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Interaction of Growth Pole and Shannon's Entropy in Banda Aceh City

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Abstract – The development of growth poles, urban activity centers, and service centers in Banda Aceh City has impacted the spread, a complex urban phenomenon challenging to measure due to urban sprawl. The increasing need for space in urban areas drives the development of suburban and random areas (urban sprawl). This is evident from the BPS Banda Aceh City data for 2024, where the population increased by 25.61% post-tsunami, affecting the density of each sub-district in Banda Aceh City. Research using Shannon's Entropy Method and the Gravitational Model is necessary to prevent uneven growth in the city of Banda Aceh. The application of Shannon's Entropy method in Banda Aceh City from 2010 to 2020 can be seen in the Relative Entropy Matrix, which shows that the linear spread pattern (Quadrant C) is more dominant in the districts of Banda Raya, Baiturrahman, Kuta Raja, Kuta Alam, Lueng Bata, and Syiah Kuala. The urban spread pattern of Banda Aceh tends to move towards the East, largely due to the landform factors that are very suitable for being developed into built-up areas. Meanwhile, the results of the gravity analysis show that the area of interaction with the most substantial interaction value as the growth pole is the interaction between Kuta Alam District and Baiturrahman District, with a value of 190,617,812.346 interactions. The results of identifying the factors influencing the development of urban sprawl, such as the distance to the CBD, the GRDP of Banda Aceh City, changes in land use, housing demand, and the availability of infrastructure facilities in the districts of Banda Aceh City, can be concluded that there is an influence of urban sprawl on the spatial structure and regional patterns in Banda Aceh City.

Keywords: Growth Pole, urban Sprawl, Shannon's Entropy, Spatial Structure

Introduction

In Banda Aceh City, there has been a shift in growth poles and urban activity and service centers, such as trade and service areas, public facilities, and other amenities, causing these activities to begin spreading in all directions throughout the city with increasing intensity (Banda Aceh City Spatial Plan 2009-2029). Fadhly (2016) explains that the shift in Banda Aceh city from the west is more focused towards the city's south and East, resulting in urban sprawl. This can be evidenced by the numerous social and public facilities being built in the southern and eastern areas of Banda Aceh city. As a result, there is a tendency for urban functions to shift to the urban fringe. The increasing need for space in urban areas encourages urban fringe development and areas' random development (urban sprawl). In addition to the urban sprawl nature of city expansion, which reduces productive land, it also causes changes in the city's shape and an irregular regional pattern when viewed from the physical condition before and after the tsunami in Banda Aceh.

The city of Banda Aceh has grown and developed until now, not simultaneously, but gradually, in certain places with different intensities (Francis Perroux, 1955). The CBD (Central Business District) will become a growth pole in urban development, followed by the spread and development to other surrounding areas. As a result, new growth centers will emerge, causing a city (Banda Aceh) to grow and develop with diverse patterns and structures.

The concept of economic space proposed by Francois Perroux forms the basis for the idea of growth poles. Perroux stated that growth does not appear in various places simultaneously. On the contrary, growth will emerge

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in various growth poles with different intensities and consequences. The Perroux theory, the "growth pole," is the basis of regional industrial development policy strategies widely used in various modern countries. Growth centers can cause spillover effects, or diffusion, of activities from the growth center to its surrounding areas, allowing those surrounding areas also to grow and develop. As a result, the development of areas around the growth center will lead to economic growth, which will also be followed by the development of the surrounding areas (Emalia, 2018).

Banda Aceh City is the administrative center of the Aceh Province government, making it the central hub for all activities, such as economy, society, culture, education, and health. The high level of activities in Banda Aceh City is causing land use changes. The increasing number of built-up areas in the city marks this. The increase in built-up land is one of the impacts of extending road lengths in every area of Banda Aceh City. This is because the road network is an important factor in supporting the mobility of people and goods. In addition, the road network also serves as a connector between one area and another (Melinda, 2020).

The development of the urban space in Banda Aceh City, which has led to an increase in built-up land, is also due to the population growth in each sub-district of Banda Aceh City. This can be seen from the increasing population growth every year. The increase in population is causing more activities to occur in the city of Banda Aceh, leading to the city's development extending to the outskirts of Banda Aceh (Melinda, 2020). Thus, it is important to understand the spatial patterns of urbanization and city growth in Banda City.

From the issue of urban sprawl based on area growth, Shannon's entropy approach is a robust statistical method to describe the strength of urban diffusion. Yeh and Li (2001) studied urban sprawl in several cities using Shannon's entropy approach, considering the distance to the city center and the main roads. This research combines the composite Shannon's entropy index for both aspects and uses a spatial matrix to identify urban sprawl patterns. This research was conducted to determine the strength of urban sprawl in Banda Aceh using Shannon's entropy index and understanding the patterns of sprawl. In addition, an analysis of the impact of urban sprawl on urban infrastructure in Banda Aceh City was also conducted.

Materials and Methods

Land Use Change

Land use change is the shift from a certain type of land use to another type, and this change can be partial or complete (Frankel A, Ashkenazi M, 2008).[4] Changes in land use include shifting land use towards different land uses or additions to existing land uses (Fadhly, 2020).[3] In its development, changes in land use have become a natural thing in urban development.

Factors Causing Changes in Land Use

Yusran in Nugroho (2013)[5] classifies the causes of changes in land use in urban areas into 3 factors, namely: 1) Human factors: human needs for housing, human potential, financial, socio-cultural, and technological., 2) Physical factors of the city: the center of activity is the center of urban growth, and the transportation network is accessible for ease of achievement; 3)Landscape factors: slope and land elevation.

Barlowe (Muiz, 2009)[6] states that in determining land use, there are three important factors to consider: land physical, economic, and institutional factors. Changes in land use are also related to land suitability at that location for a particular type of land use (Nugroho, 2013).[5] In regions with a rapid and unstable level of development, land use is more dynamic. The dynamics of this level of development are caused by the main factors, namely the human factor and the natural factor itself, which changes quickly in these circumstances.

Trends in Spatial Patterns of Residential Areas and Settlements

Land Use Patterns

Catanesse and Snyder in Hairudin (2008:36)[7] indicate that the physical basis and economic basis are spatial elements that influence the growth of a city or region where interactions occur between regions as part of forming the region's character. Theories regarding the growth and development of the structure of urban areas with land use patterns are put forward by: a). E.W. Burgess with Concentric Theory, b). Hommer Hoyt with Sectoral Theory, c) C.D. Haris and F.L. Ullman. This can be seen in the Table 1.

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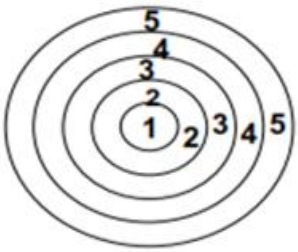
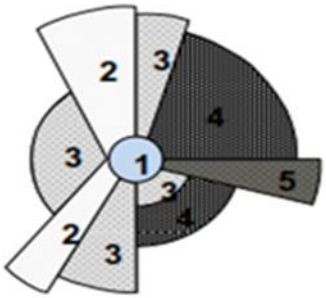
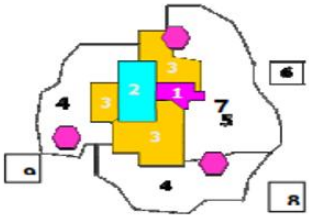
Table 1. Model Zone (Urban Area Structure)

a) Model Zone Konsentris, *E.W. Burgess (1925)* 	According to Burgess's experience, a city will consist of concentric zones reflecting different types of land use. 1. Central area of activity 2. transitional zone 3. workers' housing zone 4. good residential zone 5. the worker's zone is far away
b) Model Zone Sektoral, *Hommer Hoyt (1939)* 	Conceptually, Hoyt's theory, in some ways, still shows the distribution of concentric zones like Burgess's theory; this is seen on the lower side of the finger transportation lines (connecting the city center to more distant parts), given a significant role in shaping the pattern of the city's internal structure. 1. Central Business District 2. Trade and light manufacturing zone 3. Low-Class Residential Zone 4. Middle-Class Residential Zone 5. Upper-Class Residential Zone
c) *C.D Harris dan F.L Ullman (1945)* 	This theory illustrates the similarity between concentric theory and sectoral theory. Urban growth that starts from a center (core) becomes complex due to the emergence of new growth poles around the new centers (nucleus), which will group functionally related land uses. 1. Central Business Area 2. Wholesale and light manufacturing zone 3. Low-class residential zone 4. Middle-class residential zone 5. Upscale Residential Zone 6. Heavy Manufacturing Zone 7. Outskirt business zone 8. Fertile settlement zone 9. Suburban Industrial Zone

Regional Patterns and Urban Spatial Expressions

Fadhly (2019),[8] the city's shape as a whole reflects its geographical position and the characteristics of the place. Based on this theory, it can be interpreted that the development of a city can be determined by its geographical position and the characteristics of the place where an activity process takes place so that it can form patterns that follow the conditions of the area. The patterns of urban development on flat land are described schematically by Branch as follows:

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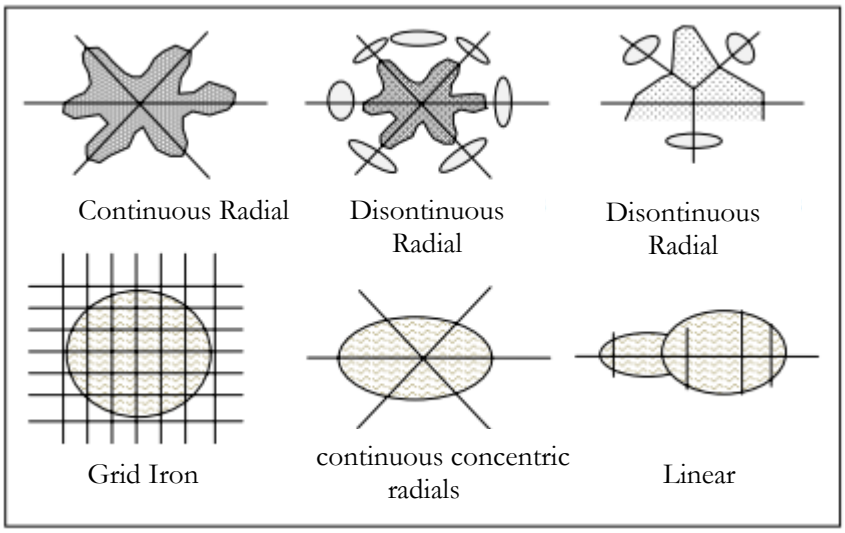

Figure 1. The Pattern of Urban Development

Texturally, regional patterns can be classified into three groups, including: (Zahnud, 1999; Hamzah, 2010) [9]:

- Homogeneous Area Pattern, A clear homogeneous arrangement of areas where there is only one structuring pattern. In this pattern, the solid and void elements that make up the area consist of shapes that tend to be the same and usually exhibit high density.
- Pattern of Heterogeneous Regions; Heterogeneous arrangement of areas where two or more patterns clash. This pattern usually has more solid and void elements, thus forming quite varied compositions.
- Scattered Area Pattern; The arrangement of scattered areas has a chaotic tendency. This area is usually formed for certain reasons. It can be seen that this area is not integrated between one function and another, so it looks like an unplanned area.

The development of the built areas in Banda Aceh City tends to be eastward. This is mostly caused by the shape of the land, which is very suitable for use as a built-up area. So, the development of the developed region towards the East is faster than the pattern towards the West, North, and South. This can be seen from the relative entropy matrix, in which the Syiah Kuala and Ulee Kareng sub-districts have an urban sprawl pattern that spreads from the city center and away from the road network. Previous research conducted by Fadhly has also proved this. Noer in 2016, when the study results showed that urban sprawl to the south of Banda Aceh was 33% and to the East of Banda Aceh was 44% of the total population of Banda Aceh in 2013.

Shannon's Entropy

Shannon's entropy equation, formulated by Claude Shannon, tends to articulate the degree of disorder, which can be translated into phenomena of changes in the Earth's surface or the degree of irregularity in spatial phenomena. The formulation of the model is as follows:

$$Hn = - \Sigma Pi\ Log\ (1Pi) \quad (1)$$

Where:

Hn = Shannon's Entropy

Pi = Likelihood or proportion of the phenomenon (variable) in its zones.

The formula determines the value of Pi:

$$Pi = Xi / \Sigma X \quad (2)$$

Where:

Xi = Observed value of variables in its zones;

X = Total built-up area.

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Relative entropy is a concept that indicates the maximum proportion of possible distributions where variables are spread between categories or zones (Fir, 1972; Arief. P: 2016). [10] The equation used is:

$$H'n=\Sigma Pi\ Log\ (1Pi)\ n \quad (3)$$

Where:

H'n = Relative Entropy;
n = Total Zones.

Propagation Pattern Using Relative Entropy Spatial Matrix

The urban distribution pattern is increasingly random and away from the city center and road network, and the relative entropy index value for the road network is smaller compared to the city center, which explains that urban distribution still follows the road network pattern (linear). These symptoms occur in every sub-district in Banda Aceh City, which can be seen in the Figure2.

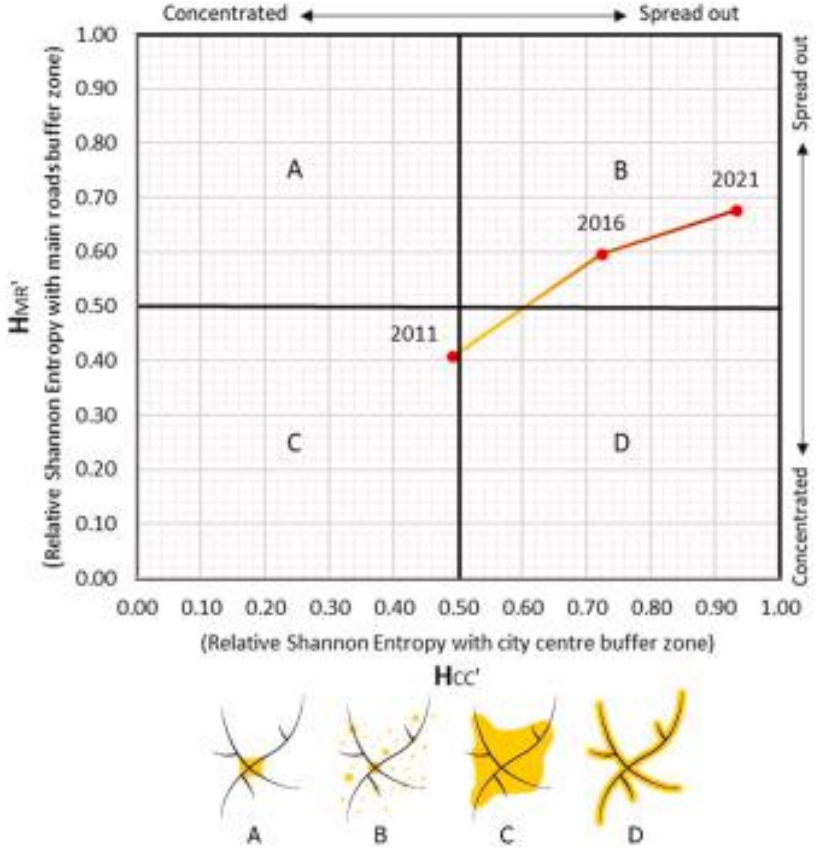

Figure2. Relative Entropy Spatial Matrix

Methodology

The data processing technique simplifies data into a form that is easy to read, understand, and interpret. This data analysis uses Shannon's Entropy model. This calculation considers the distance to the city center and the road network. The steps taken to calculate the relative entropy index are as follows:

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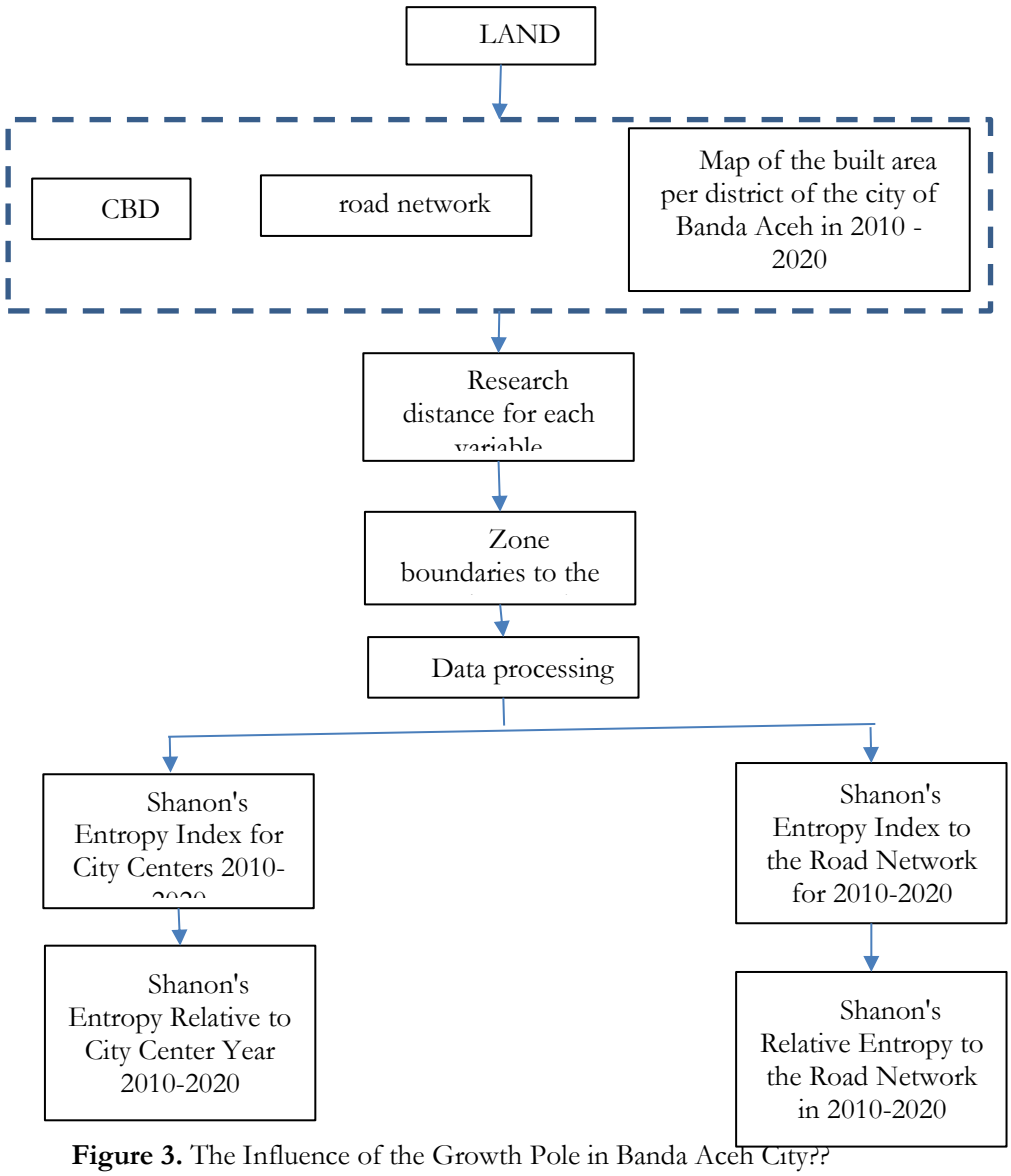

Figure 3. The Influence of the Growth Pole in Banda Aceh City??

The economic interactions between sub-districts in Banda Aceh City will create a substantial interaction area as a new growth pole based on data from before and after the tsunami in Banda Aceh City.

Based on data from the Central Bureau of Statistics of Banda Aceh City, the population in 2004 was 265,098 people, and in 2005 it was 177,881. Here, it can be seen that there was a significant decrease of 32.9% in the population from 2004 to 2005 due to the tsunami disaster in Banda Aceh. Meanwhile, in 2023, the population was 261,969 people. This indicates that there has been an increase in the population since 2005 after the tsunami, amounting to 47.27%. For more clarity, please refer to Table 2

Table 2. Population by district in Banda Aceh City

District	Population		
	2004	2005	2023
Meuraxa	34.592	2.221	25.916
Jaya Baru	21.305	12.340	27.239
Banda Raya	23.995	24.257	26.651
Baiturahman	37.715	33.582	34.111

Lueng Bata	19.232	19.284	25.802
Kuta Alam	54.718	35.033	44.836
Kuta Raja	21.632	2.978	14.943
Syiah Kuala	32.590	25.418	34.545
Ulee Kareng	19.319	22.768	27.926
Banda Aceh City	265.098	177.881	261.969

Based on the data in the Table 1, it can be seen that there was a significant decline in the districts of Banda Aceh City in 2004 and 2005 post-tsunami. The districts in question are Meuraxa District and Kuta Raja District, which each experienced a population decline of 93.58% and 86.23%, respectively.

The economic potential based on developing economic interactions between sub-districts and making the most substantial interaction areas as growth poles in Banda Aceh City can be analyzed using the gravity model.

Gravity Model

The gravity model is the most widely used model to observe the magnitude of attraction from a potential located at a specific location. This model is used to identify the economic interactions of a district with other surrounding districts that have strong economic interactions as growth centers. This theory is essentially a concept of physical law proposed by Isaac Newton, and W. J. Reilly extended its application to geography. Reilly argued that the strength of interaction between two or more areas on the Earth's surface can be measured by considering the population and the absolute distance between those areas. The formula used to calculate economic interaction between regions, according to Damayanti (2019), is:

$$I_{1\text{-}2} = k \cdot \frac{P_1 . P_2}{(J_{1-2})^2} \quad (5)$$

Explanation:

$I_{1\text{-}2}$ = the strength of interaction between areas 1 and 2

k = empirical constant (generally 1)

P1 = the population of region 1

P2 = the population of region 2

$J_{1\text{-}2}$ = the absolute distance between regions 1 and 2

Analyzing the impact of urban sprawl on spatial structure and regional patterns in light of the physical conditions of Banda Aceh city

Analyzing the impact of urban sprawl on spatial structure and regional patterns in terms of the physical condition of Banda Aceh city before and after the tsunami based on satellite imagery from 2004, 2005, and 2023 by examining the distance to the CBD, Banda Aceh's GRDP, housing demand, land use change, and the availability of infrastructure facilities and amenities in Banda Aceh city. The increasing population influences land use in the city of Banda Aceh.

Data analysis using the Geographic Information System (GIS) application. The shape of islands, administrative boundaries, rivers, roads, and other elements on the Earth's surface are displayed in SHP ArcGIS map data. An analysis was conducted using a geographic information system to analyze the spread patterns starting from land area, availability of facilities, and land availability.

Result

Spatial Pattern of Spread of Banda Aceh City

The entropy value describes the spatial pattern of urban sprawl as the spatial unit. Recapitulation of the Relative Entropy Index for each sub-district of Banda Aceh City can be seen in the Table 3. Table 3 describes the relative entropy index for the city center and the road network, which increases each period. This trend explains urban sprawl patterns that are increasingly random and away from the city center and the road network. The relative entropy index value for the road network is smaller when compared to the city canter, which explains that urban propagation still follows the road network pattern (Linear). These symptoms occur in every sub-district in Banda Aceh City

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Table 3 Recapitulation of the Relative Entropy Index in each District in Banda Aceh City

No	Subdistrict	Perspective Against	Shannon's Entropy Index by Year		
			2010	2015	2020
1	Meuraxa	Downtown (H'P)	0,4739	0,5501	0,6341
		Road Network (H'j)	0,3604	0,3829	0,4064
2	Jaya Baru	Downtown (H'P)	0,578	0,626	0,725
		Road Network (H'j)	0,314	0,482	0,515
3	Banda Raya	Downtown (H'P)	0,722	0,740	0,849
		Road Network (H'j)	0,350	0,463	0,465
4	Baiturrahman	Downtown (H'P)	0,813	0,832	0,845
		Road Network (H'j)	0,475	0,522	0,550
5	Lueng Bata	Downtown (H'P)	0,822	0,891	0,912
		Road Network (H'j)	0,481	0,492	0,584
6	Kuta Alam	Downtown (H'P)	0,876	0,885	0,927
		Road Network (H'j)	0,364	0,469	0,538
7	Kuta Raja	Downtown (H'P)	0,683	0,715	0,747
		Road Network (H'j)	0,629	0,632	0,643
8	Syiah Kuala	Downtown (H'P)	0,833	0,886	0,972
		Road Network (H'j)	0,568	0,627	0,648
9	Ulee Kareng	Downtown (H'P)	0,831	0,911	0,978
		Road Network (H'j)	0,616	0,641	0,738

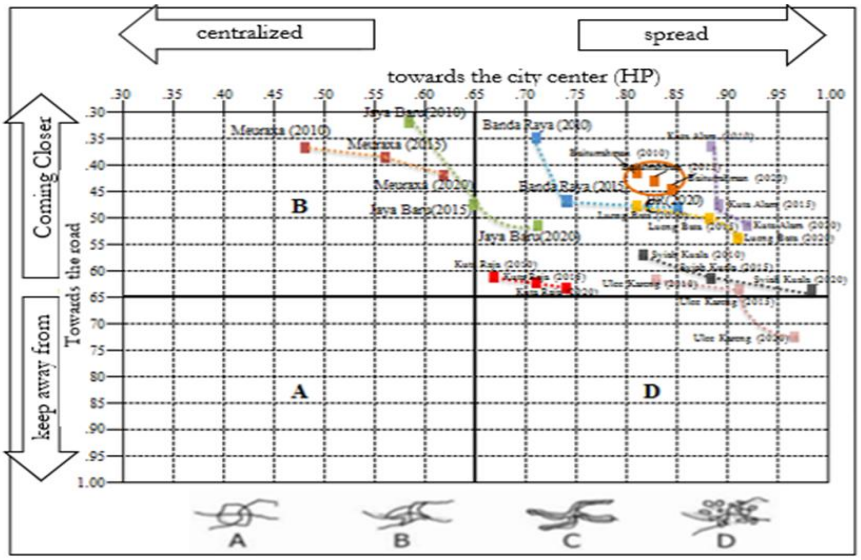

Figure 3 Relative Entropy Spatial Matrix

The picture above identifies the spreading pattern of Banda Aceh City. Meuraxa District in 2010 was in quadrant B (4.2); in 2015, it was in quadrant B (6.2); and in 2020, in quadrant B (7.3), indicating that the city spread in Meuraxa District is an elongated type of propagation (radial) to the road. Jaya Baru District in 2010 was in quadrant B (6.1), and in 2015 it was in quadrant B (7.4). This indicates that the city spread in Jaya Baru

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District is a longitudinal (radial) type of spread to the road. Changes in the propagation pattern occurred in the 2020 period, namely in quadrant C (9.5), which indicates that the city spread has changed to a linear propagation of the road.

Gravity analysis

The most commonly used model is the gravity analysis model, which determines the extent of the attractiveness of a potential location. Sub-districts in Banda Aceh City that have strong economic ties as growth centers (growth poles) can be identified using this model. The population and the absolute distance between two areas can be used to measure the relationship between two or more areas. The gravity model analysis was calculated for the districts in Banda Aceh City in 2004, 2005, and 2023 by the conditions before and after the tsunami in Banda Aceh City.

Table 4. Distance between sub-districts in Banda Aceh City

District	Meuraxa	Jaya Baru	Banda Raya	Baiturahman	Lueng Bata	Kuta Alam	Kuta Raja	Syiah Kuala	Ulee Kareng
Meuraxa		3,5	7,5	4,1	7,2	6,3	4,6	10,8	10,3
Jaya Baru	3,5		3,2	4,5	8	7,1	7,6	11,7	11,1
Banda Raya	7,5	3,2		3,8	5	6,2	6,6	10,8	7,1
Baiturahman	4,1	4,5	3,8		3,6	2,7	2,8	7,3	6,6
Lueng Bata	7,2	8	5	3,6		3,3	5,2	7,3	3,6
Kuta Alam	6,3	7,1	6,2	3,3	3,3		2,6	5,6	5,4
Kuta Raja	4,6	7,6	6,6	5,2	5,2	2,6		6,8	7,2
Syiah Kuala	10,8	11,7	10,8	7,7	7,7	5,6	6,8		5,8
Ulee Kareng	10,3	11,1	7,1	3,6	3,6	5,4	7,2	5,8	

The influence of growth poles on the infrastructure of Banda Aceh City

The results of the gravity analysis obtained the strongest interaction value as the center of growth (growth pole), which was found in the interaction between Baiturrahman District and Kuta Alam District, Banda Aceh City in 2004 (before the tsunami), 2005 (after the tsunami) and 2023 (currently). This shows that the interaction produced between the two sub-districts influences economic growth in Banda Aceh City through infrastructure development in the area by the 2012-2022 Banda Aceh City RPJMD document, namely road infrastructure. Where Baiturrahman District and Kuta Alam District themselves are the central locations of the Banda Aceh City Government and Banda Aceh City CBD (Pasar Peunayong) which have direct access to the capital city of Banda Aceh with adequate road infrastructure and transportation systems. In the 2012-2022 RPJMD for the City of Banda Aceh, it is explained that the development of road infrastructure is very important considering its role and contribution to the growth of the City of Banda Aceh.

The growth of road infrastructure that facilitates, stimulates and encourages development activities greatly influences social, economic and development growth in the city of Banda Aceh, which is the capital of Aceh Province, because of its role in connecting and increasing the movement of people and goods. This means that the results of this research relate to the RPJMD document with the strongest interaction value obtained by the interaction between Baiturrahman District and Kuta Alam District, Banda Aceh City, amounting to 209,794,347.87 interactions or an increase of 30% from 2005 (after the tsunami) proves that The existing road infrastructure meets the infrastructure needs to build the economic growth of the City of Banda Aceh and make the strongest interaction area the center of growth (growth pole) in the City of Banda Aceh.

Conclusions

The distribution pattern of Banda Aceh City tends to point towards the East. This is largely caused by land form factors that are very suitable for use as built-up areas. So the development of built-up areas towards the east is faster compared to the pattern towards the west, north and south. This can be seen from the relative entropy matrix, where the Syiah Kuala and Ulee Kareng subdistricts have urban sprawl patterns spreading from the city center and away from the road network.). The gravity analysis model also obtained results for interaction areas with the weakest interaction values between sub-districts in Banda Aceh City, seen before and after the tsunami. The weakest interaction areas were found to be the same in 2004 (before the tsunami) and 2023 (currently) in Ulee Kareng District and Jaya Baru District with interaction values of 3,340,567.283 interactions and 6,173,819.61 interactions. Meanwhile, in 2005 (after/post-tsunami) the weakest interaction area was in Kuta

Raja District and Meuraxa District with an interaction value of 312,577,410 interactions. This is because Kuta Raja District and Meuraxa District are sub-districts of Banda Aceh City.

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