Analysis of Residential Land Changes Using Object Based Image Analysis (OBIA) Method with SPOT Imagery in 2014 and 2024 (Case Study: Banyumanik, Semarang City)

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Abstract. Residential land expansion in urban areas, particularly in Banyumanik District, Semarang City, has increased significantly over the past decade. This study analyzes residential land-use changes between 2014 and 2024 using Object-Based Image Analysis (OBIA) applied to SPOT 7 satellite imagery and examines the influence of public and social facilities on these changes. An integrated spatial and statistical approach was employed. Residential land-use maps for 2014 and 2024 were generated and overlaid with public and social facility maps to assess spatial relationships, followed by statistical analysis to evaluate their influence on residential expansion.The results indicate a substantial increase in residential land area, predominantly in locations with high accessibility to public and social facilities. Statistical findings confirm that facility availability significantly influences residential land expansion, highlighting infrastructure provision as a key driver of urban growth. These findings imply that urban development can be more effectively managed by aligning the spatial distribution of public and social facilities with land-use planning and zoning regulations. Such integration is essential to promote sustainable urban growth and to mitigate uncontrolled residential expansion in Semarang City.

1 Introduction

According to the 2019 World Bank report, approximately 151 million Indonesians, or 56% of the total population, resided in urban areas. Urban regions in Indonesia have experienced significant growth, driven by the role of cities as centers of economic and social activities. This trend has encouraged population movement from rural to urban areas, a phenomenon commonly referred to as urbanization.

Urbanization in Indonesia occurs due to increasing settlement density, the expansion of infrastructure, and the development of various public facilities, which collectively contribute to the reclassification of rural areas into urban zones. Rapid urbanization often leads to unplanned land use changes. As cities expand, residential land use commonly shifts in

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response to economic, social, political, technological, environmental dynamics, and natural population growth. These factors collectively contribute to the expansion of urban areas [1].

Changes in residential land use, particularly in urban environments, pose major challenges for spatial planning and land management. This phenomenon is influenced by numerous drivers such as population growth, economic development, infrastructure expansion, and shifts in social behavior [2, 3, 4]. In Indonesia, Semarang City is among the areas experiencing significant residential land use changes.

Statistical data from BPS indicates that within a decade, residential land in Semarang City nearly doubled. In 2014, the residential land area was recorded at 17,768 hectares, increasing to 32,311 hectares in 2024. The rapid growth of residential areas has led to limited land availability in the city center, pushing development toward peripheral regions, including Banyumanik District [5].

Banyumanik District is one of the 16 administrative districts of Semarang City, consisting of 11 sub-districts: Pudakpayung, Gedawang, Jabungan, Padangsari, Banyumanik, Srondol Wetan, Pedalangan, Sumurboto, Srondol Kulon, Tinjomoyo, and Ngesrep. This area has undergone substantial land use changes, particularly the conversion of land into residential areas. These changes are influenced by urbanization processes and socio-economic dynamics. In addition, the development of infrastructure—such as the expansion of educational facilities and the growth of commercial centers—serves as a primary driver of residential land use change in Banyumanik District.

To analyze such land use dynamics, remote sensing technology plays a crucial role. Remote sensing enables rapid, efficient, and continuous acquisition of spatial data over large areas. Satellite imagery provides temporal perspectives that make it possible to monitor land use changes, making remote sensing particularly relevant for urbanization studies.

One widely applied analytical method in remote sensing is Object-Based Image Analysis (OBIA). Unlike traditional pixel-based approaches, OBIA groups pixels into meaningful objects based on spectral similarity, texture, shape, and spatial context. This method produces more accurate classification results, especially in urban areas characterized by complex spatial patterns.

In this study, SPOT satellite imagery is utilized to map and analyze residential land use changes in Banyumanik District. The high spatial resolution of SPOT imagery enables detailed and accurate detection of land use changes and allows examination of spatial relationships between residential areas and the development of supporting facilities such as educational and commercial centers. Therefore, this study aims to analyze residential land use changes in Banyumanik District between 2014 and 2024 and to identify the influence of public and social facilities on the rate of residential land conversion.

The objective of this research is to analyze residential land use changes in Banyumanik District between 2014 and 2024 using OBIA-based classification of SPOT imagery and to assess the influence of public and social facilities on the rate and spatial pattern of residential land expansion.

The research questions addressed in this study are:

1. How has residential land use in Banyumanik District changed between 2014 and 2024?
2. What is the spatial relationship between the distribution of public and social facilities and residential land expansion?
3. To what extent do public and social facilities influence the rate of residential land conversion in Banyumanik District?

2 Materials and method

2.1 Materials

In this study, the materials used include SPOT 7 imagery of Semarang City from 2014 and 2024 to identify land cover in Banyumanik District. In addition, Google Earth data and data from the Spatial Planning Agency regarding the distribution of public facilities and social facilities in Banyumanik District were also utilized.

2.2 Land covers

Land cover refers to the observable biophysical cover on the Earth's surface, which results from the management, activities, and treatment carried out by humans on specific types of land cover for production, modification, or maintenance purposes. Remote sensing data greatly supports the provision of spatial information, particularly related to land cover and land use [6]. Land cover reflects the relationship between natural processes and social processes. It provides essential information for modeling and for understanding natural phenomena that occur on the Earth's surface [7].

Land cover may consist of vegetation or artificial constructions that occupy the Earth's surface. It is related to the physical appearance of features such as buildings, lakes, and vegetation [8]. In contrast, land use refers to all types of human utilization of land, ranging from agriculture to sports fields, residential houses to restaurants, hospitals to cemeteries.

2.3 Settlements

Based on Law Number 1 of 2011, the definition of housing refers to a collection of houses intended solely as a place of residence. Meanwhile, settlements are residential areas consisting of multiple housing units and functioning not only as living spaces but also as areas that support various activities. Settlements can be understood as human-made or natural environments equipped with facilities and infrastructure that enable communities to carry out their daily activities [9].

The regulatory framework concerning housing, settlements, and the supporting environmental infrastructure refers to Law Number 26 of 2007. The objective of this law is to improve the quality of life of the community through well-organized housing and settlement development [10].

The development of settlements is closely related to urban land use planning, particularly regarding the functional division of the city into working areas, residential areas, and recreational areas. Settlement patterns, including natural physical conditions, can serve as indicators for assessing settlement development [11]. In this study, the term "settlement" refers specifically to the settlements located in Banyumanik District, Semarang City.

2.4 Public facilities and social facilities

Facilities refer to all elements considered as means to achieve certain objectives in fulfilling specific needs. In another sense, when related to settlements, facilities are activities or physical elements that serve the needs of individuals or groups within a living environment. Systematically, these activities or elements can be categorized into two main groups: physical facilities and social facilities. Although different, both types of facilities are interrelated.

Social facilities can be defined as services that fulfill the social, mental, and spiritual needs of the community. These include educational facilities, health facilities, recreational facilities, worship facilities, sports facilities, commercial facilities, and government facilities [12]. Social facilities play a crucial role and are essential in ensuring the quality of every residential environment.

Meanwhile, physical facilities refer to services that meet the physical needs of the community and include public utilities. Social facilities hold a highly significant role in regional development. The role of infrastructure and facilities in regional development is to support the functioning of social and economic systems in the daily lives of communities [13].

Both social facilities and public facilities are accessible for public use. In the context of environmental infrastructure, public utilities and social facilities are often abbreviated as fasos and fasum for convenience.

Physical facilities are defined as basic physical components of the environment that enable housing and settlements to function properly. Facilities are supporting elements that serve the implementation and development of economic, social, and cultural activities.

2.5 Remote sensing

The basic concept of remote sensing consists of several elements or components, including the energy source, atmosphere, interactions between energy and objects on the Earth's surface, sensors, data processing systems, and various data applications. Energy in remote sensing serves as the medium that carries information about objects to the sensor, and it may take the form of sound, magnetic force, gravity, or electromagnetic energy.

A remote sensing image is a representation of an object, area, or phenomenon resulting from the recording of reflected or emitted energy by a remote sensing sensor and may appear as a photograph or digital data [14].

Remote sensing data collection is carried out using detectors or data acquisition devices known as sensors. These sensors, which gather data from a distance, are generally mounted on platforms such as aircraft, balloons, satellites, or other carriers [15]. The remote sensing data produced from sensor recordings are then processed for various applications.

2.6 SPOT-7 image

SPOT is a series of Earth-observation satellites that capture high-resolution optical imagery. The satellite system is designed to provide wide-area coverage suitable for cartography and monitoring. SPOT-7 was launched by Airbus Defence & Space on June 30, 2014.

Table 1. SPOT-7 Satellite Image Spesification

Specification	Description
Spatial Resolution	1.5 m (panchromatic, nadir)
	6 m (multispectral VNIR, nadir)
Spectral Bands	1 Panchromatic (450-745 nm) 4 Multispectral: -Blue (455-525 nm) -Green (530-590 nm) -Red (625-695 nm) -Near Infrared (760-890 nm)
Altitude	694 km
Orbit Type	Sun-synchronous
Dynamic Range	12-bit per pixel
Acquisition Capacity	Up to 6 million km^2 per day

Based on these specifications, SPOT-7 imagery includes four multispectral bands—blue, green, red, and near-infrared—as well as one panchromatic band. The multispectral bands have a spatial resolution of 6 meters, while the panchromatic band has a resolution of 1.5 meters.

2.7 Image fusion

The purpose of image fusion is to integrate information from multiple images while preserving all essential visual details contained in the original imagery. Image fusion is the process of combining information from a set of images into a single, more informative image that is suitable for both human interpretation and machine analysis [14].

One commonly used image fusion method is pan-sharpening. Pan-sharpening is a technique that merges multispectral (MS) imagery with panchromatic (PAN) imagery. Multispectral images contain rich spectral information but have relatively low spatial resolution, whereas panchromatic images offer high spatial resolution but limited spectral detail. Through pan-sharpening, low-resolution multispectral data are fused with high-resolution panchromatic data from the same area to produce an image with enhanced spatial detail and preserved spectral characteristics.

The resulting fused image provides sharper geometric features and more complete spectral information, making it more suitable for identifying and analyzing targets with greater accuracy [14].

2.8 OBIA Image segmentation

Image segmentation is an essential component of image processing. It is primarily used as a preprocessing step in object recognition systems. Image segmentation involves dividing an image into homogeneous regions based on specific similarity criteria, particularly the similarities between the gray-level values of a pixel and those of its neighbouring pixels. The results of this segmentation process are then used for higher-level tasks, such as image classification and object identification [15].

There are various image segmentation techniques, which can generally be classified into two main types based on their working principles [15]. One commonly used approach is segmentation based on color intensity, which assumes that objects to be separated tend to have different color intensities, while each object exhibits relatively uniform color characteristics. One segmentation technique based on color intensity is mean clustering. In mean clustering, image segmentation is performed by dividing the image histogram. The procedure consists of determining the minimum and maximum intensity values in the image, dividing the intensity range into N intervals representing the expected number of objects, grouping pixels into the nearest clusters, and replacing pixel values in each cluster with the mean value of that cluster.

The segmentation process also involves several parameters, namely scale, shape, and compactness [15]. The scale parameter in multiresolution segmentation does not correspond to the scale definition in remote sensing related to spatial resolution or pixel size. Instead, it represents an abstract value that controls the level of heterogeneity allowed within an object. Higher scale values permit greater heterogeneity, resulting in coarser segmentation and larger object sizes.

The shape parameter is influenced by the weighting of the color parameter. The selection of shape weight should be adjusted according to the characteristics of the study area and the phenomenon being analyzed. A higher shape weight emphasizes spatial homogeneity over spectral homogeneity, which may overly stress texture and not always produce optimal segmentation results.

The compactness parameter is used to distinguish compact objects from non-compact objects with relatively similar spectral values. Higher compactness values result in objects with more compact shapes, representing a deviation from an ideal compact form.

The primary objective of remote sensing data processing is to extract objects on the Earth's surface for interpretation and analysis. Rapid object extraction methods have developed significantly in recent years. In general, remote sensing classification can be divided into two approaches: pixel-based classification and object-based classification, commonly referred to as Geographic Object-Based Image Analysis (GEOBIA). Pixel-based classification assigns each pixel to a class based on its digital number, whereas object-based classification extracts meaningful objects using spectral, spatial, and contextual characteristics. Once these objects are identified, expert knowledge can be applied in subsequent classification stages [15].

2.9 Classification Accuracy Assessment

The accuracy of the land cover classification results was evaluated using a confusion matrix. This method provides quantitative information on the agreement between the classified image and reference data. Two accuracy indicators were applied for each land cover class, namely Producer's Accuracy and User's Accuracy. Producer's Accuracy represents the probability that a reference pixel is correctly classified and is calculated as the ratio between correctly classified pixels and the total reference pixels of a given class, indicating omission errors.

User's Accuracy represents the probability that a pixel classified into a certain class actually belongs to that class on the ground. It is calculated as the ratio between correctly classified pixels and the total number of pixels assigned to that class in the classified map, indicating commission errors [8]. Image classification results are considered acceptable when the overall accuracy value reaches or exceeds 80%.

The accuracy assessment was calculated using the following equations:

User's Accuracy $: \frac{x11}{x+1} x100\%$ ………………………..……….(1)

Producer's Accuracy $: \frac{x11}{x1+} x100\%$ ………………………………….(2)

Overall Accuracy $: \left(\frac{\sum_{i=1}^{r} Xii}{N}\right) x\ 100\%$…………………………….(3)

Description:

N : The total number of pixels

X1+ : The total number of pixels in row-i

X+1 : the total number of pixels in column i

Xii : the diagonal element of the confusion matrix representing the correctly classified pixels for class i

2.10 Regression analysis

Regression analysis is a statistical technique used to examine the relationship between two or more variables. Based on its level of complexity, regression analysis is divided into two types: when the model uses only one independent variable, it is referred to as simple linear regression, whereas when it involves more than one independent variable, it is referred to as multiple linear regression. Regression analysis consists of the following components:

a. Dependent Variable (Response): the variable being predicted or explained, denoted as Y.
b. Independent Variable (Predictor): the variable(s) used to predict or explain changes in the dependent variable, denoted as X.

The multiple linear regression model can be expressed mathematically as follows [4]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_n X_n + \varepsilon \quad (4)$$

Description:

- Y: Dependent variable
- β_0: Intercept (constant term)
- β: Regression coefficient
- X: Independent variable
- ε: Error term (difference between the actual value and the estimated model)

3 Result and analysis

3.1 Land cover change

According to the land cover classification analysis for Banyumanik District in the period of 2014–2024 with the OBIA procedure, from the 2014 till 2024 land cover maps, the extent of each land cover class along with its percentage change can be stated as follows to illustrate that a great number of land cover types have been increased. Table 2 shows the percentages of land cover areas:

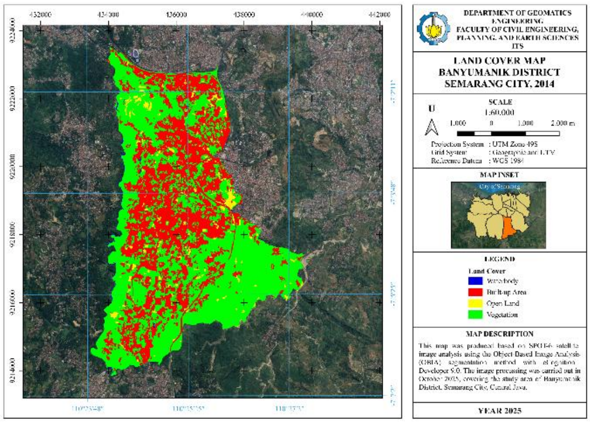

Fig. 1. Land Cover Map of Banyumanik District in 2014

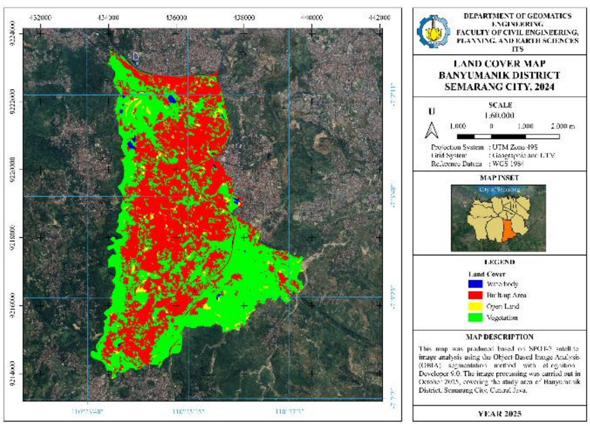

Fig. 2. Land Cover Map of Banyumanik District in 2024

Based on the land cover maps for 2014 and 2024, the area of each land cover class along with its percentage change shows that several land cover types have experienced an increase. The table of land cover area percentages is presented as follows

Table 2. Land Cover Area o Banyumanik District

Land Cover	2014		2024	
	Area (Ha)	%	Area (Ha)	%
Built-up Area	1209.414	37.93	1527.208	47.89
Open Land	109.109	3.42	79.288	2.49
Waterbody	9.923	0.31	18.113	0.57
Vegetation	1860.468	58.34	1564.305	49.05
Total	3188.914	100	3188.914	100

Based on the table above, it is shown that there is an increase in built-up land area and a decrease in open land and vegetation. Therefore, these land cover changes are interpreted through the following map and table:

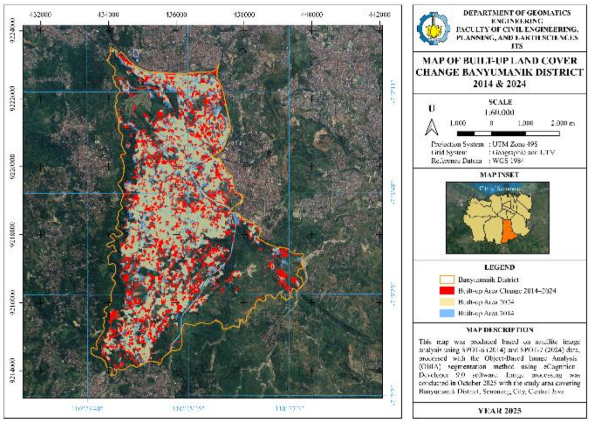

Fig. 3. Map of Land Cover Change in Banyumanik District

Table 3. Area of Land Cover Change in Banyumanik District

Land Cover	2014-2024	
	Area (Ha)	%
Built-up Area	317.794	9.97
Open Land	-29.821	-0.94
Waterbody	8.19	0.26
Vegetation	-296.163	-9.29
Total Land Cover Change	651.968	20.44

Based on the Land Cover Change Map of Banyumanik District from 2014 to 2024, the observed increase in built-up areas reflects an urban expansion process primarily driven by accessibility and infrastructure development. The concentration of land use change in the central and western parts of the district, as well as along major road corridors such as Jalan Setiabudi, indicates that residential growth has been strongly influenced by the availability of transportation networks. These corridors reduce travel time to the city center and the Tembalang education area, making adjacent land more attractive for residential and commercial development.

The dominant conversion of vegetation and open land into built-up areas is largely a consequence of limited land availability in Semarang's city center and rising land values in peripheral areas. As a result, development pressure has shifted toward Banyumanik District, where relatively large parcels of undeveloped land were still available. This process explains the substantial decrease in vegetation area (296.163 hectares) alongside the significant increase in built-up land (317.794 hectares) during the study period.

Furthermore, the clustering of land use change around public and social facilities suggests that facility provision acts as a catalyst for residential expansion. The presence of schools, healthcare facilities, commercial centers, and places of worship increases the functional attractiveness of surrounding areas, encouraging developers and households to concentrate near these services. Improved access to facilities reduces daily travel costs and enhances living convenience, which accelerates land conversion in nearby locations.

Overall, these findings indicate that residential land expansion in Banyumanik District is not random but follows a facility- and accessibility-driven development pattern. This pattern highlights the interaction between transportation infrastructure, public facility distribution, and land availability in shaping urban growth. Understanding these driving mechanisms is essential for spatial planning, particularly in controlling urban sprawl, protecting green open spaces, and guiding future development toward more sustainable urban forms.

3.2 Availability of public and social facilities

Based on the results of the analysis, field observations, and reviews of the availability of social facilities in previous years, there is a noticeable trend of increasing social facilities within the study area. As the number of social facilities increases, it affects the extent of their service coverage. The following are the maps showing the distribution of public and social facilities in Banyumanik District in 2014 and 2024.

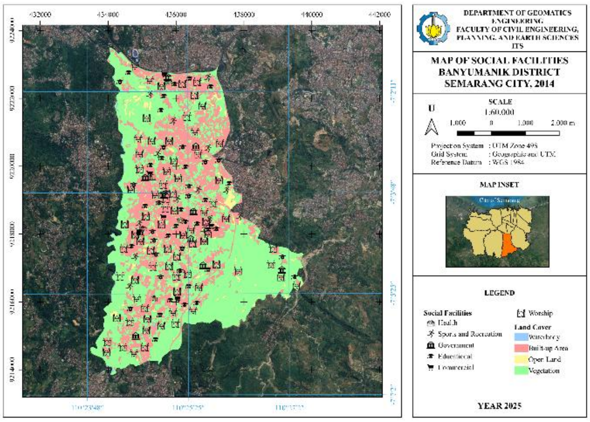

Fig. 4. Map of Distribution of Social Facilities in Banyumanik District in 2014

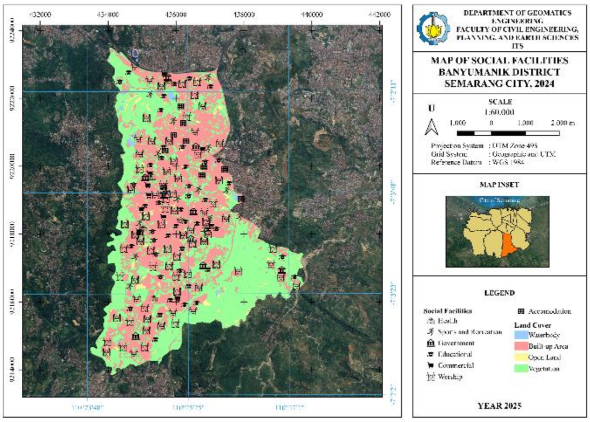

Fig. 5. Map of Distribution of Social Facilities in Banyumanik District in 2024

Table 4. Social Facilities in Banyumanik District

Public and Social Facilities	Categories	Year	
		2014	2024
Health Facilities	Hospital	2	2
	Community Health Center (Puskesmas)	4	4
Sports and Recreation Facilities	Sports Facilities	14	14
Government Facilities	District/Subdistrict Offices	10	10

Public and Social Facilities	Categories	Year	
		2014	2024
Educational Facilities	Elementary School (SD)	30	30
	Junior High School (SMP)	10	10
	Senior High School (SMA)	4	4
	University	2	2
Commercial Facilities	Markets and Malls	6	10
Worship Facilities	Mosque	67	67
	Church	7	7
	Vihara	1	1
Accommodation Facilities	Apartment	-	2
	Hotel/Guesthouse	1	10
Total		158	173

Based on tabular analysis and visual interpretation of the 2014 and 2024 social facility maps, there is an increase in the number and expansion of social facilities in Banyumanik District over a ten-year period. The number of social facilities increased from 158 units in 2014 to 173 units in 2024, indicating a growing trend in public services in line with population growth and residential development in the area.

Spatially, the 2024 map shows that the increase in facilities primarily occurred in areas experiencing residential development (built-up land). This is evident in the increasingly even distribution of facilities in the central and southern areas of the district, compared to the central and northern areas in 2014.

Several facility categories experienced significant growth, such as shopping facilities, which increased from 6 to 10 units, and accommodation, which expanded significantly from just one hotel/lodging in 2014 to 10 hotel/lodging units and two apartments in 2024. This increase aligns with the growth of residential areas and the need for commercial services in the area.

Meanwhile, educational, healthcare, religious, and government facilities remained unchanged in number, but their service coverage increased as the built-up area became denser. The distribution of facilities such as mosques, schools, and community health centers (Puskesmas) on the 2024 map appears to be more within new residential zones, which were previously vegetated in 2014.

Overall, the changes in the distribution of social facilities in the 2014–2024 period indicate that the development of built-up land is directly proportional to the need for and provision of social facilities. The increase in the availability of these facilities has the potential to improve the quality of public services, but must also be balanced with equitable distribution and sustainable planning to prevent disparities in service delivery between regions in Banyumanik District.

3.3 The influence of public facilities and social facilities on residential land-use change

Table 5. Correlation Between Social Facilities and Changes in Bulit-up Land Cover

Correlations

	Total Number of Public Facilities and Social Facilities	Residential Land Use Change

Total Number of Public Facilities and Social Facilities	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.
	N	2	2
Residential Land Use Change	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.	
	N	2	2

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the results of the Pearson correlation test, a correlation coefficient of 1.000 was obtained with a significance level of 0.01 (2-tailed). A correlation value of 1.000 indicates a very strong and perfectly positive relationship between the number of public and social facilities and changes in residential land use. This means that any increase in the number of social and public facilities is directly proportional to an increase in changes in residential land use in the study area.

In other words, the increase in facilities such as shopping centers, hotels, places of worship, healthcare facilities, and educational facilities contribute to the expansion of residential areas. This can occur because the presence of social and public facilities increases the attractiveness of the area, strengthens service functions, and encourages the development of new activity centers. Areas with more complete access to facilities tend to experience accelerated housing development to meet the increasing housing needs of the community.

However, it should be noted that the sample size (N) consists of only two time points (2014 and 2024). Therefore, although the resulting correlation is perfect, it cannot yet comprehensively describe the causal relationship. This correlation further indicates that over the analyzed time period, the increase in social and public facilities coincided with the expansion of residential land, but cannot be concluded as a direct cause without further analysis.

Overall, these results indicate that the provision of public and social facilities is related to the dynamics of land use change, particularly in areas experiencing residential growth. This finding supports the importance of integrated facility planning to ensure that residential growth remains directed, equitable, and sustainable.

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