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Urban Spatial Patterns of Banda Aceh Using a Shannon Entropy Method

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Abstract – The rapid development of Banda Aceh City has occurred mainly in suburban areas. The impact is that spillover is a complex urban phenomenon that is difficult to measure. Policymakers need a simple method to control and evaluate urban sprawl. This study integrates Shannon's Entropy model with remote sensing and GIS to analyze the pattern of sprawl in each sub-district in Banda Aceh City based on two aspects of distance, namely distance to the city center and road network in order to illustrate the pattern of urban sprawl. The application of Shannon's Entropy method in Banda Aceh City in 2010-2020 can be seen in the Relative Entropy Matrix, which shows that the linear spreading pattern (Quadrant C) is more dominant in Banda Raya Sub-district, Baiturrahman Sub-district, Kuta Raja Sub-district, Kuta Alam Sub-district, Lueng Bata Sub-district, and Syiah Kuala Sub-district. Meanwhile, the transmission pattern of Meuraxa and Jaya Baru sub-districts is in quadrant B, namely the longitudinal type transmission pattern (Radial); in 2020, Jaya Baru sub-district there was a change in the transmission pattern, namely a linear transmission pattern. In the Ulee Kareng sub-district, there is a change in the transmission pattern in 2020, which is in quadrant D, namely the leapfrog development pattern from the previous years, namely 2010 and 2015 in quadrant C with a linear transmission pattern. The spread pattern of Banda Aceh City tends to lead to the East, largely due to landform factors that are very suitable to be used as built-up areas.

Keywords: Urban sprawl, Shannon's Entropy, Geographic Information System (GIS)

Introduction

Banda Aceh City is the administrative center of the Aceh Province government, thus becoming the main center of all economic, social, cultural, educational, and health activities. The high activity in Banda Aceh City has led to a land change in Banda Aceh City. This is characterized by the increase in built-up land in the city. The increase in built-up land is one of the impacts of the increase in road length in each area in Banda Aceh City. It is because the road network is an essential factor in supporting the mobility of people and goods. In addition, the road network is also a link between one area and another (Melinda, 2020).

Land use characteristics have emphasized the type of land use that consists of the spatial expression of human activities on the land (Pontang *et al*., 2012). Land use is not static but dynamic and can continue to change depending on the factors that cause it (Pratomoatmojo, 2012). The land's dynamic nature needs to be considered in land use planning and designation. The spatial development of Banda Aceh City, which increased built-up land, also occurred due to population growth in each sub-district of Banda Aceh City. It can be seen from the population growth that increases every year. This increase in population has caused more activities to occur in Banda Aceh City, causing urban development on the outskirts of Banda Aceh City (Melinda, 2020). Thus, it is essential to know how the spatial pattern of urbanization and urban growth occurs in Banda Aceh City.

Shannon's entropy is a robust statistical approach to describe the strength of urban sprawl. Yeh et al., 2001 conducted a study on sprawl in several cities using Shannon's entropy approach by considering the distance between the city center and the main road. This study combined the composite Shannon's entropy index of these two aspects and used a spatial matrix to identify urban sprawl patterns. This research was conducted to find out how strong the urban sprawl of Banda Aceh is. In addition, it also analyzes the mainstreaming of urban sprawl on urban infrastructure in Banda Aceh City. This study aimed to determine the pattern of urban sprawl in

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each sub-district in Banda Aceh City by integrating Shannon's Entropy model and GIS to analyze the pattern of urban sprawl.

Materials and Methods

The research location is Banda Aceh City with coordinates 050°16'15" - 050°36'16" N and 950°16'15" - 950°22'35" E, which is divided into nine sub-districts. Primary data was obtained by analyzing data utilizing the Geographic Information System (GIS) application to obtain land use data, road network patterns, and building functions in Banda Aceh City. Secondary data is retrieved by collecting and studying published reports of the Banda Aceh City Government related to the research, such as BPS Banda Aceh City, Banda Aceh City Public Works and Settlement Office, Banda Aceh City Transportation Office, Banda Aceh City Spatial Plan 2009-2029, morphology and demography of Banda Aceh City, journal articles, and books relevant to this research.

Table 1. The variables used in this study are as follows:

Research data	Data sources
Change in Built-Up Area in 2010, 2015, and 2020	*Lansat Image* Interpretation
Distance to the city center (CBD)	Personal data from geospatial
Road network	information agency
Land availability	
Population size	Population census data
Main street	Transportation department of Banda Aceh city
Garbage services, electricity, water supply, Telecommunications, Drainage, and green space services	*Spatial Planning* of Banda Aceh City

Shannon's Entropy

Shannon's Entropy Model is still rarely applied in various spatial studies, especially in highly dynamic cities such as Jakarta and its surroundings, known as *Jabodetabek* urban area. Meanwhile, early identification through the model can help policymakers in regional planning, especially in monitoring land use changes in the suburban areas of Jakarta (Arief et al., 2016)

Shannon's Entropy equations formulated by Claude Shannon tend to articulate the level of irregularity, which can be expressed in the symptoms of change in the earth's surface space or the level of irregularity of spatial phenomena. The formulation of the model is as follows:

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

Where:
Hn = *Shannon's Entropy*
Pi = the probability or proportion of phenomena (variables) that occur in the *ith* zones.
The formula determines the value of Pi:

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

Where:
Xi = The observed value of the variable in the *ith* zones;
X = Total built-up area.

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

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

Where:
H'n = Relative Entropy;
n = Total Zone.

The Pattern of Transmission Using Relative Entropy Matrix

The pattern of transmission using the Relative Entropy spatial matrix is divided into four quadrants based on the range of relative entropy values, namely:

- Quadrant A is in the range of H´p 0.30 - 0.65, and the value of H´j is in the range of 0.65 - 1. The transmission pattern is centered towards the city core (radial).
- Quadrant B is in the range of H'p values 0.3 - 0.65 and (H'j) values 0.30 - 0.65. The spread begins to show a change in pattern other than centering but also approaching the road network

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- Quadrant C H'p value 0.65 - 1 and (H'j) value in the range 0.30-0.65. The transmission pattern is linear to the road network and shows a ribbon development pattern.
- Quadrant D with an H'p value of 0.65 - 1 and a value (H'j) in the range of 0.65 - 1. This quadrant reflects the type of sprawl that is dispersed to both the urban core buffer and the road network buffer. The spatial matrix referred to in the description above can be seen in Figure 2 as follows:

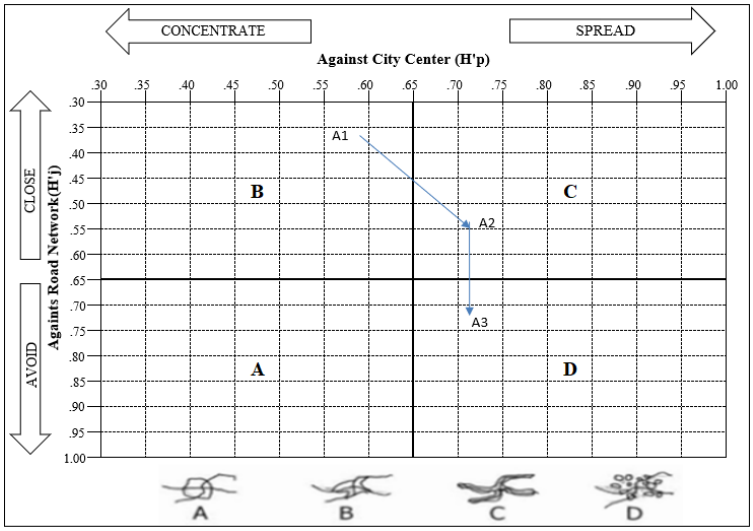

Figure 2. Relative entropy spatial matrix

The research flow chart can be seen in Figure 3 as follows:

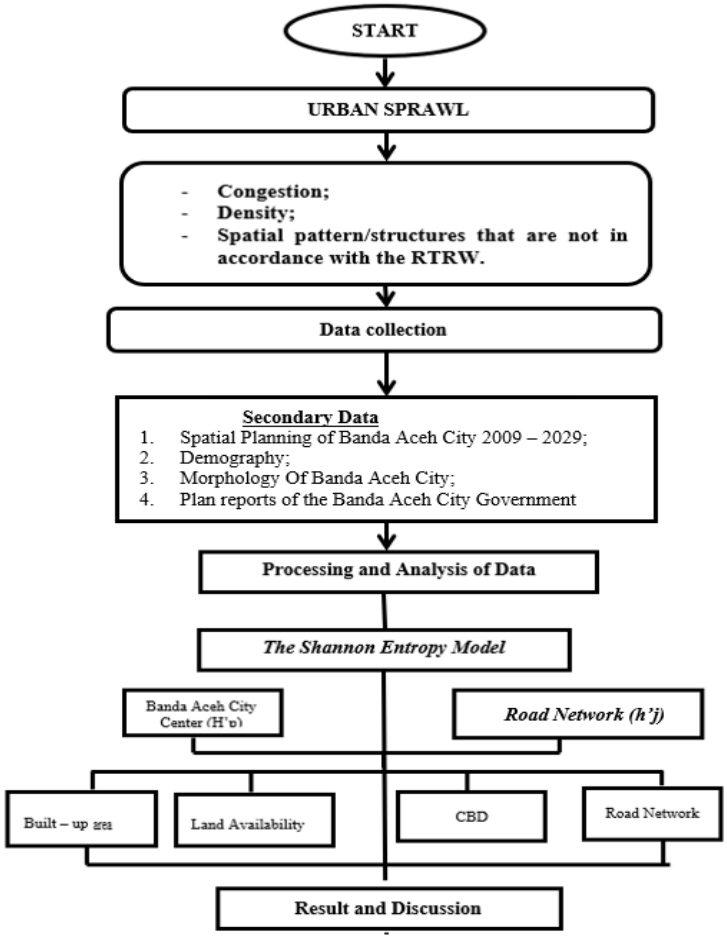

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Figure 3. Flow Chart of research

Data Processing Techniques

The data is calculated based on the processing technique applied in this research. This calculation considers the distance to the city center and the road network. The steps taken to calculate the relative entropy index are shown in Figure 4

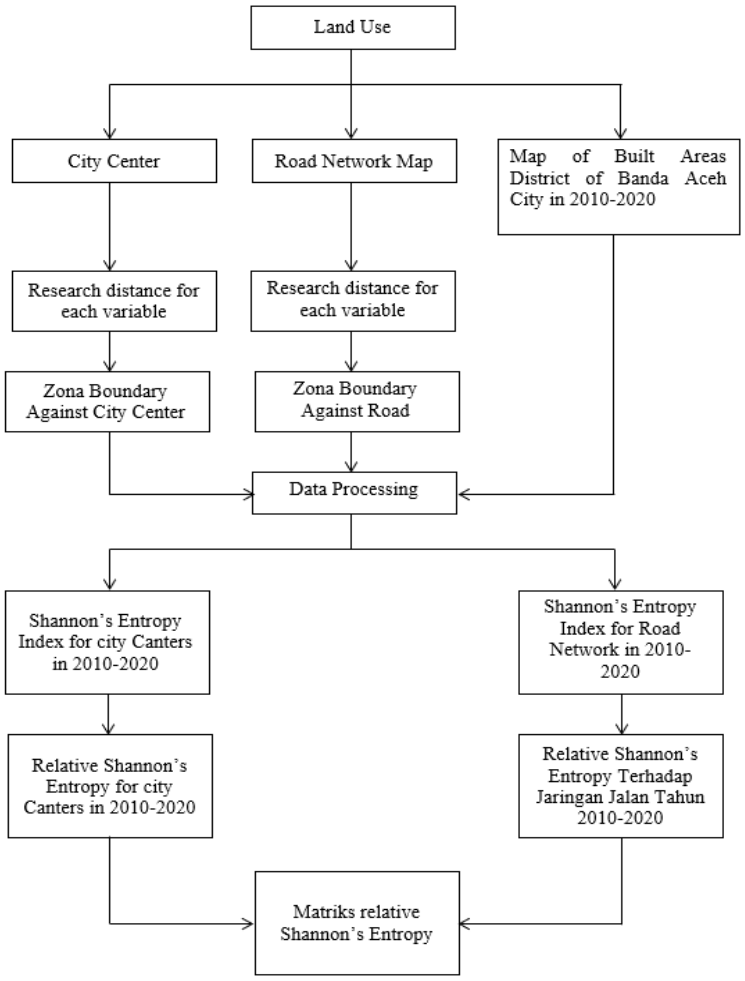

Figure 4. Relative Entropy Calculation Methodology

Results

The relative entropy index assessment was conducted using administrative boundaries from 2010 to 2020, where the Banda Aceh municipality consists of 9 sub-districts. The calculation results are presented in Table 2. Table 2 illustrates that the relative entropy index with respect to the city center and road network increases every period. This tendency explains the increasingly random pattern of urban sprawl away from the city center and road network. The value of the relative entropy index towards the road network is smaller than towards the city center, which explains that urban sprawl still follows the road network pattern (Linear). These symptoms occur in every sub-district in Banda Aceh City.

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Table 2. Recapitulation of Relative Entropy Index in each Sub-district in Banda Aceh City

No	Subdistrict	Perspective Against	Shannon's Entropy Index by Year		
			2010	2015	2020
1	Meuraxa	City Center (H'P)	0,4958	0,5390	0,6334
		Road Network (H'j)	0,3604	0,3829	0,4064
2	Jaya Baru	City Center (H'P)	0,578	0,626	0,725
		Road Network (H'j)	0,314	0,482	0,515
3	Banda Raya	City Center (H'P)	0,722	0,740	0,849
		Road Network (H'j)	0,350	0,463	0,465
4	Baiturrahman	City Center (H'P)	0,813	0,832	0,845
		Road Network (H'j)	0,475	0,522	0,550
5	Lueng Bata	City Center (H'P)	0,822	0,891	0,912
		Road Network (H'j)	0,481	0,492	0,584
6	Kuta Alam	City Center (H'P)	0,876	0,885	0,927
		Road Network (H'j)	0,364	0,469	0,538
7	Kuta Raja	City Center (H'P)	0,683	0,715	0,747
		Road Network (H'j)	0,629	0,632	0,643
8	Syiah Kuala	City Center (H'P)	0,833	0,886	0,972
		Road Network (H'j)	0,568	0,627	0,648
9	Ulee Kareng	City Center (H'P)	0,831	0,911	0,978
		Road Network (H'j)	0,616	0,641	0,738

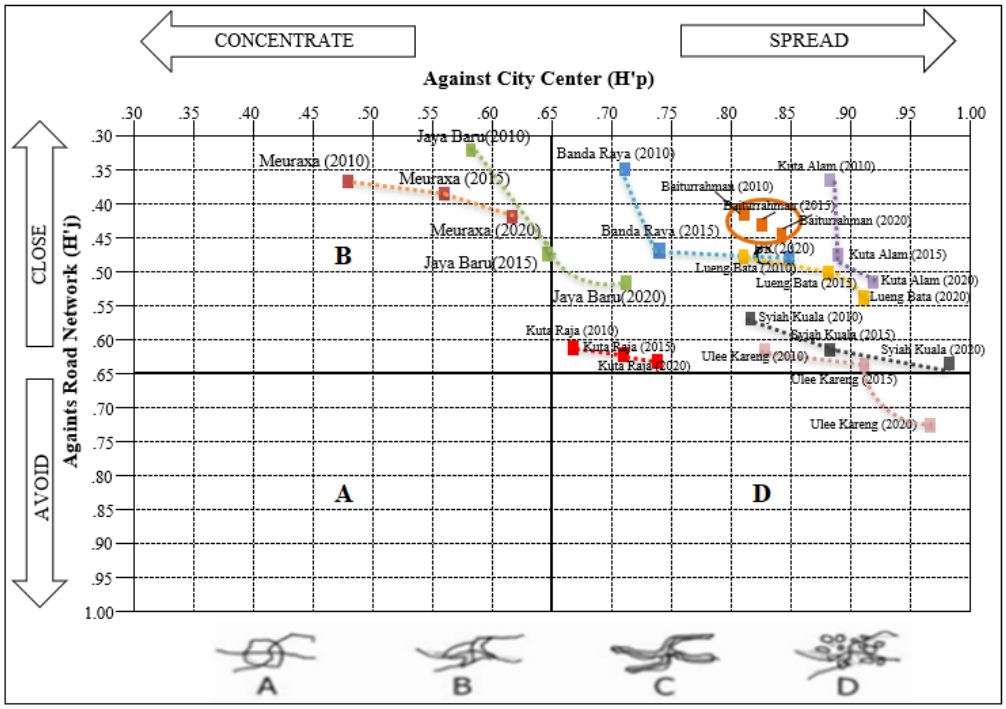

Figure 5. Matrix of relative entropy

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Figure 6 identifies the transmission pattern of Banda Aceh City. Meuraxa sub-district in 2010 was in quadrant B (4.2) in 2015 it was in quadrant B (6.2) then in 2020 in quadrant B (7.3) which indicates that the spread of the city in Meuraxa sub-district is an elongated (radial) type of spread towards the road. Jaya Baru sub-district in 2010 was in quadrant B (6.1), in 2015 it was in quadrant B (7.4), indicating that urban sprawl in Jaya Baru sub-district is longitudinal (radial) to the road. Changes in the transmission pattern occurred in the 2020 period, namely in quadrant C (9.5), which indicates that urban transmission has changed to linear transmission on the road.

Banda Raya sub-district in the 2010-2020 period remained in quadrant C with a linear transmission pattern towards the road. However, the increase in H'p and H'j values caused a shift in the matrix. In 2010, the transmission pattern was in matrix C(9,1). This position shifted in 2015 to quadrant C(9,4) and then in the 2020 period to quadrant C(11,4).

The transmission in Baiturrahman Sub-district in 2010-2020 was in quadrant C (11,3), the position in this matrix did not change in the 2010-2020 period, but there was a shift in the composite index of relative entropy, which moved to the right and moved downward, indicating a more dispersed transmission pattern towards the city center and away from the road network.

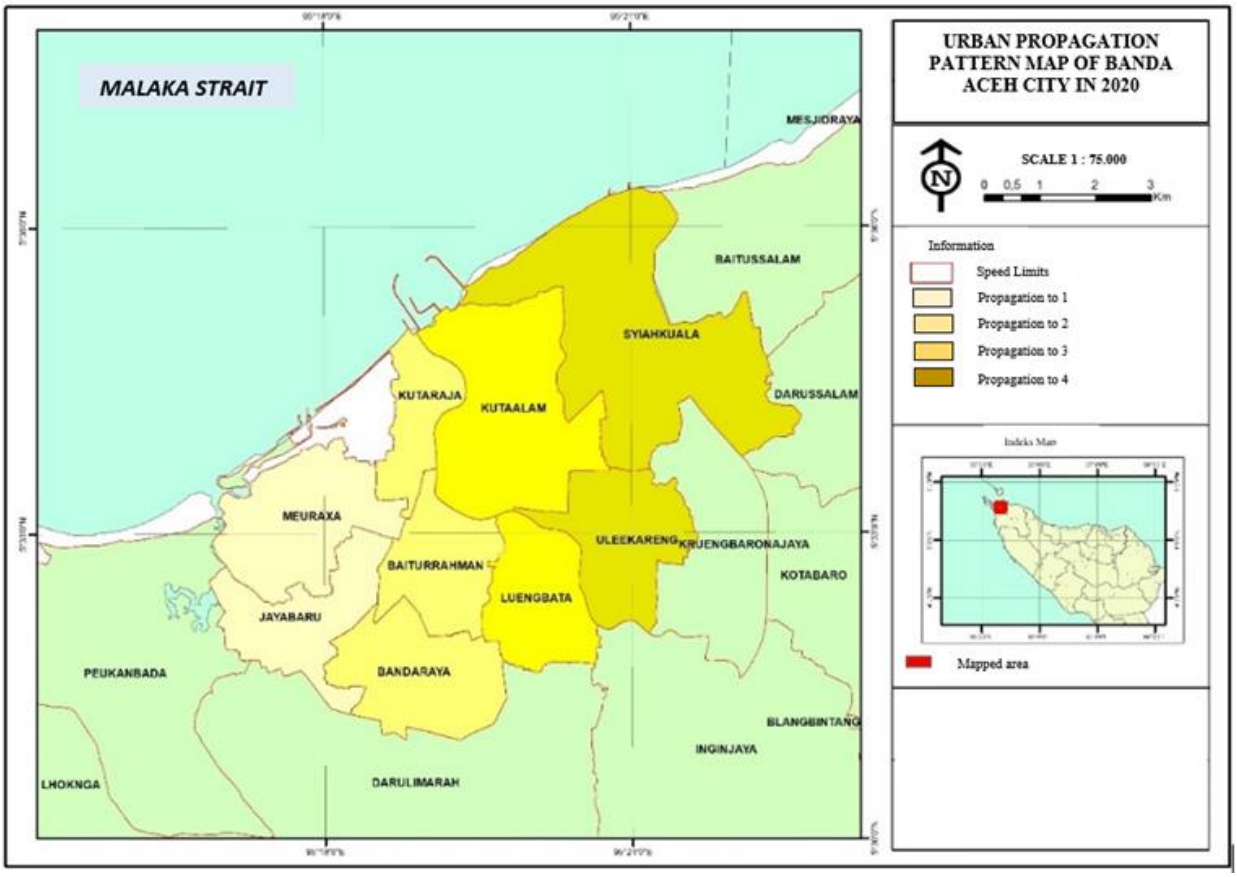

Figure 6. Urban Spatial Pattern Map of Banda Aceh City

The transmission pattern of Lueng Bata Sub-district in the 2010-2020 period remains in quadrant C with a linear transmission pattern towards the road. However, the increase in H'p and H'j values caused a shift in the matrix. In 2010, the transmission pattern was in matrix C(11,4). This position shifts to the right and downward in 2015 to quadrant C(12.4) and then in the 2020 period changes to quadrant C(13.5), indicating that in the 2015-2020 period, there is a shift in the composite index of relative entropy, which moves to the right and moves downward, indicating a more dispersed transmission pattern towards the city center and away from the road network.

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The transmission in Kuta Alam Sub-district for the 2010-2020 period remains in quadrant C with a linear transmission pattern towards the road. However, the increase in H'p and H'j values causes a shift in the matrix. In 2010, the transmission pattern was in matrix C(12,2). In 2015, it became quadrant C(12,4). This position shifts downwards away from the road network, while in 2020, it becomes quadrant C(13,5).

The transmission pattern in Kuta Raja Sub-district for the 2010 period is in quadrant C (8,7), and for the 2015-2020 period, it is in quadrant C (9,7). It shows that the position of the matrix is very close to the boundary of quadrant D, so it has the potential to experience changes in the transmission pattern in quadrant D, namely the scattered transmission pattern towards the city center and road network.

The transmission pattern of Syiah Kuala Sub-district in the 2010-2020 period remains in quadrant C with a linear transmission pattern towards the road. However, the increase in H'p and H'j values caused a shift in the matrix. In 2010, the spreading pattern was in matrix C(11,6); this position shifted to the right and downward in 2015 to quadrant C(12,7), and then in the 2020 period, it changed to quadrant C(14,7). This indicates that in the 2015-2020 period, there was a shift in the composite index of relative entropy, which moved to the right and downward, indicating a more dispersed spreading pattern towards the city center and away from the road network.

The transmission pattern of Ulee Kareng Subdistrict in 2010-2015 remained in quadrant C. In 2010, the transmission pattern was in quadrant C (11.7), while in 2015, it became quadrant C (13.7), indicating a linear transmission pattern towards the road. Changes in the pattern of development occurred in 2020, namely in quadrant D(13.9), which shows the change in the leapfrog development pattern. The illustration of Banda Aceh City that sprawl from 2010 to 2020 where the sprawl is further away from the road network with more low-density built-up areas.

Discussions

From the calculation of the identification of urban sprawl patterns in each sub-district in Banda Aceh City by integrating the Shannon'n Entropy model, it can be concluded that the resulting relative entropy index value towards the city center and road network increases every period. This tendency explains the increasingly random urban pattern spreading away from the city center and road network when looking at the results of previous research conducted by Arief *et al.* (2016), where the value of the relative entropy index of the road network in *Bodetabek* is always smaller when compared to the city center which explains that urban sprawl still follows the road network pattern (Linear).

The development of built-up areas in Banda Aceh City tends to lead to the East. This is mostly due to landform factors that are very suitable for use as built-up areas. So, the development of built-up areas towards the East is faster than the pattern towards the West, North, and South. It can be seen from the relative entropy matrix that the Syiah Kuala and *Ulee Kareng* sub-districts have urban sprawl patterns spread from the city center and away from the road network. It also has been proven by previous research conducted by Fadhly *et al.* (2016), where the results showed that the occurrence of urban sprawl to the south of Banda Aceh city was 33% and the East of Banda Aceh city was 44% of the total population of Banda Aceh city in 2013.

The urban spreading pattern in Banda Raya, Baiturrahman, Kuta Raja, Kuta Alam, Lueng Bata, and Syiah Kuala sub-districts is linear. However, there is an increase in the value of H'p and H'j, which causes a shift in the matrix to spread towards the city center and away from the road network. In the Ulee Kareng sub-district, there is a change in the pattern of transmission in the year (2020) in quadrant D, namely the leapfrog development pattern from the previous years, namely 2010 and 2015 in quadrant C with a linear transmission pattern.

The urban sprawl pattern of Banda Aceh City is generally linear towards the leading road network that connects sub-districts in Banda Aceh City. Measurement of the relative entropy index towards the road network is lower than towards the city center, further confirming that the urban sprawl pattern is linear towards the leading road network. Two sub-districts are in the elongated type of transmission pattern (Radial): Meuraxa Sub-district and Jaya Baru Sub-district. However, in the Jaya Baru Sub-district, there is a change in the transmission pattern in 2020, namely a linear transmission pattern. Based on the reverence of the Regional Spatial Plan Document (RTRW) of Banda Aceh City in 2009-2029, Banda Aceh City is included in the pattern of urban development of the concentric radial type, while the results of calculations using the Shannon 'Entropy Model obtained the results of the urban development pattern of Banda Aceh City are elongated radial type and Leafrog, while the pattern of urban areas tends to the Heterogeneous type.

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References

Arief, P. 2016. *Pola Spasial Penjalaran Perkotaan BODETABEK: Studi Aplikasi Model Shannon'n Entropy, Departemen Geografi, Program studi Ilmu Lingkungan, Universitas Indonesia*

Budiharjo, Eko. 2009. Housing and Settlements in Indonesia. Bandung: Alumni.

Budiharjo, Eko and Sudanti Hardjohubojo. 2009. Insight Environment in Urban Development. London: Alumni.

Budiharjo, Eko. 2009. Setup Room and Urban Development. London: Alumni.

Darman, Edy. 2009. Space Public in City Architecture. Semarang. Body Publisher University Diponegoro.

Djojodipuro, Marsudi. 1992. Theory Location. Jakarta. Institution Publisher Faculty UI Economics.

Fadly, Noer. 2016. The Relationship between Spatial Structure and Travel Generation in Banda Aceh. The 19th International Symposium of FSTPT, Islamic University of Indonesia.

Frankel A., & Ashkenazi M. (2008). *Measuring Urban sprawl; How Can We Deal With It? In Environment and Planning B*: Planning and Design, Vol. 35 Issue (1).

Grigg Neil S. 1987. Infrastructure Engineering and Management. Printed in the United States of America. John & Sons, Inc.

Hairudin, Safrin. 2008. Study Development Spatial Region on Region Center Development. Semarang. Undip MPWK Library.

Jayadinata, Johara. T. 1999. Internal Land Use Planning country side Urban and Territory. Bandung. ITB Publisher.

Koestor, Raldi Hendro. et al. 2001. Dimensions space City: Theory and case. Jakarta. Publisher Indonesian University.

Kuswartojo, Tjuk. et al. 2005. Housing and Settlements in Indonesia. ITB Publisher, Bandung.

Melinda, D. 2020. *Manfaat Sosial dan Manfaat Ekonomi Masyarakat Dari Ruang Terbuka Hijau Blang Padang Kota Banda Aceh,* Jurnal Ilmiah Mahasiswa Ekonomi Pembangunan, Fakultas Ekonomi dan Bisnis, Universitas Syiah Kuala.

Mishra Sabyasachee, Ye Xin, Ducca Fred, & Jan Knaap Gerrit. 2011. *A functional integrated land use-transportation model for analyzing transportation impacts in the Maryland-Washington*, DC Region, Sustainability: Science, Practice, & Policy Fall 2011 | Volume 7 | Issue 2.

Muhadjir, H. Noeng. 1996. Methodology Study Qualitative. Yogyakarta. Rakes Sarasin.

Musra, Factors _ Determinant Delay in Road Construction, Publishing Bureau Planology Undip , 2014.

Yeh, A.G.O and Li, X. (2001). *Measurement And Monitoring Of Urban sprawl In A Rapidly Growing Region Using Entropy*. Photogrametric Engineering & Remote Sensing. Vol 67 No1 Januari 2001.