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Facing the Challenges of Urbanization: Analysis of Service Center Structure in Penajam Village

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ABSTRACT

Massive urban land use change has become a significant global phenomenon in recent decades, affecting city morphology, environment, and biodiversity. Uncontrolled urbanization causes land conversion, changes farmers' livelihoods, and drives agglomeration and concentration of urban areas. The structure of urban space, including the network system of facilities and infrastructure, supports social and economic activities and connects centers and sub-centers through transportation networks. By focusing on determining the service center in Penajam Village, Penajam Paser Utara Regency, which has experienced significant population growth, this study aims to identify service centers with an urban area scope, as well as the availability of facilities in the context of urbanization around the development of the new national capital (IKN). This study uses centrality index analysis, population density analysis, building density, road network density, beta index, entropy index and kernel density. The results of this study indicate different functions and roles in the socio-economic and infrastructure networks in each observed segment. This indicates the existence of connectivity and potential diversity, which can be a reference in future regional development strategies.
Keywords: Centrality Index, Integrated Spatial Planning, Service Center, City Spatial Structure, Urbanization

ABSTRAK

Perubahan tata guna lahan perkotaan secara massif telah menjadi fenomena global yang signifikan dalam beberapa dekade terakhir, yang memengaruhi morfologi kota, lingkungan, dan keanekaragaman hayati. Urbanisasi yang tidak terkendali menyebabkan konversi lahan, mengubah mata pencaharian petani, dan mendorong aglomerasi serta pemusatan kawasan perkotaan. Struktur ruang kota, termasuk sistem jaringan sarana dan prasarana, berfungsi untuk mendukung kegiatan sosial dan ekonomi serta menghubungkan pusat dan sub pusat melalui jaringan transportasi. Dengan berfokus pada penentuan pusat pelayanan di Kelurahan Penajam, Kabupaten Penajam Paser Utara, yang mengalami pertumbuhan penduduk signifikan, penelitian ini bertujuan untuk mengidentifikasi pusat pelayanan dengan ruang lingkup kawasan perkotaan, serta ketersediaan fasilitas dalam konteks urbanisasi di sekitar pembangunan ibu kota negara (IKN) baru. Penelitian ini menggunakan analisis indeks sentralitas, analisis kepadatan penduduk, kepadatan bangunan, kepadatan jaringan jalan, indeks beta, indeks entropi dan kernel density. Hasil dari studi ini menunjukkan adanya fungsi dan peran yang berbeda dalam jaringan sosial-ekonomi dan infrastruktur pada setiap segmen yang diamati. Hal tersebut mengindikasikan adanya keterhubungan dan keberagaman potensi, yang dapat menjadi acuan dalam strategi pengembangan daerah di masa mendatang.
Kata kunci: Indeks Sentralitas, Perencanaan Ruang Terpadu, Pusat Pelayanan, Struktur Ruang Kota, Urbanisasi

1. INTRODUCTION

At all levels of civilization, urbanization is slowly but surely becoming a global issue. Rapid urbanization is occurring in all countries, whether developing, developed, or impoverished. Urban expansion can be a pathway from traditional rural economies to modern, advanced ones (Alzahrani et al., 2024). Unsustainable urbanization is reflected in the increasing number of people migrating to cities, which in turn amplifies the demand for residential space. This situation indicates that more land and natural resources will be required to meet their housing and commercial activity needs. However, the limited availability of land and natural resources in city centers makes it difficult to accommodate the ever-growing population (Abdulai & Osumanu, 2023). The high population density in Jakarta, coupled with its associated impacts such as traffic congestion, environmental pollution, and overcrowding, has led to solutions such as relocating the national capital to East Kalimantan to address these challenges (Kementerian PPN/Bappenas, 2020). On the other hand, the relocation of the capital city, Nusantara, could trigger an uncontrolled "expansion" effect in the areas surrounding the new capital.

Urbanization has the potential to stimulate economic activity, such as increasing the Regional Gross Domestic Product and infrastructure investment, including transportation networks and energy supply. A lack of infrastructure can hinder growth and reduce the quality of life (Anisa et al., 2024). Urbanization also risks creating economic and social inequalities, altering patterns of social interaction, and causing environmental degradation due to the reduction of green spaces and increased pollution (Simamora, 2024). Similarly, a case study in Yogyakarta showed that the lack of green open spaces and high levels of air pollution are major challenges in urban areas (Evianto, 2018). Analysis of the global urbanization transition across approximately 195 countries indicates that per capita Gross Domestic Product, energy consumption, and CO_2 emissions increase with urbanization. This trend poses significant challenges to global sustainability, particularly concerning rising energy demands and the climatic consequences of fossil fuel combustion (Burger et al., 2019) .

Penajam Village, as part of the buffer zone for the national capital Nusantara, faces unique dynamics involving population displacement, socio-economic transformation, and environmental pressures. These challenges, such as unequal infrastructure distribution, changes in land use patterns, and the social impact of population migration, are also experienced by other urban areas, both in Indonesia and globally. However, the most significant difference between Penajam and other urban areas is Penajam Village's mandated role to serve the national capital while also being designated as a *PKWp* to serve activities at the provincial or multi-district scale, undergoing a spatial transformation from an agrarian to an urban area within a large-scale National Development project.

Thus, Penajam Village holds a highly strategic position. Establishing an urban service center in Penajam Village is crucial for several reasons: its strategic location allows for the efficient distribution of essential services to the community; it facilitates the management of urban growth to prevent uncontrolled urban sprawl resulting from urbanization (Tondobala, 2015), it mitigates environmental impact; and it supports mobility and connectivity accompanied by the development of adequate transportation infrastructure. A study analyzing urban land expansion patterns across 14 regions and countries over 29 years revealed a trend of convergence in urban land expansion. This implies increasingly similar patterns or directions across different regions or countries regarding how urban land develops, marked by a shift in the distribution of urban areas from an initial power-law pattern to an exponential distribution. In other words, this trend indicates that urbanization processes in various locations are increasingly following similar patterns, influenced by global social, economic, and spatial planning factors (Hu et al., 2023). An analysis of urban land expansion patterns across 14 regions and countries over 29 years revealed a convergent trend. This means that the patterns or directions of urban land development are becoming increasingly similar across different regions and countries. This is marked by a shift in the distribution of urban areas from an initial power-law pattern to an exponential distribution. In other words, this trend indicates that urbanization processes in various locations are increasingly following similar patterns due to global social, economic, and spatial planning factors.

To mitigate the impacts of urbanization, it's necessary to identify and manage central urban areas that serve as hubs of economic, social, and cultural activity to support overall regional growth. Strategically designed central areas can enhance the efficiency of service and infrastructure distribution. Adequate infrastructure can strengthen economic productivity, improve access to basic services, enhance inter-regional connectivity, and promote economic growth and quality of life (Awainah et al., 2024).

Previous research has explored urban service centers and spatial structures using various methods. For example, one study determined the urban service center of Patalassang, Takalar Regency, by combining Zipf's Law (using population data), Centrality Index (using facility count data), and Kernel Density (using building density data) with GIS analysis to identify the main and sub-urban centers (Hidayat et al., 2022). Another study determined the urban service center in Tanjungpinang City using a quantitative approach based on urban order analysis and central place theory, employing scalogram analysis and spatial interaction analysis (Apriana & Rudiarto, 2020). Most research on determining urban service centers uses scalogram analysis, which identifies a region's role based on its capacity to provide services. This analysis involves data on regional center names, population, and various types and facilities recorded in matrix form (Rahayu & Santoso, 2014). Centrality index analysis has also been used, for instance, to determine economic growth centers in East Java and urban service centers in Jatinangor District (Taufiqqurrachman, 2024) (Fasa & Revayanti, 2021).

Another study in Srinagar and Jammu, India, took a different approach, aiming to determine the suitability of urban land for providing urban facilities. The suitability assessment was conducted using an AHP model with criteria involving geophysical and socioeconomic variables, including slope, elevation, land use/cover, and existing facility status (Parry et al., 2018). While these studies offer methods for determining urban service centers, they lack consideration of certain aspects, such as the land use entropy index, its relationship with the beta index using road segment and node data, road density, and kernel density. No prior research has linked these analyses, including centrality index analysis. This research offers a novel approach to strengthen the determination of urban service centers. The analysis is supported by GIS technology and high-accuracy spatial data for efficient data collection and analysis, multi-source data integration, and informative visualization. It's crucial to evaluate how these aspects influence the determination of central areas within the new capital's perimeter to ensure that planning and development meet community needs and mitigate potential challenges. Identifying urban service centers is expected to support the development of Indonesia's new capital, a significant national project with international implications (Wijaya, 2023).

2. METHODOLOGY

The scope of this research is focused on Penajam Village, located on the northern coast bordering Balikpapan Bay. Data collection involves secondary data from institutional databases available on official websites and literature studies to enhance analysis interpretation. Required data includes mapping shapefiles, the "Penajam Village in Figures" document, and the *RTRW* document of North Penajam Paser Regency. Techniques employed to determine the central and sub-central services encompass centrality index analysis, population density analysis, building density analysis, road network density analysis, beta index analysis, and entropy index analysis.

Centrality Index Analysis is a method for determining centers of activity or service by considering regional growth, involving not only the diversity of facilities but also the frequency of each type of facility (Wansaga et al., 2020). The data used in this analysis is the number of each type of facility, which is then weighted into a function index. The first step is to collect data on the distribution of facilities in each segment, starting from educational facilities, health facilities (hospitals, health centers, auxiliary health centers, village health posts, drug stores, and pharmacies), worship facilities (mosques, small mosques, churches, temples, monasteries), trade and service facilities (banks, cooperatives, restaurants, shops, markets, minimarkets, hotels, and malls), and government and public service facilities (government offices, police stations, post offices). The total number of each type of facility is then divided by the total centrality (100%) to obtain its weight. Finally, the segments are ranked based on the largest weight.

Population Density Analysis compares the population count with the inhabited area, providing insights into population density, which is crucial for residential location decisions. Population density and growth impact economic growth, which in turn expands service coverage and increases economic specialization. Therefore, higher population density in an area strengthens its service center characteristics (Antara & Suryana, 2020) & (Yunianto, 2021). The analysis uses population count and area data for each segment. Population density is calculated by dividing the population by the area for each segment, which is then used to determine the order of all segments.

$$Population\ Density = \frac{Total\ of\ population\ number\ (person)}{Area\ (Ha)} \qquad (1)$$

Building density analysis is crucial for managing spatial planning, building development, and the environment, considering aesthetic, functional, harmonious, and ecological aspects of land use. Higher building density strengthens an area's identity as a service center. The analysis uses the number of buildings and the area of each segment. Building density is calculated by dividing the number of buildings by the area for each segment. Building counts are obtained using GIS software for precision. Finally, the order of all segments is determined.

$$Building\ Density = \frac{Total\ number\ of\ Building\ (Unit)}{Area\ (Ha)} \qquad (2)$$

Road network density analysis encompasses road network patterns and systems, including highways, inner ring roads, outer ring roads, and radial routes, along with the various functions of the city's road network. The analysis utilizes road length data in meters and the area of each segment. Road network density is calculated by dividing the road length (meters) by the area (hectares) for each segment. Data acquisition is facilitated by GIS software for efficiency and accuracy. Finally, the order of all segments is determined.

$$Street\ System\ Density = \frac{Street\ length\ (Meter)}{Area\ (Ha)} \quad \ldots\ldots\ldots\ldots 2$$

Beta Index Analysis measures road network connectivity. A higher β value indicates greater connectivity. The required data includes the number of road segments and the number of nodes. All road classifications and intersections within the study area are included as data, using GIS software for efficiency and accuracy. The Beta Index is calculated by dividing the number of road segments by the number of nodes for each segment. Finally, all segments are ordered.

$$Beta\ Index = \frac{The\ number\ of\ street}{The\ number\ of\ Junction} \quad \ldots\ldots\ldots\ldots 3$$

Entropy Index Analysis is used to indicate the level of land use diversity. A higher value suggests more diverse land use (Ridhoni, 2017)

$$EI = (-1) \times (\frac{b}{a} \times \ln\frac{b1}{a}) : \ln (n) \quad \ldots\ldots\ldots\ldots 4$$

Description:

EI : Entropy Index

b : Land Use Area

a : Total Land Use Area

n : Number of Land Use Types

A higher value indicates greater diversity of land use within an area. The data used includes land use types, land use areas, and the number of land use types. For example, in segment 1, there is scrub forest (0.91 Ha), natural forest (13.05 Ha), plantation (0.01 Ha), pond (8.8 Ha), and temporarily open land (3.45 Ha). The areas of all land use types are summed to obtain the total land use area. Each land use type's area is then divided by the total land use area. The natural logarithm (ln) of this result is multiplied by the result of the division, and then these products are summed. Finally, all segments are ordered.

According to several sources (King et al., 2015, 2016; Z. Wang et al., 2021; Yang et al., 2019), determining the intensity or hierarchy of spatial structure requires analysis of the planning area, one of which is using Kernel Density. Kernel density analysis is used to determine the density level of an area. The variable used is the density of each building within the planning area, in this case, the Pattalassang urban area.

$$\text{Density Search Radius} = 0{,}9\ x\ Min\ (SD, \sqrt{\tfrac{1}{\ln(2)}}\ x\ Dm)\ x\ n^{-0{,}2}) \quad \ldots\ldots 5$$

Description:
SD : standard deviation, Dm : median data, n : number of building data

The spatial structure analysis of Penajam Village is concluded by calculating the average of 7 analyses: centrality index, population density, building density, road network density, beta index, entropy index, and kernel density. The next step determines the central and sub-centers based on the scoring results.

The data used is relevant and representative, covering key elements for determining service centers in Penajam Village:

1. **Diverse Data Sources:** Data originates from official sources like mapping shapefiles, "Penajam Village in Figures" documents, and the RTRW of Penajam Paser Utara Regency, ensuring data validity and accuracy.
2. **Alignment with Research Objectives:** The primary research objective is identifying service centers, considering urbanization and new capital city development. Data like population density, building density, road network density, centrality index, and entropy index directly support this analysis.
3. **Multidimensional Approach:** The analysis employs various indicators, reflecting the social, economic, and physical conditions of the area holistically.
4. **GIS Technology for Accuracy:** Using GIS in data processing enables precise and efficient analysis, such as calculating building and road network density.
5. **Unique Local Context:** The data reflects Penajam Village's unique dynamics as a strategic area supporting the new capital city, requiring efficient service distribution and growth management.

This approach ensures data relevance not only for research needs but also for addressing urbanization challenges and providing applicable recommendations for regional development.

3. RESULT AND DISCUSSION

Penajam Village is a strategic area in Penajam Paser Utara Regency with abundant natural resources. As a developing area, it contributes to regional economic growth. Its varied geography includes forests, rivers, and agricultural land, supporting agriculture and fishing. The tropical climate fosters diverse flora and fauna. The economy is driven by agriculture, fishing, and trade. Growth is rapid, especially along the provincial road to the Penajam ferry port.

This research focuses on determining area segments based on the author's needs, resulting in 49 segments using a grid division method, with the following findings:

1. Penajam urban area as the government center of Penajam Regency.
2. Development of regional-scale trade and service areas.
3. The Marine Research Port area is strategically important for science and technology.
4. *Waterfront City* is a strategic area with water-oriented activities.
5. Fish landing base development.
6. Urban Settlement area designation.

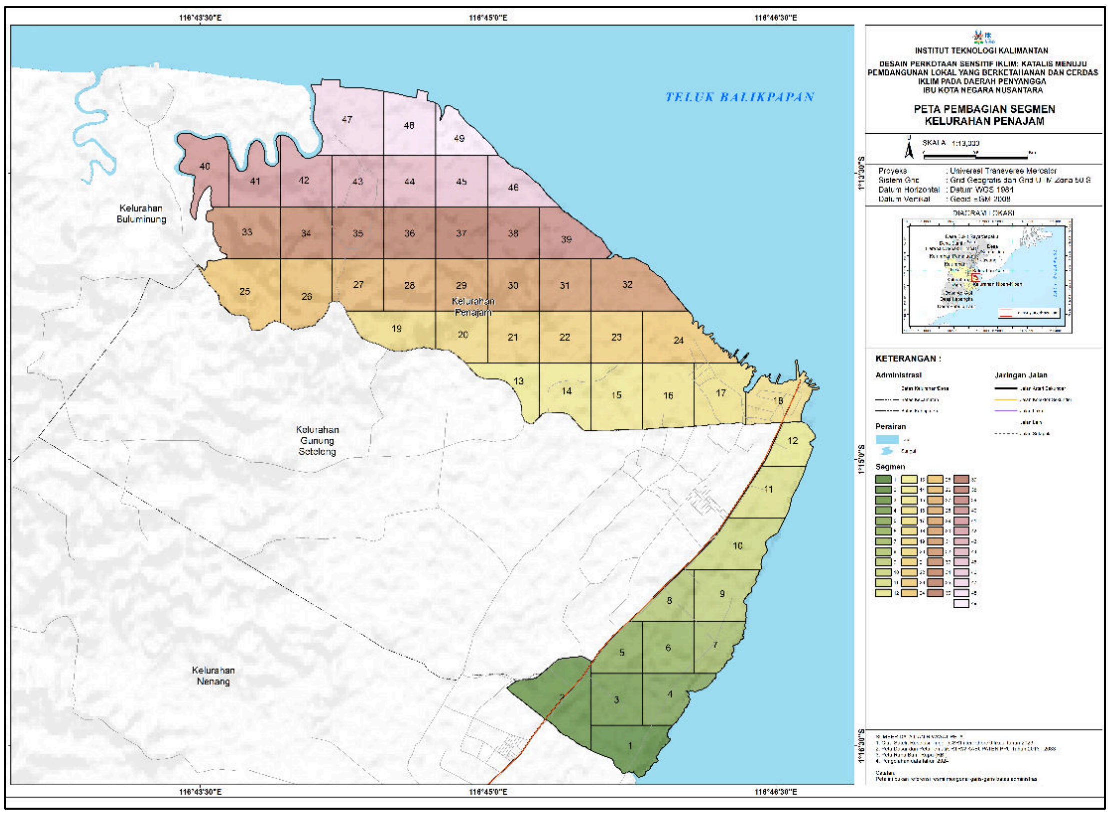

Figure 1. *Map of Penajam Subdistrict Segment Division*

3.1. Population Density Analysis

Based on the population density analysis, Table 1 (which you did not include) shows the order ranking and main characteristics of the studied segments. Segments ranked 1 to 3 (Segments 18, 17, and 24) have the highest population and density, indicating dense activity and urban centers. Segments 8, 5, and 12 also show relatively high density (30-45 people/ha), although lower than the top three. These segments likely function as transition zones or settlements with moderate activity levels.

Segments 10 and 11 fall into the medium density classification (around 30 people/ha), suggesting significant settlements with basic facilities. On the other hand, Segments 2 and 16 have lower densities (around 20 people/ha) but larger areas, indicating further development potential.

Regarding potential, Segments 18, 17, and 24 are high priority for infrastructure and service improvements (transportation, health, and education) due to their high population density. Urbanization control is also needed to maintain environmental quality and comfort. Segments 8, 5, and 12 have potential as developing residential areas; investment in housing and public facilities could increase their attractiveness. Segments 2 and 16, with their large areas and moderate density, are suitable for new developments like light industrial zones or educational areas.

Table 1. Population Density Analysis of Penajam Village

Segment	The number of population (Jiwa)	Area (Ha)	Population Density	Order
1	0	27,33	0,000	27
2	840	41,25	20,364	9
3	120	25	4,800	12
4	20	24,35	0,821	19
5	748	18,18	41,144	5
6	348	25	13,920	11
7	4	19,56	0,204	25
8	836	18,69	44,730	4
9	76	26,97	2,818	14
10	908	30,35	29,918	8
11	736	24,43	30,127	7
12	564	15,55	36,270	6
13	24	18,91	1,269	18
14	60	26,89	2,231	17
15	80	32,5	2,462	16
16	612	31,41	19,484	10
17	3.564	30,74	115,940	2
18	2.876	24,32	118,257	1
19	8	27,3	0,293	24
20	60	22,41	2,677	15
21	0	25	0,000	28
22	0	25	0,000	29
23	8	25	0,320	20
24	2.036	33,47	60,831	3
25	0	38,39	0,000	30

Segment	The number of population (Jiwa)	Area (Ha)	Population Density	Order
26	0	30,75	0,000	31
27	0	24,04	0,000	32
28	0	25	0,000	33
29	0	25	0,000	34
30	0	25	0,000	35
31	0	25	0,000	36
32	0	36,42	0,000	37
33	0	31,74	0,000	38
34	0	25	0,000	39
35	8	25	0,320	21
36	8	25	0,320	22
37	96	25	3,840	13
38	0	25	0,000	40
39	0	24,87	0,000	41
40	0	26,08	0,000	42
41	0	24,37	0,000	43
42	0	27,5	0,000	44
43	8	25	0,320	23
44	0	25	0,000	45
45	4	25	0,160	26
46	0	21,79	0,000	46
47	0	43,64	0,000	47
48	0	29,19	0,000	48
49	0	18,47	0,000	49

High-ranking segments (1-10) require special attention in spatial planning due to their dense populations or significant development potential. This analysis can inform the development of balanced development strategies and facility distribution, supporting sustainability.

3.2. Building Density Analysis

Table 2 presents an analysis of building density in several segments and their priority order as urban centers. Segments 18 and 17 exhibit very high building densities, both above 29,000, ranking first and second as urban centers. Although Segment 24 ranks third with fewer buildings, this suggests that the number of buildings isn't the sole determinant of a segment's functionality as a city center. The city center ranking appears more related to building density and distribution, reflecting the concentration of urban activity and infrastructure.

Segment 17 has the highest number of buildings but a lower density than Segment 18 (720 buildings with a density of 29,605). This indicates that segment areas can vary; a segment with fewer buildings can still have a high density if its area is smaller. City center ranking is heavily influenced by density, not just the number of buildings. Segment 18, with a density of 29,605, ranks first despite having fewer buildings than Segment 17. This implies that high-density areas tend to be centers of activity, potentially including more commercial functions, public services, or public facilities.

There's a significant density drop from the second-ranked to the third-ranked, from 29,000 to 15,208, suggesting zoning separation between the city center and buffer or residential areas. Lower-ranked segments (12, 11, and 10) exhibit sparser densities, likely representing residential or peripheral areas. Segment 8, despite having relatively few buildings, ranks fourth. This might be due to building type or functionality; buildings in this segment could be important structures like government offices or commercial centers, or its strategic location could make it a hub for essential activities. The analysis identifies ten segments functioning as urban centers, with significant density differences between ranks 1-2 and 3-10. This suggests a fragmented urban pattern, with only a few highly dense segments, while others are more evenly distributed or serve as buffer areas.

Table 2. Building Density Analysis of Penajam Village

Segment	The number of Building	Area (Ha)	Building Density	Orde
1	0	27,33	0,000	28
2	210	41,25	5,091	9
3	30	25	1,200	12
4	5	24,35	0,205	20
5	187	18,18	10,286	5
6	87	25	3,480	11
7	1	19,56	0,051	26
8	209	18,69	11,182	4
9	19	26,97	0,704	15
10	227	30,35	7,479	8
11	184	24,43	7,532	7
12	141	15,55	9,068	6
13	6	18,91	0,317	19
14	15	26,89	0,558	18
15	20	32,5	0,615	17
16	153	31,41	4,871	10
17	906	30,74	29,473	2
18	720	24,32	29,605	1
19	2	27,3	0,073	25
20	15	22,41	0,669	16

Segment	The number of Building	Area (Ha)	Building Density	Orde
21	0	25	0,000	29
22	0	25	0,000	30
23	2	25	0,080	21
24	509	33,47	15,208	3
25	0	38,39	0,000	31
26	0	30,75	0,000	32
27	0	24,04	0,000	33
28	0	25	0,000	34
29	0	25	0,000	35
30	0	25	0,000	36
31	0	25	0,000	37
32	0	36,42	0,000	38
33	0	31,74	0,000	39
34	0	25	0,000	40
35	2	25	0,080	22
36	2	25	0,080	23
37	24	25	0,960	13
38	0	25	0,000	41
39	0	24,87	0,000	42
40	0	26,08	0,000	43
41	0	24,37	0,000	44
42	0	27,5	0,000	45
43	2	25	0,080	24
44	0	25	0,000	46
45	1	25	0,040	27
46	0	21,79	0,000	47
47	33	43,64	0,756	14
48	0	29,19	0,000	48
49	0	18,47	0,000	49

3.3. Road Network Density Analysis

The relationship between road length and road network density is shown through road network density analysis. Segment 8, with a road length of 2,943,409 m, has the highest network density of 157.49, placing it first. In contrast, Segment 17 has a road length of 4,618.52 m but ranks second with a network density of 150.24. This indicates that the area and function of each segment influence road network density. High density is often found in areas with many intersections or dense road infrastructure. Segments with high network density, such as Segments 8, 17, and 18, tend to function as urban centers, requiring high accessibility and complex road networks.

On the other hand, Segments 24 and 16 have low densities (44.79 and 48.87) despite significant road lengths. This suggests that these areas may have fewer intersections or less connectivity, or they may function as peripheral regions. Segment 8, ranking first in both road length and density, indicates that this area is likely a major urban center with high accessibility, supporting mobility and connectivity. Meanwhile, Segments 17 and 18, with their high densities, serve as sub-centers or supporting areas. High-ranking urban centers require good road network density to support economic activity and public mobility. Conversely, lower-ranked segments, like Segments 24 and 16, function more as buffer or residential areas with less critical accessibility compared to urban centers.

Table 3. Road Network Density Analysis

Segment	Street Lenght (m)	Area (Ha)	Road Network Density	Orde
1	0	27,33	0,00	**31**
2	2687,64	41,25	65,15	**6**
3	474,82	25	18,99	**24**
4	0	24,35	0,00	**32**
5	2150,22	18,18	118,27	**4**
6	632,307	25	25,29	**20**
7	238,505	19,56	12,19	**27**
8	2943,409	18,69	157,49	**1**
9	301,04	26,97	11,16	**28**
10	2102,24	30,35	69,27	**5**
11	1266,67	24,43	51,85	**8**
12	628,48	15,55	40,42	**12**
13	1067,72	18,91	56,46	**7**
14	586,14	26,89	21,80	**21**
15	500,25	32,5	15,39	**26**
16	1406,807	31,41	44,79	**10**
17	4618,52	30,74	150,24	**2**
18	2959,56	24,32	121,69	**3**
19	1049,65	27,3	38,45	**14**
20	781,62	22,41	34,88	**17**
21	0	25	0,00	**33**
22	0	25	0,00	**34**
23	0	25	0,00	**35**
24	1635,64	33,47	48,87	**9**
25	1187,48	38,39	30,93	**18**
26	653,707	30,75	21,26	**23**
27	182,15	24,04	7,58	**29**
28	544,81	25	21,79	**22**
29	178,34	25	7,13	**30**

Segment	Street Lenght (m)	Area (Ha)	Road Network Density	Orde
30	0	25	0,00	**36**
31	0	25	0,00	**37**
32	0	36,42	0,00	**38**
33	0	31,74	0,00	**39**
34	0	25	0,00	**40**
35	431,86	25	17,27	**25**
36	1057,86	25	42,31	**11**
37	0	25	0,00	**41**
38	0	25	0,00	**42**
39	0	24,87	0,00	**43**
40	0	26,08	0,00	**44**
41	0	24,37	0,00	**45**
42	0	27,5	0,00	**46**
43	964,45	25	38,58	**13**
44	948,27	25	37,93	**15**
45	0	25	0,00	**47**
46	0	21,79	0,00	**48**
47	1346,402	43,64	30,85	**19**
48	1094,905	29,19	37,51	**16**
49	0	18,47	0,00	**49**

3.4. Beta Index Analysis

In Table 4, the data analysis reveals that the beta index measures road network and node connectivity. Higher index values indicate better connectivity and more efficient transportation systems. Segments 12, 20, and 36 have the highest beta index (3.000), suggesting excellent connectivity with few nodes. Segment 11, with a beta index of 2.429 and a significant number of road segments, also demonstrates a reasonably efficient system.

Conversely, Segments 1, 3, 4, 7, and others have a beta index of 0.000, indicating the absence of road segments or nodes. This implies these areas may be underserved in terms of transportation. Many segments with low beta indexes reflect inefficient land use concentration, requiring attention in urban planning.

Generally, a higher beta index correlates with a better ranking. For instance, Segments 12 and 20, with high values, are at the top. Additionally, Segment 43, with a beta index of 2.333, ranks 7th, indicating reasonably good connectivity.

Table 4. Beta Index Analysis of Penajam Village

Segment	The number of Read network	The number of junctions	Beta Index	Orde
1	0	0	0,000	**19**
2	16	9	1,778	**16**
3	1	0	0,000	**20**
4	0	0	0,000	**21**
5	23	11	2,091	**10**
6	13	7	1,857	**13**
7	1	0	0,000	**22**
8	35	20	1,750	**18**
9	3	0	0,000	**23**
10	34	19	1,789	**15**
11	17	7	2,429	**6**
12	3	1	3,000	**1**
13	1	0	0,000	**24**
14	1	0	0,000	**25**
15	1	0	0,000	**26**
16	9	4	2,250	**8**
17	55	31	1,774	**17**
18	22	12	1,833	**14**
19	1	0	0,000	**27**
20	3	1	3,000	**2**
21	0	0	0,000	**28**
22	0	0	0,000	**29**
23	0	0	0,000	**30**
24	17	8	2,125	**9**
25	0	0	0,000	**31**
26	1	0	0,000	**32**
27	1	0	0,000	**33**
28	1	0	0,000	**34**
29	1	0	0,000	**35**
30	0	0	0,000	**36**
31	0	0	0,000	**37**
32	0	0	0,000	**38**
33	0	0	0,000	**39**
34	0	0	0,000	**40**
35	2	1	2,000	**11**
36	3	1	3,000	**3**
37	0	0	0,000	**41**
38	0	0	0,000	**42**
39	0	0	0,000	**43**
40	0	0	0,000	**44**
41	0	0	0,000	**45**

Segment	The number of Read network	The number of junctions	Beta Index	Orde
42	0	0	0,000	**46**
43	7	3	2,333	**7**
44	3	1	3,000	**4**
45	0	0	0,000	**47**
46	0	0	0,000	**48**
47	8	4	2,000	**12**
48	3	1	3,000	**5**
49	0	0	0,000	**49**

3.5. Entropy Index Analysis

The data analysis in Table 5 shows that the entropy index measures the level of diversity or dispersion within a segment. Higher values reflect greater diversity, while lower values indicate concentration or homogeneity. Segment 49 has the highest entropy index (1.00) and ranks first, suggesting maximum diversity in land use or function. Segments 36 and 29 also show high index values (0.99 and 0.98), indicating good diversity.

Conversely, Segments 41 and 26 have the lowest entropy index values (0.00), indicating a high concentration of a single land use type or characteristic. This suggests these areas might be very homogenous, such as industrial areas or residential areas lacking mixed functions. Segments 20 and 23 also show low index values, indicating a potential lack of diversity.

Generally, a higher entropy index tends to correlate with a higher ranking, as seen in Segments 29, 36, and 49. However, there are exceptions; for example, Segment 13 has a high entropy index (0.92) but ranks 5th. Also, Segment 5, with an index of 0.85, ranks 6th, suggesting that a high entropy index can be a positive indicator for a city center function.

Table 5. Entropy Index Analysis of Penajam Village

Segment	Entropy Index	Orde
1	0,68	21
2	0,71	20
3	0,75	16
4	0,77	14
5	0,85	6
6	0,47	38
7	0,81	11
8	0,83	8
9	0,66	23
10	0,83	9
11	0,73	19

Segment	Entropy Index	Orde
12	0,52	35
13	0,92	5
14	0,77	13
15	0,60	30
16	0,52	34
17	0,66	24
18	0,44	41
19	0,58	31
20	0,19	45
21	0,34	42
22	0,67	22
23	0,16	46
24	0,65	25
25	0,61	28
26	0,00	48
27	0,73	18
28	0,61	27
29	0,98	4
30	0,08	47
31	0,82	10
32	0,46	39
33	0,77	15
34	0,27	43
35	0,56	32
36	0,99	3
37	0,61	29
38	0,52	37
39	0,84	7
40	0,27	44
41	0,00	49
42	0,79	12
43	0,75	17
44	0,52	36
45	0,55	33
46	0,44	40
47	0,63	26
48	0,99	2
49	1,00	1

3.6. Centrality Index Analysis

The centrality index is used to measure a segment's importance within a network based on the presence of facilities and accessibility. A higher index value indicates that the segment is more central and serves as a crucial point in the network. Based on Table 6 (not provided), Segment 18 has the highest centrality index with the most facilities, indicating it is a very significant center of activity. Segment 10 also shows a high index with 6 facilities, making it another crucial segment.

Conversely, many segments, such as 1, 6, and 19 through 49, have a centrality index and number of facilities of zero, indicating they are underserved and require more attention in infrastructure development. Segments with more facilities tend to have higher centrality indexes. For example, Segment 2, with 8 facilities, has a centrality index of 53, although not as high as Segments 10 and 18. Additionally, segments with few facilities but higher centrality indexes, like Segment 13 with an index of 33, could be targets for further development.

Table 6. Centrality Index Analysis of Penajam Village

Segment	Facilities	Centrality Index	Orde
1	0	0	15
2	8	53	5
3	1	4	11
4	1	4	12
5	1	4	13
6	0	0	16
7	0	0	17
8	2	37	6
9	0	0	18
10	6	116	2
11	4	16	9
12	2	8	10
13	1	33	7
14	0	0	19
15	1	4	14
16	2	75	3
17	2	75	4
18	10	345	1
19	0	0	20
20	0	0	21
21	0	0	22
22	0	0	23
23	0	0	24
24	0	0	25
25	0	0	26
26	0	0	27
27	0	0	28
28	0	0	29
29	0	0	30

Segment	Facilities	Centrality Index	Orde
30	0	0	31
31	0	0	32
32	0	0	33
33	0	0	34
34	0	0	35
35	0	0	36
36	0	0	37
37	0	0	38
38	0	0	39
39	0	0	40
40	0	0	41
41	0	0	42
42	0	0	43
43	0	0	44
44	0	0	45
45	0	0	46
46	0	0	47
47	0	0	48
48	1	25	8
49	0	0	49

Table 7 displays the results of segment order determination for the urban village area. Segments 8, 5, 10, 17, 11, 18, 2, 12, 24, and 16 are within the urban village center, ranked from 1 to 10. This indicates their importance as main points for social and economic activity in the Penajam region.

Sub-center 1 comprises Segments 13, 3, 36, 6, 14, 20, 4, 9, 48, and 7, suggesting their significant role in providing additional facilities and services, though not as primary as the urban village center. Sub-centers 2 and 3 include segments with the potential to become larger activity centers but are not as strong as the urban village center. Meanwhile, segments within Sub-center 4 have more limited functions compared to the other sub-centers.

Segments with the lowest order determination value indicate the highest importance in terms of accessibility, facility presence, and role in the socio-economic network. Conversely, higher order determination values (closer to 49) suggest that those segments may be underserved or do not function as activity centers.

Table 7. Classification of Results of Determination of the Central Order of the Penajam Subdistrict Area

Segment	Orde Determination	Orde	Information
8	6,83	1	Penajam Village Area Center

Segment	Orde Determination	Orde	Information
5	7,17	2	Penajam Village Area Center
10	7,83	3	Penajam Village Area Center
17	8,50	4	Penajam Village Area Center
11	9,33	5	Penajam Village Area Center
18	10,17	6	Penajam Village Area Center
2	10,83	7	Penajam Village Area Center
12	11,67	8	Penajam Village Area Center
24	12,33	9	Penajam Village Area Center
16	12,50	10	Penajam Village Area Center
13	13,33	11	sub center 1
3	15,83	12	sub center 1
36	16,50	13	sub center 1
6	18,17	14	sub center 1
14	18,83	15	sub center 1
20	19,33	16	sub center 1
4	19,67	17	sub center 1
9	20,17	18	sub center 1
48	21,17	19	sub center 1
7	21,33	20	sub center 1
43	21,33	21	sub center 2
15	21,50	22	sub center 2
1	23,50	23	sub center 2
19	23,50	24	sub center 2
35	24,50	25	sub center 2
25	27,33	26	sub center 2
47	27,67	27	sub center 2
22	27,83	28	sub center 2
29	28,00	29	sub center 2
27	28,83	30	sub center 2
37	29,17	31	sub center 3
23	29,33	32	sub center 3
28	29,83	33	sub center 3
21	30,33	34	sub center 3
31	31,50	35	sub center 3
44	31,83	36	sub center 3
26	32,17	37	sub center 3
33	34,00	38	sub center 3
39	36,00	39	sub center 3
30	36,83	40	sub center 3
32	37,17	41	sub center 4
45	37,67	42	sub center 4
42	39,33	43	sub center 4

Segment	Orde Determination	Orde	Information
34	39,50	44	sub center 4
38	40,17	45	sub center 4
49	41,00	46	sub center 4
40	43,00	47	sub center 4
41	44,67	48	sub center 4
46	46,00	49	sub center 4

Strengthening the Urban Village Center Area: Focus on developing infrastructure and facilities in the urban village centers, especially in higher-ranked segments. Developing Sub-Centers: Sub-centers 1, 2, and 3 should receive attention regarding facility improvements to attract more activity and enhance connectivity with the urban village center.

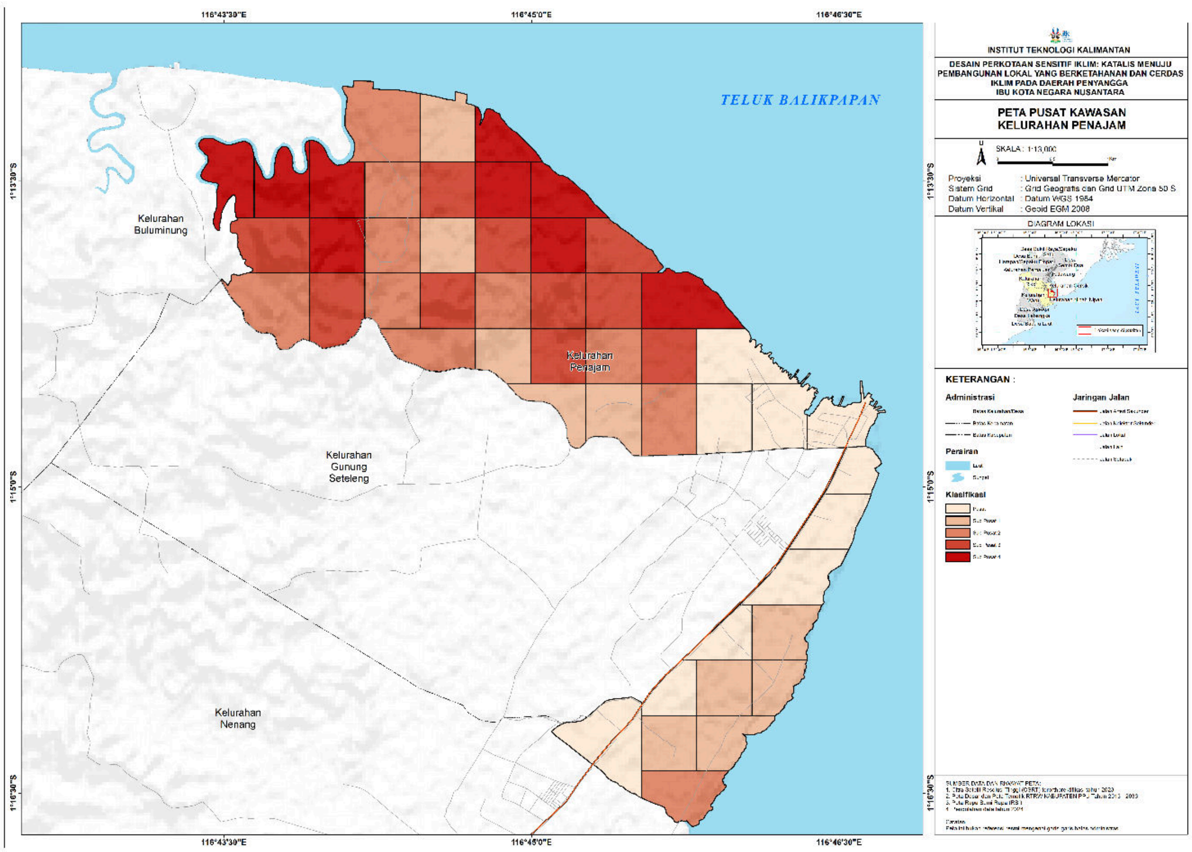

Figure 2. Map of Classification Results for Determining the Central Order of the Region

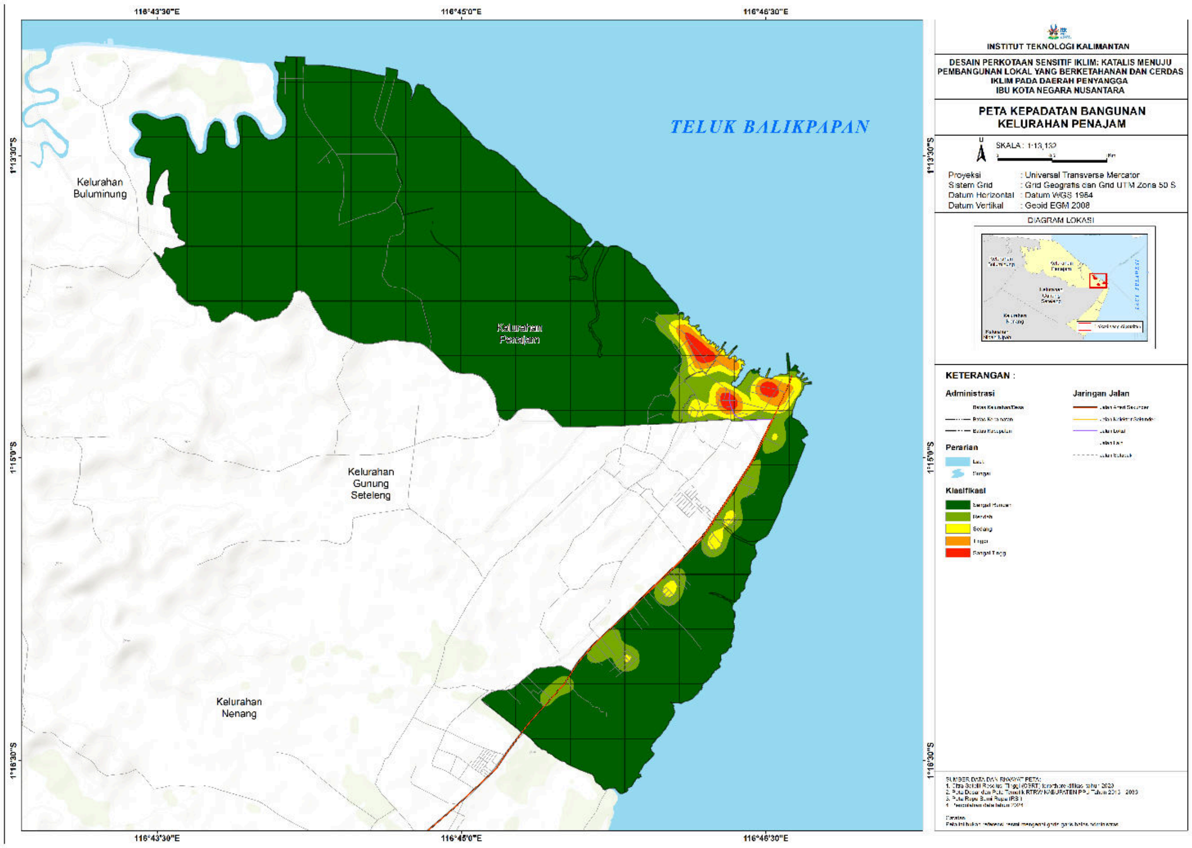

Figure 3. Regional Center Kernel Density Map

3.7. Impact of Service Center Planning in Penajam Village

This study not only provides a technical overview of service center determination in Penajam Village but also reflects the multidimensional impact of such planning:

a. Social Impact

Improved service center planning, as conducted in Penajam Village, has a significant impact on improving residents' quality of life. By identifying strategic service center segments through centrality index and population density analysis, access to basic facilities such as education, health, and transportation becomes more equitable. This reduces social inequality and improves inter-regional connectivity, creating a more inclusive and comfortable environment for the community.

b. Economic Impact

- **Efficiency of Service Distribution**: Data-driven planning prioritizes areas with the highest economic growth potential, such as segments with high population density and road networks. This allows for more efficient service distribution, reducing operating costs and increasing community access to economic facilities.

- **Increased Investment**: With strategically planned service centers, investment in infrastructure and the service sector will increase. Highly accessible areas, such as segments with high beta and centrality indexes, become more attractive to investors. This can trigger regional economic growth and strengthen Penajam Village's role as a supporter of the new capital city.

c. Environmental Impact

Data-driven planning can help reduce the environmental impact of urbanization by:

- Identifying segments with high urbanization pressure to prevent uncontrolled urban sprawl.
- Optimizing land use through entropy index analysis, ensuring land function diversity according to needs.
- Integrating sustainable transportation in areas with high road network density, reducing emissions and energy consumption.

d. Sustainability Impact

- **Increased Mobility**: Data-driven determination of service centers and sub-centers supports the development of efficient road networks, increasing resident mobility. This supports Sustainable Development Goal 11, which aims to make cities and settlements inclusive, safe, resilient, and sustainable.
- **Better Living Conditions**: With better access to public services, such as education and health facilities, the quality of life for the community improves. This aligns with SDGs 3 and 4, ensuring healthy lives and promoting quality education.
- **Reduced Environmental Impact**: Managing urbanization through data-driven planning helps protect green spaces and mitigate pollution, supporting SDG 13 on climate action and SDG 15 on protecting terrestrial ecosystems.

This overall planning creates a holistic approach that strengthens social, economic, and environmental sustainability in Penajam Village as part of developing the new national capital.

4. CONCLUSION

The analysis conducted on various segments in the Penajam region reveals differences in the roles and functions of each segment within the socio-economic and infrastructure network. Main segments, such as 8, 5, 10, and others, serve as urban village centers with good accessibility and fac`ilities, supporting significant social and economic activities. Meanwhile, segments within sub-centers 1, 2, and 3 play an essential role in providing additional services, although not as strong as the urban village centers.

The centrality, entropy, and beta indexes reveal that segments with high values indicate better connectivity and diversity, while segments with low values indicate a lack of services and development potential. To improve the social and economic network, it is necessary to develop infrastructure and facilities in the urban village centers and pay special attention to sub-centers to attract more activity. This strategy is expected to create a balance in regional development and improve the quality of life for the Penajam community.

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