BAREKENG: Journal of Mathematics and Its Applications
December 2024 Volume 18 Issue 4 Page 2319–2328
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol18iss4pp2319-2328

PREDICTING LAND USE CHANGES USING MARKOV CHAIN ANALYSIS AND HIERARCHICAL ANALYSIS OF PUBLIC SERVICE CENTERS IN BANDA ACEH CITY

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Article History:

Received: 4th March 2024
Revised: 22nd May 2024
Accepted: 18th July 2024
Published: 14th October 2024

Keywords:

Hierarchical;
Public Service Center;
Markov Chain;
Scalogram;
Centrality Index;
Gravity.

ABSTRACT

The city of Banda Aceh, as the center of development in its region, is faced with a series of complex problems, one of which is the lack of optimal distribution of public service centers throughout the city. Banda Aceh City Central Statistics Agency (BPS) documents 2012-2022 and Banda Aceh City Spatial Plan (RTRW) documents 2009-2029 related to this research. Data in tabulated and descriptive form includes geographical conditions of the research area, land use area, types of facilities and their numbers, population, and distance between areas, and maps related to the research. This study aims to see land use conditions using the markov chain method and provide an overview of the public service center system of Banda Aceh City using the Scalogram method, centrality index, and gravity. Based on Markov chain analysis, land use predictions indicate that residential areas, offices and trade, tourism, worship, and sports facilities will continue to increase, while water bodies, green open spaces (RTH), and non-green open spaces (RTNH) will continue to decline. Predictions until 2039 show that conditions have begun to stabilize. Scalogram analysis takes into account hierarchy based on the type of facilities available, centrality index that calculates hierarchy based on many available facilities, and gravitational interaction that takes into account the strength of interaction between sub-districts shows that Kuta Alam District has the potential to become a major service center in Banda Aceh City. This sub-district has the most complete facilities, supported by the highest interaction value.

How to cite this article:

M. H. Rahmaniar, S. Rusdiana and Zahnur., "PREDICTING LAND USE CHANGES USING MARKOV CHAIN ANALYSIS AND HIERARCHICAL ANALYSIS OF PUBLIC SERVICE CENTERS IN BANDA ACEH CITY," *BAREKENG: J. Math. & App.*, vol. 18, iss. 4, pp. 2319-2328, December, 2024.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*
Research Article · Open Access

1. INTRODUCTION

The issue of disparity and equitable development in a region is one of the key national and local concerns. Efforts to reduce the gap between regions are the main focus of the national development agenda. This disparity refers to the differences between various areas that arise due to uneven development in different regions [1][2]. This issue can be addressed by optimizing the service centers located in a particular region [3][4]. The regional disparity also influences the dynamics of human development in Indonesia. The vast territory of Indonesia and uneven development can lead to disparities. The city of Banda Aceh, which serves as a center for government services, trade, services, education, health, and religion, is located in one of the vast regions of Indonesia. This city serves as a primary hub of activities in Aceh Province, encompassing areas of development such as Sabang City, Aceh Besar Regency, Pidie Regency, and Pidie Jaya Regency [5], [6]. Banda Aceh City already has policies and strategies for developing spatial structures so that there are no gaps between regions in Banda Aceh City [7].

Public Service Centers play a crucial role in providing services to the community, particularly in the management of administrative services and public interests within a region. The operational efficiency of public service centers is essential to ensure optimal service delivery to the community. One approach that can be used to enhance efficiency and service quality is through mathematical analysis. One methodological approach used to improve comfort in Majene City is the Markov Chain model [8]. The Markov Chain model can be applied to address financial issues, climate change, earthquake analysis, and land use planning [9]. Land use prediction and analysis of Public Service Centers in Banda Aceh also employ methods such as scalogram, centrality index, and gravity model [10]. Several studies have utilized scalogram, centrality index, and gravity model methodologies to analyze the suitability of Public Service Centers in spatial plans in several cities [11]-[15]. The scalogram method and centrality index are applied to assess the role of each district based on its ability to provide services to the community [16]-[18]. Furthermore, the gravity model is also useful for understanding the dimension and distance between two locations, such as service centers and their surrounding environments, as well as how far the influence of a service center affects and interacts with its surrounding areas [19]-[21].

Based on the above references, the researcher is interested in conducting a mathematical model analysis of Public Service Centers in Banda Aceh City. This hierarchical analysis is crucial for understanding future land use trends in Banda Aceh City. By predicting land use changes, we can better assess the optimal locations for public service centers to serve the community effectively and equitably. This integrated approach ensures a thorough evaluation and development of public service centers, addressing both current needs and future growth trends. The results of these methods can significantly contribute to the evaluation and development of Public Service Centers in Banda Aceh City. This research advances the field by using the Markov Chain approach to forecast land use changes in Banda Aceh City over future periods until equilibrium is reached, while also assessing the spatial characteristics of the city for optimal placement of public service centers through the utilization of the scalogram method, centrality index method, and gravity model method.

2. RESEARCH METHODS

This research significantly advances the field by employing the Markov Chain approach to forecast land use changes in Banda Aceh City over future periods until equilibrium. Concurrently, it assesses the spatial characteristics of the city for optimal placement of public service centers using the scalogram method, centrality index method, and gravity model. This integrated approach ensures a thorough evaluation and development of public service centers, addressing both current needs and future growth trends. The scalogram method evaluates the hierarchical structure and service provision capacity of different districts. The centrality index method identifies the central areas with the highest accessibility and service provision. The gravity model helps understand the spatial interactions between service centers and their surrounding areas. Integrating these methods provides a comprehensive understanding of the optimal placement and role of public service centers in Banda Aceh City.

This research was conducted based on the flowchart in **Figure 1** and data collection from nine districts in Banda Aceh City, meticulously gathered. The districts included in the study are: Meuraxa District, Jaya Baru District, Banda Raya District, Baiturrahman District, Lueng Bata District, Kuta Alam District, Kuta Raja District, Syiah Kuala District, and Ulee Kareng District. The data collection process involved various aspects, such as the geographical conditions of the research area, land use area, types and quantities of facilities, population size, and distances between regions, obtained from the years 2011-2022. Subsequently, the data were analyzed using four prepared methods: the Markov Chain model, scalogram analysis, centrality index analysis, and gravitational analysis. All these analysis processes were supported by the use of software such as Microsoft Excel and MATLAB to ensure the accuracy and reliability of the results. Thus, this research aims to provide a better understanding of the dynamics of urban areas in the context of Banda Aceh City and to offer clearer insights into the potential future developments.

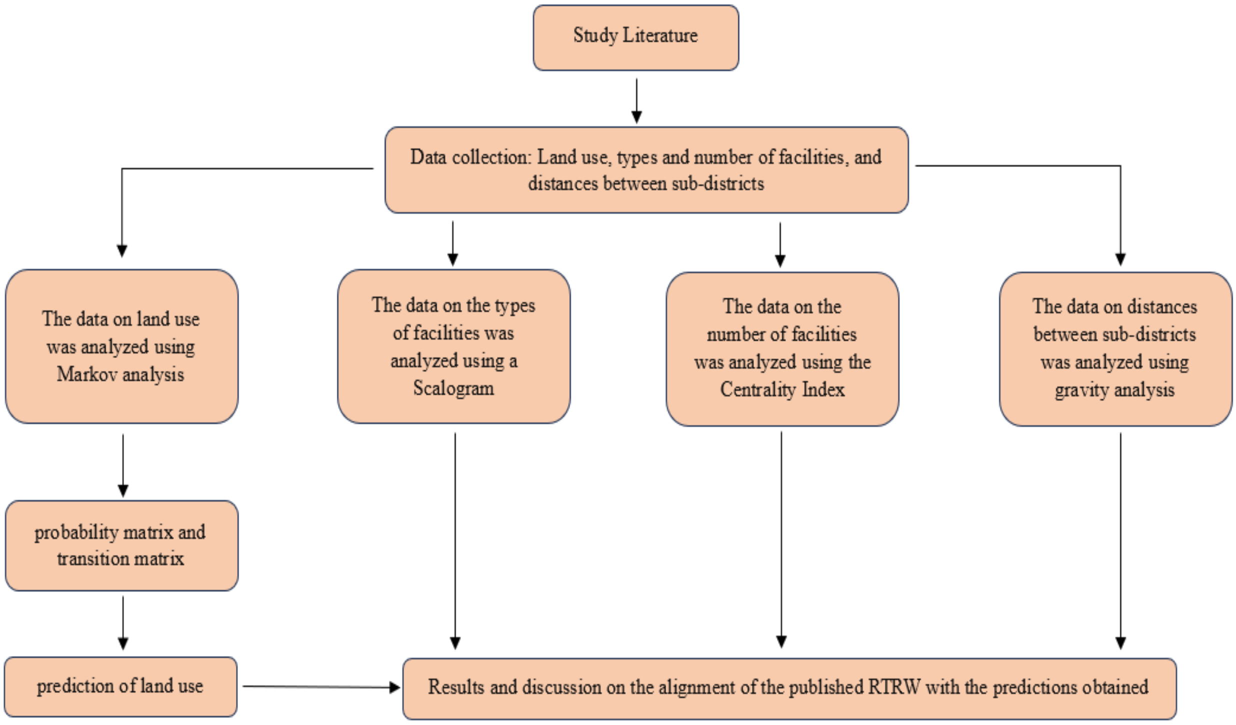

Figure 1. Research Flow Diagram

2.1 Markov Chain Method

Mathematical analysis is widely employed within the context of Markov chains to scrutinize and comprehend the characteristics of such chains. Various mathematical analysis aspects associated with Markov chains include transition matrices, which elucidate the probability of transitioning from one state to another. Mathematical analysis techniques are utilized to compute and manipulate these transition matrices. The analytical process commences with the utilization of the Markov Chain model to prognosticate land use patterns in Banda Aceh City for forthcoming periods by classifying data based on its utility into five distinct categories. The Markov process is a stochastic process denoted as $\{X_t, t = 0,1,2, \dots\}$ where the conceivable values of X_t are finite or computable. If $\boldsymbol{X_t = i}$, then the process is considered to be in state-i. Subsequently, when the process resides in state-i it undergoes transition to state-j with probability denoted as $\boldsymbol{P_{ij}}$, where $\boldsymbol{P_{ij}}$ which remains independent of t. In other words, if:

$$\boldsymbol{P\{X_{t+1} = j |\ X_t = i,\ X_{t-1} = i_{t-1},\ \cdots\ ,\ X_1 = i_1,\ X_0 = i_0\}} \\ \boldsymbol{P\{X_{t+1} = j | X_t = i\} = P_{ij}} \quad (1)$$

For all of t states $\boldsymbol{i_0, i_1, \cdots, i_{t-1}, i, j}$,, and all of $\boldsymbol{t \geq 0}$ thus, the stochastic process is known as a Stationary Markov chain. From Equation (1) it can be interpreted that in the context of a Markov chain, we can comprehend the probability of the next event $\boldsymbol{X_{t+1}}$, depends only on the current event $\boldsymbol{X_t}$. This is also known as the Markovian property. This Markovian characteristic indicates that the probability of future events depends on the current state, without considering the history of previous events. The state space in a Markov chain is represented by non-negative integers $\boldsymbol{X_t = i}$, states that $\boldsymbol{X_t}$ located in state t. In the context of selecting states in a Markov chain related to land use change (increasing state, steady state, and decreasing state), the selection steps of the initial state can be guided by the characteristics of historical changes in land use. **Equation (2)** is a system of linear equations that describes the equilibrium condition of the stationary distribution.

$$(\pi_1 \quad \pi_2 \quad \pi_3) = (\pi_1 \quad \pi_2 \quad \pi_3)\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix} \tag{2}$$

This equation arises from the condition that the sum of probabilities for each state must equal 1 (equilibrium condition). Therefore, each row represents one state, and each equation states that the sum of transition probabilities out of that state must equal the sum of transition probabilities into it.

2.2 Scalogram Method

The scalogram analysis is subsequently emploted to categorize districts based on their existing facilities, establishing a hierarchical order where the smallest order denotes the highest hierarchy. The presence of various facilities tends to draw visitors from neighboring regions towards a particular area. Consequently, the abundance and diversity of public amenities within a district correlate positively with its hierarchical position within the scalogram [21]. Scalogram analysis serves as a tool for discerning districts with the potential to function as focal points for growth. Those districts exhibiting the most extensive array of facilities are discerned as prime candidates for designation as central service hubs [22][23]. The equation of *coefficient of reproducibility* (COR) using **Equation (3)** is necessary to know that the scalogram analysis is worth using, if the scale is in the range of 0.9 to 1, indicating that the service center in a region has a significant impact.

$$\mathrm{COR} = 1 - \frac{\sum e}{N \times K} \tag{3}$$

Where

e : number of errors (difference between elements of the scalogram matrix and the ideal matrix)
N : number of subjects/regions studied
K : number of objects/facilities studied

In the scalogram model, hierarchy is solely determined based on the quantity of facilities available in a given area. This results in regions with numerous facilities being ranked higher, even if their diversity and level of service provision are limited. Each region is weighted by assigning a weight of 1 if a particular type of facility is present and 0 if it is absent.

2.3 Centrality Index

Furthermore, the value of the centrality index is studied to determine the role of each sub-district as a service center in urban areas. This process is very dependent on the frequency of facilities in a sub-district. The higher the frequency, the greater the value of centrality. After the scalogram analysis is performed, the next step is the principle of facility weighting calculated by dividing the combined centrality value by the total facilities in all service centers. The number and completeness of facilities in an area are indicators of the development of the region [24]. The combined centrality value reaches 100 because it represents the highest value in percentage. The service centers are then grouped into intervals based on the value of centrality using the following equation:

$$C = \frac{TS}{T}$$

$$C = \frac{100}{T} \tag{4}$$

Where

TS : The value of combined centrality
C : Weight of the functional attributes of a facility
T : Total number of facility assets/attributes in the system

After the weight of each facility is obtained, the centrality index of each sub-district is calculated with the formula:

$$\boldsymbol{IS} = \boldsymbol{C} \times \boldsymbol{F} \tag{5}$$

Where

IS : Centrality index
F : Number of each facility in each region
C : Weight of the functional attributes of a facility

The Struges method is used to determine the order of service centers. The formula for determining the number of classes of each region as a service hub is as follows:

$$\boldsymbol{k = 1 + 3.3 \log n} \tag{6}$$

Where,

k : The number of classes
n : The number of regions

Next, to determine the size of the class intervals, the method involves:

$$\boldsymbol{I = \frac{A - B}{k}} \tag{7}$$

Where

A : Highest number of facilities
B : Lowest number of facilities
k : The number of classes

2.4 Gravitational Interaction Method

Finally, gravity analysis is used to assess the relationship between sub-districts. The high comparative value in this analysis indicates a strong linkage between the two sub-districts, indicating potential as a service center. The gravity method is used to determine the dimensions and distance between two locations, namely the service center and the surrounding area, as well as the extent to which the area that is the service center affects and interacts with the surrounding area [17]. The first study on the gravitational model was conducted by Carey and Ravenstein in the 19th century. Findings from their research indicated that the migration of populations to a particular region is influenced by the population size in the origin region, the population size in the destination region, and the distance between the two regions. This aligns with Sir Isaac Newton's law of gravity, which states that "the gravitational force between two nearby masses is proportional to the product of their masses." From this research, the formula for the gravitational model is as follows.

$$\boldsymbol{F = G\frac{M_1 \times M_2}{r^2}} \tag{8}$$

The equation of the gravity model is changed to **Equation (9)** to calculate the interaction between sub-districts, as follows:

$$\boldsymbol{T_{12} = \frac{p_1 \times p_2}{(d_{12})^2}} \tag{9}$$

Where

F : The force of attraction between two objects
G : Earth's gravitational constant
$\boldsymbol{M_1}$: Mass of the first object
$\boldsymbol{M_2}$: The mass of the second object
r : distance between two objects

T_{12} : Tug-of-war between region 1 and region 2
p_1 : Many inhabitants in region 1
p_2 : Many inhabitants in region 2
d_{12} : Distance between regions 1 and 2

The greater attraction between two regions, more intense the interaction that occurs between them. The higher the level of interaction of a region, the higher its position in the territory hierarchy [13].

3. RESULTS AND DISCUSSION

3.1 Markov Chain Analysis in Forecasting Land Use

The use of Markov chain analysis to forecast future land use patterns in Banda Aceh City. The forecasting process begins with identifying and establishing the initial state of the system, reflecting the current situation of land use. The next step is to identify possible changes through a transition table, which describes the potential change from one condition to another in a given period of time. In this case, the conditions or "states" used include up (S1), fixed (S2), and down (S3). The initial step in predicting land use changes is to create a probability matrix by observing the state changes each year from 2011-2022. Here is one of the obtained transition probability matrices for changes in residential land use.

$$P = \begin{pmatrix} \frac{1}{2} & 0 & \frac{1}{2} \\ 1 & 0 & 0 \\ 0 & \frac{2}{3} & \frac{1}{3} \end{pmatrix}$$

After obtaining the probability matrix, the state probability vector for the initial state or the year 2022 is multiplied by the probability matrix to predict land use for the year 2023.

$$\begin{pmatrix} \frac{2}{5} & \frac{3}{10} & \frac{3}{10} \end{pmatrix} \begin{pmatrix} \frac{1}{2} & 0 & \frac{1}{2} \\ 1 & 0 & 0 \\ 0 & \frac{2}{3} & \frac{1}{3} \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{5} & \frac{3}{10} \end{pmatrix}$$

This process is repeated continuously until the results obtained show no further changes. The final step is to multiply the results from the initial state vector and the transition probability matrix by the total land area of Banda Aceh City to prediction land use in Banda Aceh City for the coming year. The results of the prediction land area of the future period are obtained as follows:

Table 1. Land area use prediction of the future period

Year	Land area use prediction (hectares)				
	Settlement	Office and Trade	Tourism, Worship, and Sports	Waters	RTH, RTNH, and More
2023	1771.92	430.35	45.15	344.87	1854.07
2024	1712.86	425.57	46.19	356.36	2039.48
2025	1683.32	427.16	46.32	358.28	2132.18
2026	1707.93	426.76	46.31	356.04	2054.93
2027	1713.68	426.87	46.31	356.95	2036.90
2028	1704.52	426.84	46.31	356.74	2065.66
2029	1704.13	426.85	46.31	356.74	2066.87
2030	1707.25	426.85	46.31	356.77	2057.09
2031	1706.86	426.85	46.31	356.75	2058.31
2032	1705.88	426.85	46.31	356.76	2061.37
2033	1706.17	426.85	46.31	356.76	2060.45
2034	1706.45	426.85	46.31	356.76	2059.58

Year	Land area use prediction (hectares)				
	Settlement	Office and Trade	Tourism, Worship, and Sports	Waters	RTH, RTNH, and More
2035	1706.31	426.85	46.31	356.76	2060.04
2036	1706.24	426.85	46.31	356.76	2060.25
2037	1706.30	426.85	46.31	356.76	2060.06
2038	1706.31	426.85	46.31	356.76	2060.02
2039	1706.29	426.85	46.31	356.76	2060.09
2040	1706.29	426.85	46.31	356.76	2060.09

Based on **Table 1**, it can be observed that in the year 2039, a steady state condition begins to occur in Banda Aceh City. This stability is achieved because when the predicted state for 2039 is multiplied by the transition probability matrix, it consistently yields the same result. During that year, the prediction land use indicates that the areas of residential, office, commercial, tourism, religious, sports, water bodies, as well as green open space (RTH) and non-green open space (RTNH) have reached stability. A stable state is achieved when the state distribution vector remains unchanged after repeated applications of the transition probability matrix. This is supported by literature indicating that the state distribution in a Markov chain model will remain constant when the system reaches a steady state **[8]**. The projected land use areas are as follows: residential area covering 1706.29 ha, office and commercial area covering 426.85 ha, tourism, religious, and sports area covering 46.31 ha, water bodies covering 356.76 ha, and RTH and RTNH were covering 2060.09 ha. **Figure 2** illustrates the land use condition in Banda Aceh City when it reaches a stable state, converted into percentages to show the changes in land use expected in the coming years.

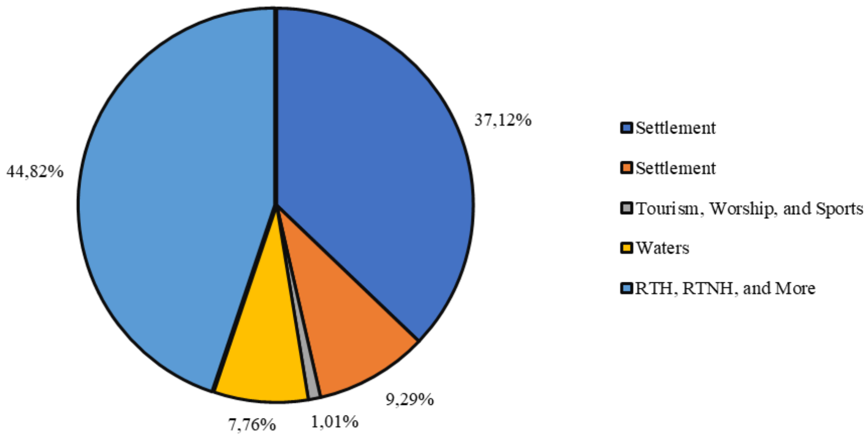

Figure 2. Land Use During Steady State Conditions

3.2 Hierarchical Analysis of Public Service Centers Using Scalogram and Centrality Index

The scalogram and centrality index analyses are conducted by calculating the quantity and types of facilities available in a given area. The capability of a region to provide services to its residents is assessed based on the diversity of facilities available. In other words, the evaluation of public service effectiveness is meticulously performed by considering the availability and types of facilities in the area. This research encompasses 26 objects comprising educational, religious, healthcare, economic facilities, and 9 subjects in conducting scalogram and centrality index analyses. The results of these calculations are compiled in the following table:

Table 2. Results of the Scalogram Method and the Centrality Index

District	Scalogram	Centrality Index	RTRW
Kuta Alam	Herarchy I	Herarchy I	Herarchy III
Syiah Kuala	Herarchy II	Herarchy III	Herarchy III

District	Scalogram	Centrality Index	RTRW
Baiturrahman	Herarchy III	Herarchy IV	Herarchy I
Banda Raya	Herarchy III	Herarchy IV	Herarchy II
Kuta Raja	Herarchy III	Herarchy IV	Herarchy IV
Lueng Bata	Herarchy III	Herarchy IV	Herarchy III
Jaya Baru	Herarchy III	Herarchy IV	Herarchy IV
Ulee Kareng	Herarchy III	Herarchy IV	Herarchy II
Meuraxa	Herarchy IV	Herarchy IV	Herarchy III

The analysis results indicate that public service centers in Banda Aceh City can be categorized into four tiers. The district occupying the top rank in the hierarchy, as the primary public service center, is Kuta Alam. This district has the most comprehensive and adequate facilities, according to the scalogram and centrality index analysis, which place it at the top of the hierarchy among other districts. These findings indicate changes in urban service centers as predicted by the RTRW compared to the current conditions.

3.3 Gravity Analysis

Gravitational analysis is utilized to assess the strength of the relationship between public service centres and their surrounding areas, taking into account variables such as population size and the distance between districts. The interrelations among regions can be recognized as gravitational interactions because they exert an attractive force influencing the movement of goods and the activities of the population in each area, both in the context of social and economic relationships. Through calculations performed using MATLAB to quantify the magnitude of interactions in gravitational analysis, employing equations derived from research conducted by Carey and Raven stein in the 19th century, the following results were obtained:

Table 3. Results of the Sub-District Gravity Interaction Model in Banda Aceh City

District	Meuraxa	Jaya Baru	Banda Raya	Baitur-rahman	Lueng Bata	Kuta Alam	Kuta Raja	Syiah Kuala	Ulee Kareng
Meuraxa	0.00	38,194,138.58	28,908,476.24	88,856,902.15	24,120,783.70	49,388,359.48	16,176,637.98	18,317,864.93	21,690,356.94
Jaya Baru	38,194,138.58	0.00	63,776,076.95	54,650,182.12	26,044,955.28	31,654,447.03	10,262,554.52	12,881,185.56	14,475,203.51
Banda Raya	28,908,476.24	63,776,076.95	0.00	117,232,278.19	248,591,798.44	55,001,602.27	10,687,968.94	15,418,873.00	21,069,235.85
Baitur-rahman	88,856,902.15	54,650,182.12	117,232,278.19	0.00	181,682,914.29	207,433,831.07	39,911,631.02	39,911,631.02	75,377,657.14
Lueng Bata	24,120,783.70	26,044,955.28	248,591,798.44	181,682,914.29	0.00	116,020,786.00	11,855,142.94	23,358,722.03	37,187,230.94
Kuta Alam	49,388,359.48	31,654,447.03	55,001,602.27	207,433,831.07	116,020,786.00	0.00	36,458,030.34	181,514,216.96	227,482,863.89
Kuta Raja	16,176,637.98	10,262,554.52	10,687,968.94	39,911,631.02	11,855,142.94	36,458,030.34	0.00	15,604,466.14	20,094,945.68
Syiah Kuala	18,317,864.93	12,881,185.56	15,418,873.00	39,911,631.02	23,358,722.03	181,514,216.96	15,604,466.14	0.00	104,120,594.44

District	Meuraxa	Jaya Baru	Banda Raya	Baitur-rahman	Lueng Bata	Kuta Alam	Kuta Raja	Syiah Kuala	Ulee Kareng
Ulee Kareng	21,690,356.94	14,475,203.51	21,069,235.85	75,377,657.14	37,187,230.94	227,482,863.89	20,094,945.68	104,120,594.44	0.00
Total Interaction	285,653,520.00	251,938,743.55	560,686,309.88	805,057,027.00	668,862,333.62	904,954,137.04	161,051,377.56	411,127,554.08	521,498,088.39

Based on the MATLAB output results, gravitational interaction analysis reveals that the Kuta Alam district exhibits the highest interaction, reaching 904,954,137.04. This indicates a significant level of relationship between the eight districts, rendering it potentially a public service center. This interaction signifies a substantial inflow and outflow of population, possibly attributed to the comprehensive infrastructure and facilities in Kuta Alam. Furthermore, the most substantial interaction occurs between the Banda Raya and Lueng Bata districts, amounting to 248,591,798.44. This is likely due to their geographical proximity and the comprehensive facilities in Lueng Bata, encouraging significant interaction of Banda Raya residents with Lueng Bata.

4. CONCLUSIONS

Based on the results of the study, it can be concluded that:

1. Markov chain methods for residential land use, office and trade, tourism, worship and sports continue to increase, but water areas, RTH, RTNH and others continue to decline. Predictions for the future in 2039 will not be a significant change in the use of the land.
2. Scalogram analysis that calculates herarchy based on the type of facilities available, centrality index that calculates herarchy based on many available facilities, and gravitational interaction that takes into account the strength of interaction between sub-districts, obtained sub-district that has the potential to become a service center in Banda Aceh City is Kuta Alam District, because it has the most and most complete facilities among other sub-districts.
3. Kuta Alam District also has the potential to develop which is supported by the highest interaction value to Kuta Alam District. Based on the RTRW, Banda Aceh City in 2009-2029 has undergone changes in accordance with the dynamic development of the city.
4. Limitation of this study is that external factors such as natural disasters can affect predictions or forecasts regarding land use and the placement of public service centers, potentially causing deviations from the predictions made for the current year.

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