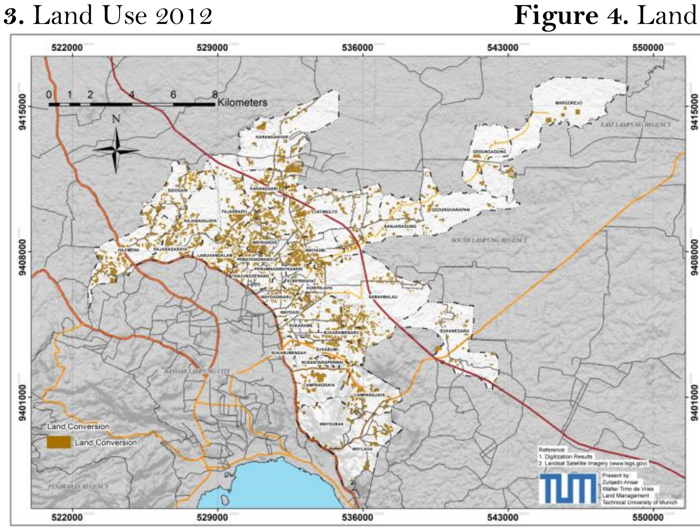

Figure 5. Land Use Change 2012 - 2022

Figure 3, 4, and 5 visually illustrate the land use maps in 2012 and 2022, respectively. The maps provide a clear visual representation of the changes in land use over the course of a decade. It is worth noting that residential areas are shown in brown, while agricultural land is shown in ivory. Upon comparison of the two maps, it becomes apparent that there has been a significant conversion of agricultural land into built-up areas. Specifically, the data shows that 1,254.79 hectares of agricultural land were converted into built-up areas over the course of the decade, averaging roughly 125 hectares per year. This represents a substantial loss of agricultural land, which has important implications for food production and the environment. Interestingly, the conversion of land was dominated by residential areas, which rapidly expanded beyond the administrative boundaries. In 2012, the residential area was 3,013 hectares, but by 2022, it had increased by 4,268 hectares. Meanwhile, agricultural land drastically declined to 2,732 hectares. This data is presented in Table 3, which provides a more detailed breakdown of the changes in land use over the decade.

3.3. The Variations and Inter-relations Between Independent and Dependent Variables

3.3.1. Land Conversion and Topography

The analysis results are derived by utilizing the land use map, which provides critical information about the land conversion process based on topography class. Figure 6 presents a detailed overview of the land conversion, highlighting the various regions where changes have occurred throughout the area.

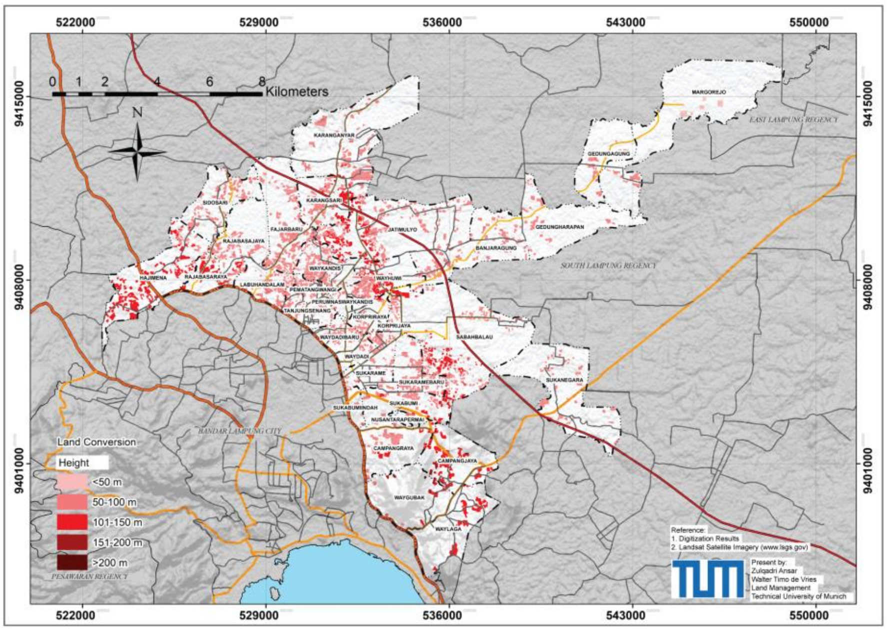

Figure 6. Land Use Change based on Topography

Upon examining Figure 6, it becomes evident that the majority of the land conversion occurred at an elevation of 51-100 meters above sea level (masl), accounting for a total of 901 hectares or 72% of the conversion. Additionally, another 331 hectares, or 27%, were converted at an elevation of 101-200 masl. Interestingly, the areas classified as high topography, which are above 200 masl, accounted for less than 1 hectare or approximately 0.3% of the overall land conversion. It is evident that the differences in elevation play a significant role in the conversion process, indicating a direct correlation between elevation and land use changes. Moreover, the data highlights the need for more in-depth studies into the effects of topography on land use conversion processes, which could help develop more effective land use policies and strategies.

3.3.2. Land Conversion and Infrastructure

The next analysis carried out is the analysis of the type of infrastructure on land use change in the suburban area of Bandar Lampung, the aim is to find out how much the development of various types of infrastructure contributes to land use change in the area. The Table 4 presented below provides an overview of the extent of land conversion that has taken place in the vicinity of recently constructed infrastructure. The land conversion is categorized into two distinct groups: road connections and other urban facilities, which include universities, hospitals, government buildings, and flyover roads. It is important to note that the observational radius of the infrastructure varies depending on the type of road. Arterial roads, for instance, span an impressive 500 meters to the left and right, while collector roads span 200 meters to the left and right. These observational radii are significant because they directly impact the extent of land conversion that has taken place in the area.

As such, it is crucial to understand the implications of this land conversion, particularly with respect to environmental degradation and urban sprawl.

Table 4. Land Use Change based on Road Infrastructure and Public Infrastructure

Road Classification (Radius 500 m)	Area (ha)	Public Infrastructure (Radius 1 km)	Area (ha)
Arterial Primary Road	183.91	Toll Gate	27.47
Arterial Secondary Road	14.58	High Education Facilities	130.25
Primary Collector Road	61.57	Health Facilities	53.52
Secondary Collector Road	710.67	Market	52.76
		Industrial Park	13.73
		Government district	45.60
Total	**970.73**	**Total**	**323.34**

Upon thorough analysis, it was discovered that 26% of the total land conversion, equivalent to 323.34 hectares, occurred around new infrastructure projects. This indicates that the majority of the land was repurposed for these projects. Moreover, 77% or approximately 970.73 hectares are situated around or along road networks, underscoring the significance of road networks in facilitating land conversion. To provide a more comprehensive understanding of the situation, Figure 7 and 8 have been included, which shows the percentage distribution of different types of infrastructure on land conversion in the peri-urban area of Bandar Lampung. This visualization serves as a valuable resource for anyone seeking to gain a deeper understanding of the underlying dynamics of land conversion in this area.

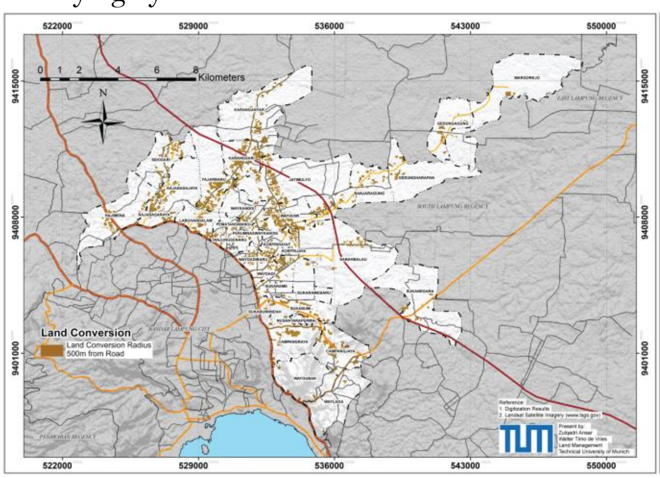

Figure 7. Land Use Change based on Road Infrastructure

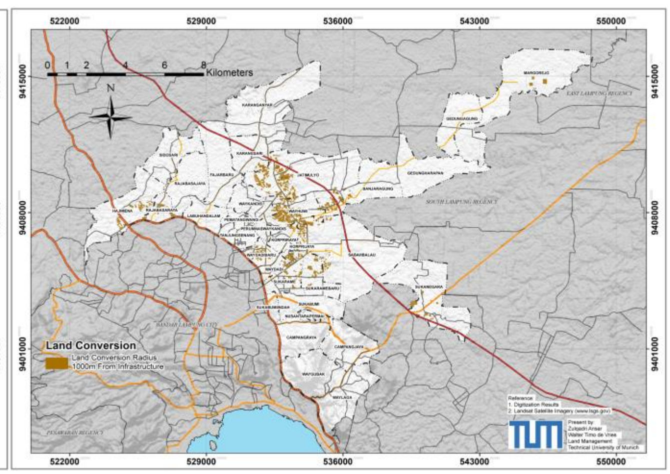

Figure 8. Land Use Change based on Public Infrastructure

3.4. Discussion

Urban sprawl, the uncontrolled expansion of urban development, affects many cities worldwide, including Bandar Lampung, Indonesia. This phenomenon involves the rapid transformation of rural and agricultural land into urban areas, leading to increased car dependency and reduced population density. Characterized by the swift conversion of land use into urban built-up areas, urban sprawl significantly increases these developed areas (Sahana et al., 2018). This study aims to understand the occurrence, influencing factors, and growth patterns of urban sprawl in Bandar Lampung. By combining field research and literature findings, this study analyses quantitative data on land use change and population density, comparing them with previous research theories. It pays particular attention to the impact of development policies and infrastructure development on urban expansion. The study concludes by providing practical, evidence-based recommendations for policy makers, urban planners, and other stakeholders to manage future urban sprawl.

This research offers a unique geographical and social perspective on urban sprawl in medium-sized cities, providing in-depth knowledge of the phenomenon. It offers critical insights that can impact urban planning and policy-making for similar sized cities. The study expands our understanding of how urban sprawl happens, specifically how infrastructure and topographic factors influence the development of medium-sized cities. This knowledge can aid in creating more effective strategies to control urban sprawl. A unique aspect of this research is the application of the spatial analysis method of buffer and overlay analysis. This approach produces more accurate and reliable results, crucial for urban planning decisions. The study also provides a comprehensive analysis of urban sprawl drivers, using a combination of quantitative and qualitative methods. This approach allows for a deeper understanding of the complexity of the urban sprawl phenomenon. Lastly, the research utilizes advanced GIS and photo-imaging technologies to analyze spatial patterns and the impact of infrastructure on urban sprawl. This approach offers a current perspective that improves the reliability and accuracy of the results.

3.4.1. Symptoms and Process

Urban sprawl, or urban expansion, is defined by higher population growth rates in the suburbs compared to the city centre. This research indicates a faster growth rate in the suburbs, with ratios of 27.63% and 18.25% respectively. Urban expansion is often a result of people relocating from the city centre to the more financially accessible suburbs (Bagheri & Tousi, 2018; Carlucci et al., 2018a). This shift increases housing demand in the suburbs (Carlucci et al., 2018a). In Bandar Lampung, suburban land is less expensive and housing construction is largely subsidized by the government, making it more affordable. The availability of land also influences population growth and contributes to urban sprawl (Nandi & Dewiyanti, 2019). Bandar Lampung's suburbs offer plentiful land, attracting urban residents with more affordable prices and larger land areas.

The population density of an area often reflects the type of development. The study area shows a stark contrast between the suburban and urban areas. The suburban areas have a much lower population density of about 2,501 people/km, compared to 5,901 people/km in the urban areas. This low population density results in a sparse settlement distribution, contributing to the outward expansion of urban areas (Shi et al., 2023). However, challenges arise when urban expansion occurs without proper control or planning. Unchecked growth can lead to urban sprawl, limited access to public services, increased infrastructure costs, and loss of green space. If based on appropriate spatial planning, low-density development can be beneficial. Unfortunately, low-density urban growth is often poorly planned and managed. Ideal planning should manage urban growth to maintain quality of life, support sustainable development, and ensure equitable access to public services. Despite low density, access to essential facilities such as health, education, clean water, and sanitation is crucial in supporting quality of life. Therefore, urban planning needs to consider how to integrate low-density suburban areas with the infrastructure of larger cities, such as transport and public services.

Contemporary urbanisation is characterised by urban sprawl, which is an extensive form of land use with negative environmental impacts (Nuissl & Siedentop, 2021). Rapid population growth has spurred increased demand for housing and land in peri-urban areas for residential, commercial, and office activities. Due to the low population density, land availability in peri-urban areas is limited. This has significant implications for urban planning, including the loss of open land. This study found that high population growth in peri-urban areas has led to a significant reduction in agricultural land. In the past decade, there has been a notable conversion of land use in the suburbs of Bandar Lampung. More than 1,250 hectares of agricultural land, plantations, and pastures were converted to residential land. On average, 125 hectares of open land are converted to residential land each year, reflecting the rapid urbanisation of the area.

Out of the 1,250 hectares converted, 89% was agricultural land turned into developed land. Developers often prefer transforming paddy fields, as these have an abundant groundwater supply near the surface, eliminating the need for deep excavation to access water. Furthermore, the soil structure of paddy fields ensures high stability for housing foundations. Conversely, other open land types like wetlands and peatlands possess irregular soil structures and inadequate groundwater conditions. The expansion of urban areas onto agricultural land poses a threat to the livelihoods of farmers in peri-urban regions. A decrease in agricultural land can significantly impact food production, leading to reduced food availability for the community. This can directly affect the income of individuals in peri-urban areas (Bae & Chang, 2019).

The subsequent symptom is the evolution of facilities and road infrastructure. The study revealed that 95% of the converted land is situated along road infrastructure, with the remainder around public facilities. This indicates that road infrastructure on the city's periphery is vital for accommodating urban growth. Convenient access to major roads is essential for urban expansion and land conversion. An article by Ewing & Rong (2008) highlights that road development typically occurs in long, linear patterns along motorways and arterial roads. This type of development tends to be unplanned, featuring jumps and ribbon patterns, which can result in spatial inefficiencies and sprawl.

3.4.2. Urban Sprawl Manifestation

The research demonstrates that the urban sprawl in Bandar Lampung is evident and quantifiable. Data indicates a significant geographical expansion of the city boundary, with an increase in the built-up area of 1255 ha over the past decade. The transition in land use from agricultural to residential, educational, commercial, and industrial signifies the city's rapid and often unpremeditated growth, pointing to urban sprawl. The study also reveals a population growth rate of 27.63% in Bandar Lampung's suburbs. This statistic is a testament to the general urbanization trend, where residents are moving from dense city centers to expansive suburbs. Factors driving this trend include the quest for affordable housing, improved quality of life, and infrastructure development such as roads and public transportation, which facilitate access to the city center. These findings align with numerous references that define urban sprawl attributes. The literature indicates that urban sprawl typically involves vast geographical expansion, increased land use, and population dispersion to suburban areas (Brueckner, 2000; Johnson, 2001; Tian et al., 2017) further emphasize that sprawl often stems from infrastructure development that enables population mobility and easy access to urban resources.

However, unique factors emerge in the specific context of Indonesia, where dynamics such as local government policies and regional economic factors significantly influence urban sprawl patterns. For instance, in Bandar Lampung, local government policies that encourage infrastructure development without sufficient planning may have expedited urban sprawl beyond what is typically seen in developed countries' cities. Urban sprawl in Bandar Lampung is evident through substantial geographical expansion and land use change, substantiated by data demonstrating a shift from agricultural to more urbanised uses of land. This local context provides a unique perspective to this phenomenon, highlighting the necessity to consider local factors when understanding and managing urban sprawl. This growth can jeopardise the livelihoods of farmers in the surrounding areas. There could be a significant reduction in agricultural land, impacting food production and availability. This, in turn, directly affects the income of people living in these areas (Bae & Chang, 2019).

3.4.3. Systemic or Sporadic

This data demonstrates that urban sprawl in Bandar Lampung exhibits a mixed pattern, with certain aspects being systematic and others sporadic. Systematic patterns of expansion emerge through the land use changes along the arterial and collector road corridors, marked by a significant rise in residential and commercial development. On the other hand, sporadic patterns of sprawl are observed as well, especially in areas less accessible to major development plans. Development in these regions appears spontaneous and irregular, frequently driven by uncoordinated land speculation and property investment.

The observed patterns mirror those observed in other global cities. Urban sprawl often unfolds systematically due to government policies and substantial infrastructure investments, according to Nazarnia et al. (2019). Conversely, the literature also acknowledges that sprawl can transpire sporadically, particularly in rapidly growing cities with lax land use regulations (Vargas-Hernández & Zdunek-Wielgołaska, 2021; Xi-Liu & Qing-Xian, 2018). Economic, social, and political factors often dictate whether urban sprawl is systematic or sporadic, as highlighted by Nuissl & Siedentop (2021). In Bandar Lampung the presence of both patterns suggests variations in local policy effectiveness and responses to swift economic pressures. Urban sprawl in Bandar Lampung is a blend of systematic and sporadic trends. These tendencies underscore the need for a more dynamic and responsive planning approach, as well as further research to gain a deeper understanding of how policy, infrastructure, and economic factors interact to shape urban development patterns.

3.4.4. How can Sprawl be Explained and Predicted?

This study reveals that factors such as topography, road development, and public infrastructure significantly influence the patterns of urban sprawl in Bandar Lampung. Data analysis indicates that areas with a flat, easily developed topography tend to experience faster urban expansion compared to regions with more challenging contours. This implies that the ease of development affects the pace and direction of urban expansion. Infrastructure development, especially roads, and public facilities like schools and health centres are key predictors of urban development. Areas newly accessible by arterial and other collector roads often become prime locations for new residential development, attracting more residents to settle outside the city centre.

These findings corroborate existing theories in urban studies and planning literature. The literature has consistently recognized the importance of topography in urban development. Research by Herold et al. (2003) and Yang et al. (2023) demonstrate how topography influences not just physical development but also infrastructure costs and land use. This affirms that favorable topography can expedite urban sprawl by lessening the costs and technical challenges of development. Moreover, the urban expansion model explained by Brueckner (2000) and the springboard development theory (Kakar & Prasad, 2020; Mohammady & Delavar, 2016) illustrate that infrastructure, particularly roads, play a pivotal role in shaping the patterns and extent of urban sprawl. New roads and transport infrastructure make previously inaccessible or less desirable areas more accessible, promoting faster and farther urban expansion from the city centre.

The findings validate these theories by demonstrating that the manifestations of urban sprawl in Bandar Lampung, in terms of topography and infrastructure, align with principles identified in recent literature. These insights can aid in more sustainable urban planning and development. A deeper understanding of these factors can help stakeholders make better-informed decisions about infrastructure development.

4. Conclusion

Urban sprawl refers to the uncontrolled and unplanned expansion of urban areas into neighboring rural regions. This process is typically characterized by the transformation of rural land into low-density residential, commercial, or industrial developments. Urban sprawl introduces a variety of economic, social, and environmental impacts. It's essential to manage this process effectively to mitigate potential negative consequences. Urban expansion in Bandar Lampung has largely occurred to the east, in suburban areas where public infrastructure development has occurred and led to considerable land conversion of approximately 1255 hectares. The direction of urban expansion has been guided by public infrastructure development, including roads and educational facilities. Housing demand and population growth rates are significant factors influencing the magnitude of urban expansion. Urban sprawl typically develops in the direction of new infrastructure and, without proper planning, can result in unregulated expansion. Land prices, particularly in areas where they are lower, significantly influence the direction of sprawl. The private sector, driven by profit, often spearheads this process, while the government's involvement remains limited. These factors together indicate a deviation from the intended controlled urban growth, suggesting the failure of the initiative. Urban expansion often leads to an increased dominance of the private property sector in spatial development, thereby reducing the role of local governments. This imbalance can result in the private sector governing land use decisions, often at the expense of coherent urban planning and enforcement. Efforts by the government to increase low-cost housing also contribute to urban sprawl, pushing low-income households into new suburbs.

This study aims to explore and elucidate the symptoms and processes of urban sprawl by identifying its spatial manifestations, patterns, and directions of expansion in mid-sized metropolitan regions. The research contributes to the scientific field by providing tangible evidence on the dynamics of urban sprawl and the factors propelling it in mid-sized cities, with a particular focus on the roles of infrastructure and landscape. Moreover, it offers valuable insights into the efficacy of current urban planning strategies. Future studies could explore strategies to regulate urban sprawl and promote sustainable urban development. This could encompass enhancing land use regulations, improving government oversight of the private sector, or advocating for urban planning strategies that prioritize sustainable development. Strategies could also include advocating for higher densities and mixed-use development to mitigate urban sprawl. Additionally, evaluating the effects of urban sprawl on different socio-economic groups and investigating strategies to alleviate its negative impacts would be beneficial.

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