Geographica: Science and Education Journal
GSEJ
Website: http://usnsj.id/index.php/geographica
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INTEGRATION OF CELLULAR AUTOMATA - ARTIFICIAL NEURAL NETWORK TO PREDICT THE PATTERN OF LAND CHANGE INTO RESIDENTIAL AREAS ON REMPANG ISLAND

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ARTICLE INFO

ISSN: 2716-4837
Vol. 7, No. 2, December 2025
URL: http://usnsj.id/index.php/geographica

Suggestion for the Citation and Bibliography
Citation in Text: Siregar, R. Z., & Anurogo, W. (2025)
Bibliography:
Siregar, R. Z., & Anurogo, W. (2025). Integration of Cellular Automata – Artificial Neural Network to Predict The Pattern of Land Change into Residental Areas on Rempang Island. *Geographica: Science & Education Journal, 7 (*2, December*)* 65-80.

Abstract

Unstable or fluctuating land use changes cause land degradation, reduced absorption capacity, and decreased land value. This study aims to predict land use on Rempang Island in 2029 using the Cellular Automata - Artificial Neural Network (CA-ANN) method to obtain a spatial overview of land use development, particularly settlements, so that the negative impacts of change can be anticipated early on. CA is applied to simulate the spatial dynamics of land use change, while Artificial Neural Network is used to analyze historical data (land use in 2014, 2019, and 2024) and driving factors in predicting future land use changes. The driving factors used are slope, zoning, and disaster risk. Land use change modeling was carried out using the MOLUSCE plugin in QGIS software. The results of the study show that land use change in 2029 will experience a decrease in vegetation area of 5,987.15 hectares and open land of 7,373.78 hectares. Meanwhile, the area of settlements and water bodies is expected to increase, with the area of settlements increasing to 1,932.32 hectares and the area of water bodies to 170.55 hectares. Predictive modeling of land use on Rempang Island in 2029 produced an accuracy value with a strong interpretation of 79.01%. The validation methods used in the MOLUSCE plugin include "% of correctness" to measure the accuracy of predictions in percentage terms, Kappa (overall) to assess the suitability of predictions with land use in 2024, Kappa (histogram) to evaluate the accuracy of land use category distribution, and Kappa (location) to assess the accuracy of predicted locations compared to actual locations. The novelty of this study compared to previous CA-ANN studies lies in the integration of disaster risk factors as key driving variables, which have not been widely explored in conventional CA-ANN models, as well as its specific application to small islands with land change dynamics influenced by large-scale development projects such as Rempang Eco City. Practically, these prediction results can support regional planning on Rempang Island by providing guidance for disaster risk mitigation and sustainable land *management in the context of national strategic project development involving population relocation and the preservation of traditional villages.*

Keywords: Land Use Change; Cellular Automata; Artificial Neural Network

A. Introduction

Land use encompasses all actions taken on land to support human life, whereby every development on the earth's surface affects its usage patterns. Land use change is a process whereby the function of land is permanently or temporarily altered from its original use to another use, often triggered by social, economic, or environmental shifts. This conversion of land use can have negative impacts, such as reduced water absorption, land degradation, and decreased productivity and land value, especially if it occurs in an uncontrolled or fluctuating manner. Demand for land for recreation, health, offices, trade, settlements, and services drives this conversion, while population growth increases the need for settlement land as a basic need closely related to the economy, industrialization, and development.

Location also influences the rate of land use change, with land near regional development centers, transportation, retail, office, and industrial areas having a higher risk of change. Batam City, as one of the largest industrial centers in Indonesia with 26 industrial estates and more than 1,306 companies employing around 169,000 workers, has experienced significant population growth as a result of this industrialization. Rempang Island, part of Batam City with two subdistricts (Rempang Cate and Sembulang), has been planned for development since 2001-2002 through the Rempang Eco City project, which was officially approved in 2004 by the Batam City Regional Representative Council. This project, which involves tourism, trade, and integrated industry, aims to increase Indonesia's competitiveness with Malaysia and Singapore, but it correlates positively with population growth and the need for residential land.

The urgency of this research lies in the potential negative impacts of the Rempang Eco City project on the environment and society, such as land degradation on small islands that are vulnerable to disaster risks (e.g., flooding or erosion), as well as the relocation of residents and the loss of traditional villages. A gap analysis shows that previous studies on land use change in Indonesia have often focused on large mainland areas or general urbanization, but have not explored the context of small islands with large-scale industrial projects and the integration of disaster risk as a driving factor (for example, a study in Sleman only considered roads and education without considering disaster risk). Therefore, this research is needed to provide a scientific basis for sustainable planning, anticipate socio-environmental conflicts, and support national policies.

Analyzing land use change requires temporal spatial data to monitor the location of change, visualize patterns, and estimate increases/decreases in land area, for which Geographic Information Systems (GIS) are effective for temporal studies. The Cellular Automata-Artificial Neural Network (CA-ANN) method was chosen for its ability to simulate complex, non-linear spatial dynamics through CA cellular rules that model local interactions, as well as the power of ANNs in capturing historical patterns from multi-variable data. Compared to Multi-Layer Perceptron (MLP)-Markov Chain, which relies on Markov transition probabilities but is less accurate for detailed spatial representation and non-linear interactions, CA-ANN is superior in integrating driving factors such as disaster risk for more precise predictions in small areas such as islands.

A literature review shows that CA-ANN has been used in several studies for land use prediction. For example, research in Sleman Regency used CA-ANN to predict land changes based on data from 2015 and 2017, with supporting variables such as roads and education, resulting in a Kappa accuracy of 0.956 and a suitability of 93.52%, indicating an increase in settlements of 287.342 ha and a decrease in rice fields of 291.93 ha. Another study in Wuhan City, China, applied CA-ANN to model urbanization using historical data from 2000-2010, resulting in an accuracy of 85% and emphasizing the method's ability to capture complex spatial patterns. However, these studies generally do not integrate disaster risk as a major factor, so this study fills that gap for island contexts such as Rempang.

The objectives of this study are to analyze land use change patterns on Rempang Island using the CA-ANN method, predict land use in 2029, and obtain a spatial overview of land development, particularly settlements, in order to anticipate the negative impacts of change at an early stage.

B. Methodology

1. Research Design

This research was conducted on Rempang Island with geographical coordinates 104°7'44.618“ E 0°56'8.636” N. Administratively, Rempang Island consists of two subdistricts, namely Rempang Cate and Sembulang. The research implementation stage began with downloading Landsat satellite image data, slope inclination, land use, and disaster risk. The satellite image data underwent geometric and radiometric correction, then the processed images were classified into land use categories using the Maximum Likelihood Classification algorithm. In the modeling process, several driving factors that could trigger change were needed, such as slope, land use, and disaster risk (landslides and floods). At the input stage, land use in 2014 was used as the initial data, land use in 2019 as the final data, and land use in 2024 for validation. Artificial Neural Network was used to simulate changes in land use, while Cellular Automata was used to predict land use in 2029. The output was a map predicting land use in 2029. The driving factors used in this study, namely slope inclination, land use, and disaster risk (landslides and flooding), were selected due to their high relevance to the geographical context of Rempang Island as a small island that is vulnerable to land changes due to topography and natural disaster threats, which often trigger land conversion into settlements or infrastructure. Slope gradient affects land stability and the likelihood of change, while disaster risk is directly related to the Rempang Eco City project, which could exacerbate vulnerability. Other factors such as population density or socio-economic aspects (e.g., per capita income or road accessibility) were not considered due to the limited spatial data available on this small island, as well as the research focus on physical variables and risks that are more dominant in triggering land change in remote areas. Although socio-economic factors such as population density can influence urbanization, this study prioritizes variables that can be accurately measured from satellite and GIS data to avoid excessive model complexity.

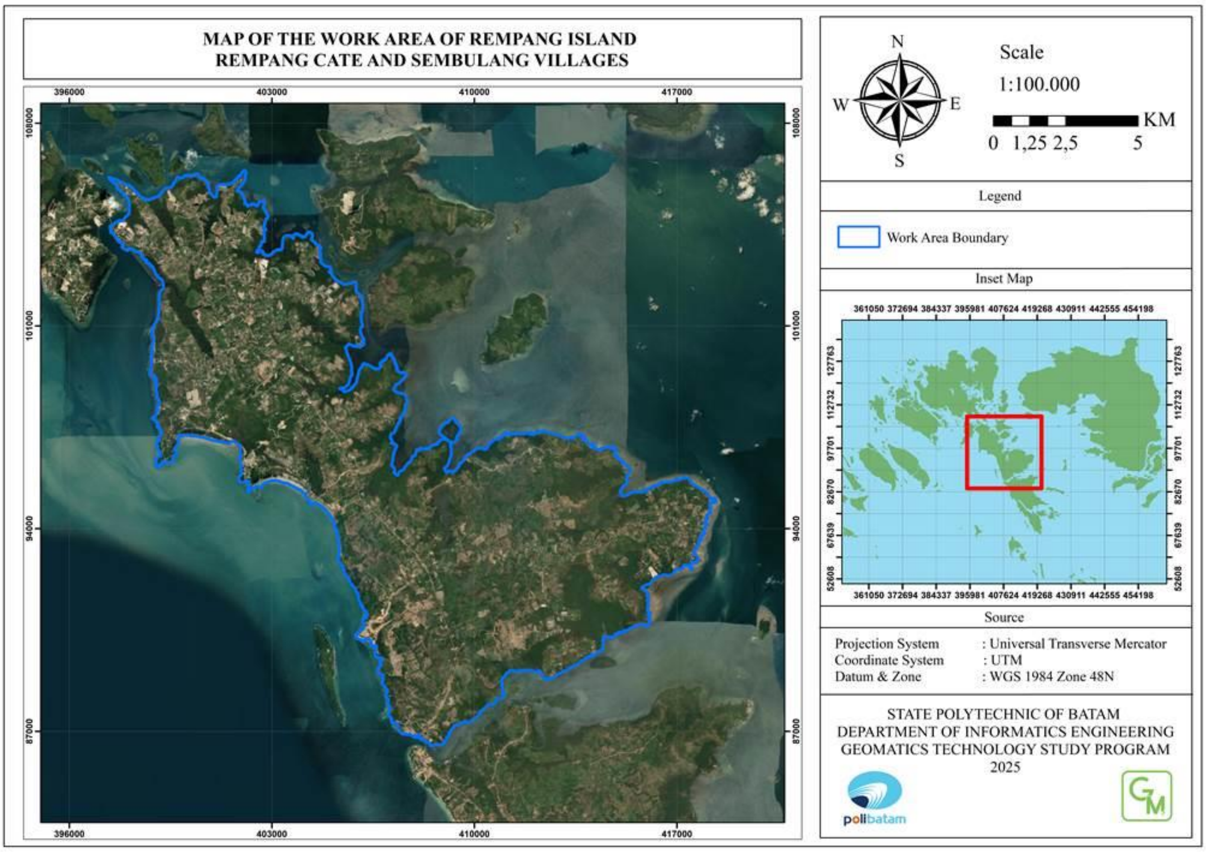

Figure 1. *This map shows the research location on Rempang Island, Batam City, with geographical coordinates 104°7'44.618“ E and 0°56'8.636” N, covering two main subdistricts, namely Rempang Cate and Sembulang.*

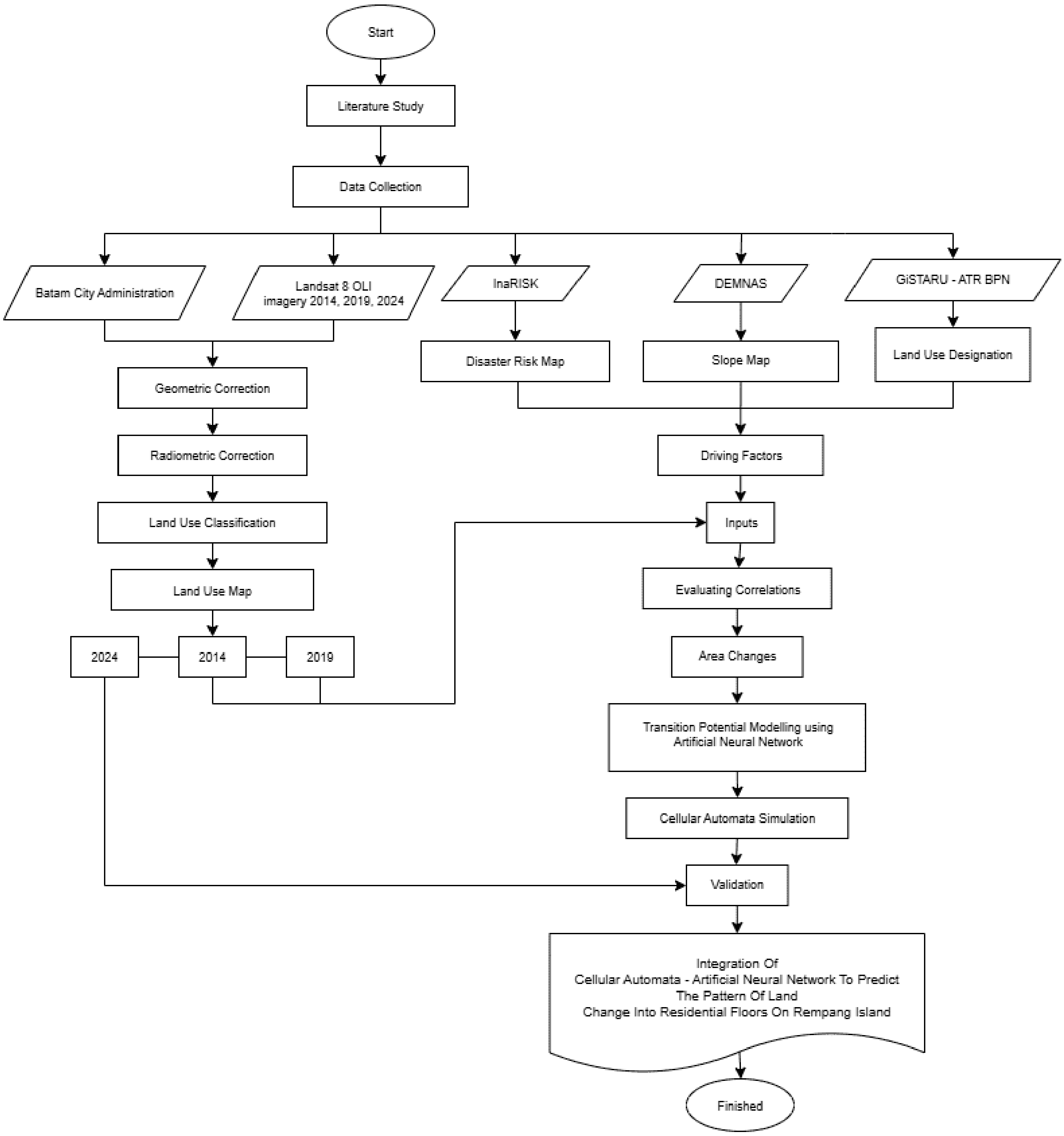

Figure 2. *This flowchart illustrates the research process, which includes data collection, processing, modeling, and validation to predict land use change on Rempang Island using the CA-ANN method.*

2. Instruments

This study uses a laptop as the main medium for collecting data, running data processing applications, and creating reports. Microsoft Word is used to compile research reports. ArcMap is used for data processing and map creation. ENVI is used for image correction and land use classification. Quantum GIS is used for Cellular Automata - Artificial Neural Network modeling. This study used instruments in the form of data collection via the internet with administrative data sources for the city of Batam from the Ina-Geoportal website (URL: https://www.ina-geoportal.go.id), Landsat image data from the USGS - EarthExplorer website (URL: https://earthexplorer.usgs.gov), slope data from the DEMNAS website (URL: https://tanahair.indonesia.go.id/portal-web/unduh/demnas), disaster risk data from the InaRISK website (URL: https://inarisk.bnpb.go.id), and spatial planning data for Batam City from the GiSTARU - ATR BPN website (URL: https://gistaru.atrbpn.go.id). The Landsat imagery used is Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) type, with a spatial resolution of 30 meters, enabling accurate land use classification.

3. Technique of Data Analysis

a. Layer Stacking

Layer stacking is the process of combining multiple bands in an image file by combining images from separate bands (band 1 - band 11) into a single file. The layer stacking process is carried out so that the bands used in this study have the same coordinate reference system and correspond to the research location. Layer stacking is important because it makes it easier for users to analyze images.

b. Cropping

The purpose of cropping or image cutting is to focus on the area of study or area to be studied, to facilitate image processing, and to reduce storage memory, thereby making the process more efficient.

c. Geometric Correction

Geometric correction is the stage of minimizing inaccuracies caused by the sweeping motion of the explorer and satellite, the curvature of the earth, and the rotation of the earth, which cause positions to shift relative to the reference coordinate system. Geometric correction is also the transformation of remote sensing images so that they have mapping characteristics related to shape, projection, and scale. The purpose of geometric correction is to correct or restore images so that their coordinates match the geographic coordinates.

d. Radiometric Correction

Radiometric correction is a correction made because the appearance of the earth is not always clear due to atmospheric effects. Top of Atmosphere is a radiometric correction made to eliminate numerical errors caused by differences in the angle of the sun during recording.

According to the United States Geological Survey, the ToA reflectivity correction formula is:

$\rho\lambda' = M\rho Qcal + A\rho$

Explanation:

$\rho\lambda'$ = TOA reflectance, without correction for the sun angle.

$M\rho$ = REFLECTANCE_MULT_BAND_x, where x is the Band Number

$A\rho$ = REFLECTANCE_ADD_BAND_x, where x is the Band Number

Qcal = Digital Number (DN)

Then use the following formula to correct for the sun angle:

$$\rho\lambda' = \frac{\rho\lambda\prime}{\sin(\theta SE)}$$

Explanation:

$P\lambda$ = ToA reflectance

θSE = Sun elevation

e. Masking

Masking is a process performed before image classification with the aim of separating the area to be analyzed from other areas that will be removed.

f. Supervised Classification

Classification is the process of grouping image pixels into specific categories by analyzing their brightness values. This study uses the Supervised classification method, which is very important for converting multispectral satellite image data into specific spatial classes. This classification requires a training area or specified sample. Supervised classification uses the Maximum Likelihood algorithm. The benefits of this classification approach include more stable, consistent, and rational statistical results for each pixel classification. The ML algorithm relies on the similarity of pixel values in the image. Each pixel in its category is represented by different characteristics. This technique achieves a very high level of accuracy.

Based on Malingreau's Class I classification, land use types are divided into four categories, namely green vegetation, cream-colored open land, brown residentials, and blue water bodies. Malingreau's land use classification is divided into four main categories, namely water, land and vegetation, with the addition of human-made resources such as residentials. Malingreau acknowledges that no single classification can truly meet long-term needs at all levels, professions, and organizations. This is because each party has its own objectives, and it is difficult to create a classification that meets these different objectives. Therefore, Malingreau only classifies land according to its land use characteristics, with the aim that this simple classification is open and adaptable to accommodate future additions and various uses.

g. Processing of Driving Factors

During the modeling process, several driving factors are needed to spur change. Before modeling and prediction, all driving factors are first processed into raster data in ArcGIS 10.8 software so that they can be entered and read by the MOLUSCE system.

1) Slope

Slope affects surface runoff volume and rate, drainage, land use, and erosion. On gentle slopes, surface runoff moves more slowly, causing puddles to form, while on steeper slopes, runoff occurs more quickly, allowing rainwater to drain away immediately after falling, reducing the likelihood of flooding in the area.

Slope analysis is divided into five categories according to specific slopes. Slopes of 0–8 m are considered flat, 8–15 m are considered gentle, 15–25 m are considered steeper, 25–45 m are considered steep, and slopes > 45 m are considered very steep. Therefore, the topographical characteristics of an area can be identified based on its slope. Areas with flat slopes are more suitable for residential development.

Table 1. *Slope Class*

Slope Class	Value
Flat	0 – 8
Gentle	8 – 15
Moderately Steep	15 – 25
Steep	25 – 45
Very Steep	> 45

2) Land Use Designation

The classification of land use in this study refers to Batam City Regulation No. 3 of 2021 concerning the 2021-2041 Batam City Spatial Plan.

3) Disaster Risk

The combination of disaster risk maps with spatial planning, architecture, and the environment can be an important reference in reducing disaster risk. Disaster risk data is obtained through the InaRISK website, where the data (flood and landslide disaster risk) is in the form of raster data that has been classified into 3 classes, namely low, medium, and high.

a) Flood

Floods are caused by the submergence of normally dry land (non-swamp areas) with water due to high rainfall and varying topography from lowlands to depressions. Low soil infiltration capacity can also cause the soil to no longer absorb water, leading to flooding.

Table 2. *Flood Disaster Risk Class according to BNBP*

Flood Class	Value
Low	0 – 0.3
Moderate	0.3 – 0.6
High	0.6 – 1.0

b) Landslide

Landslides are phenomena in which slope-forming materials slide down slopes in the form of rocks, debris, or a mixture of these materials. Landslides occur when water seeps into the ground, causing an increase in soil weight.

Table 3. *Landslide Disaster Risk Class according to BNBP*

Landslides Class	Value
Low	0 – 0.3
Moderate	0.3 – 0.6
High	0.6 – 1.0

h. CA – ANN modeling

The selection of slope inclination, land use, and disaster risk as the main driving factors in the CA-ANN model is based on the theory of land use change, which emphasizes the interaction between physical conditions, spatial policies, and environmental vulnerability. Slope gradient theoretically affects land stability and erosion potential, where steep slopes tend to be less desirable for conversion into settlements or infrastructure due to greater degradation risks, thereby triggering more controlled change patterns. Land use zoning, as a planning policy instrument, legally determines land use zones and influences land transitions by limiting or encouraging conversion based on development priorities, as in the context of the Rempang Eco City project, which integrates industry and tourism. Disaster risks, particularly landslides and floods, theoretically act as barriers or drivers of change, where high-risk areas tend to avoid intensive development, but large projects can exacerbate vulnerability, making this factor crucial for predictive models on small islands such as Rempang. These factors were selected due to their relevance to the non-linear spatial dynamics that can be captured by ANN in CA.

CA–ANN modeling was performed in QGIS software using the MOLUSCE plugin. The input data used in the processing were land use maps from 2014, 2019, and 2024, as well as driving factors (slope, land use designation, and disaster risk) that were processed into raster data. The prediction process consisted of the following six stages:

1) Inputs

   Land use data and driving factors were entered into Check Geometry to check the geometric compatibility between raster data so that the process could proceed to the next stage.

2) Evaluating Correlations

   Using Pearson's Correlation to see the relationship between variables, which is a statistical matrix that calculates the dependence and linear relationship between two random variables determined by variables X and Y. Pearson's Correlation ranges from -1 to 1. A higher correlation value indicates a stronger influence between variables.

3) Area Changes

   This stage shows the results of changes in land use area in the first and last years and the likelihood of such changes in land use occurring. A higher transition value indicates a more significant shift in land use class. The transition matrix value ranges from 0 to 1. Values between 0.01 and 0.99 reflect the probability of change, while values between 0 and 1 indicate the possibility of no change.

4) Transition Potential Modeling

   The Artificial Neural Network method is used in this stage. The way ANN works in processing data is inspired by the way the human brain's nervous system works. One way to improve ANN performance is by training data through proper iteration, which is an important process in developing ANN models. Through the correct iterative process, the model's performance will gradually improve. The model then uses the backpropagation technique to adjust the weights and biases of the entire network based on error calculations. The purpose of this training is to optimize the weights and biases of the entire network so that the ANN model can make accurate predictions on the training data. The application of ANN in land use change modeling involves several stages, such as determining the input and network architecture, training the network, testing the network, and predicting future land use changes using the information generated by the network.

5) Cellular Automata Simulation

   Cellular Automata Simulation is the stage where the land use prediction modeling process takes place. CA is a spatial modeling framework and paradigm for thinking about the complexity of spatial and temporal phenomena. Future-oriented spatial planning requires a CA mechanism, namely determining sustainable land use changes on Rempang Island. During the CA simulation phase, multiples are applied. The starting year is 2014, the ending year is 2019, and the prediction result is 2024. To predict 2029, 2 iterations are required.

6) Validation

   MOLUSCE has its own validation phase in measuring the performance of prediction models, including "% of correctness," Kappa (overall), Kappa (histogram), and Kappa (location). "% of correctness" includes information related to prediction accuracy in percentage terms, Kappa (overall) includes information related to the suitability of predictions for land use in 2024, Kappa (histogram) provides information related to the accuracy of model performance in the distribution of land use categories, and Kappa (location) provides information on how accurate the location predicted by the model is compared to the actual location.

Table 4. *Kappa Accuracy*

Kappa Coefficient Value	Interpretation
< 0.20	Low
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Strong
> 0.80	Very Strong

C. Findings and Discussion

1. Findings

a. Land Use

Land use on Rempang Island was analyzed based on satellite imagery data processed using the Supervised classification method with the Maximum Likelihood algorithm. This analysis was conducted for the years 2014, 2019, and 2024, with land use categories consisting of settlements, water bodies, open land, and vegetation. The following table shows the area of each land use category during these periods, providing an overview of land use dynamics due to factors such as population growth and development policies.

Table 5. *Land Use Area in 2014, 2019, 2024*

Land Use	2014 (Ha)	2019 (Ha)	2024 (Ha)
Residential	1,567.59	2,078.93	1,285.36
Waterways	235.86	196.71	167.31
Open Land	7,604.41	7,310.75	7,578.41
Vegetation	6,055.93	5,877.41	6,432.72

This table summarizes the area for each land use category based on satellite image classification. The data shows significant fluctuations, such as an increase in settlements from 2014 to 2019, followed by a decline in 2024, reflecting the impact of development policies. These figures are calculated in hectares (Ha) and validated with field observations to ensure classification accuracy.

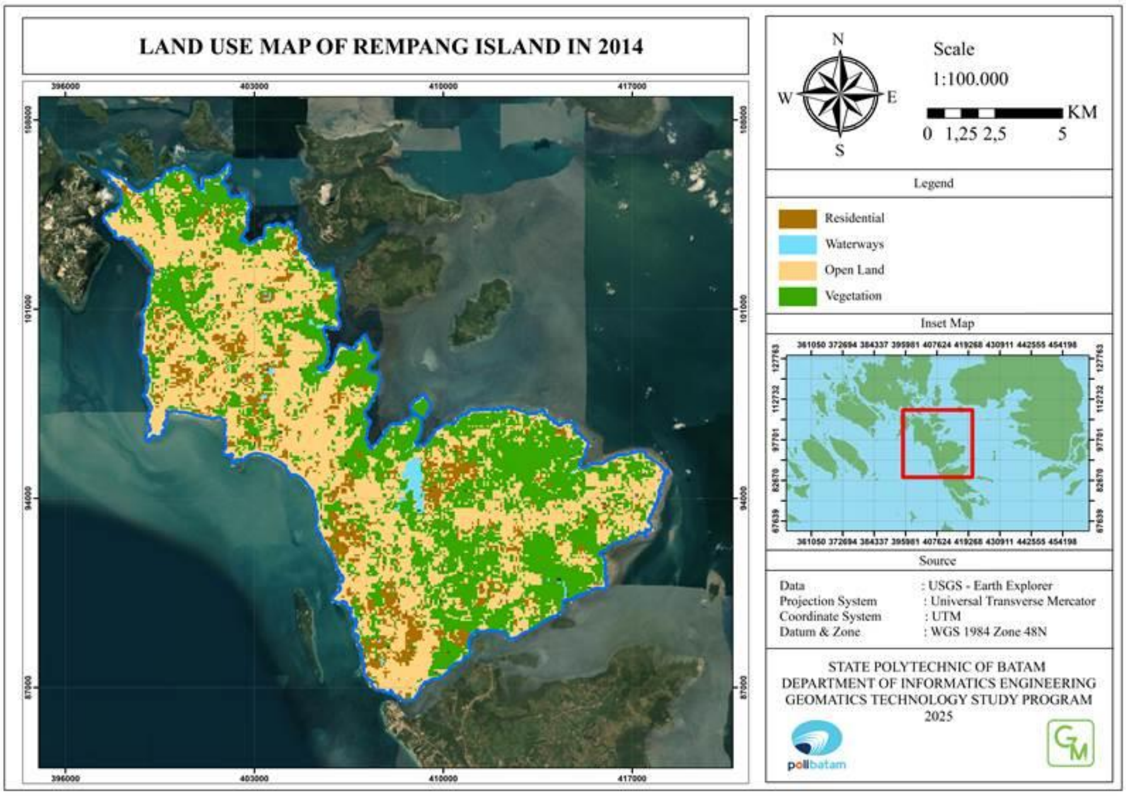

Figure 3. *Land Use in 2014*

This map depicts land use distribution on Rempang Island in 2014 at a scale of 1:100,000 and a spatial resolution of 30 meters. The colors on the map represent the following categories: brown for residential (1,567.59 Ha), blue for waterways (235.86 Ha), cream for open land (7,604.41 Ha), and green for vegetation (6,055.93 Ha).

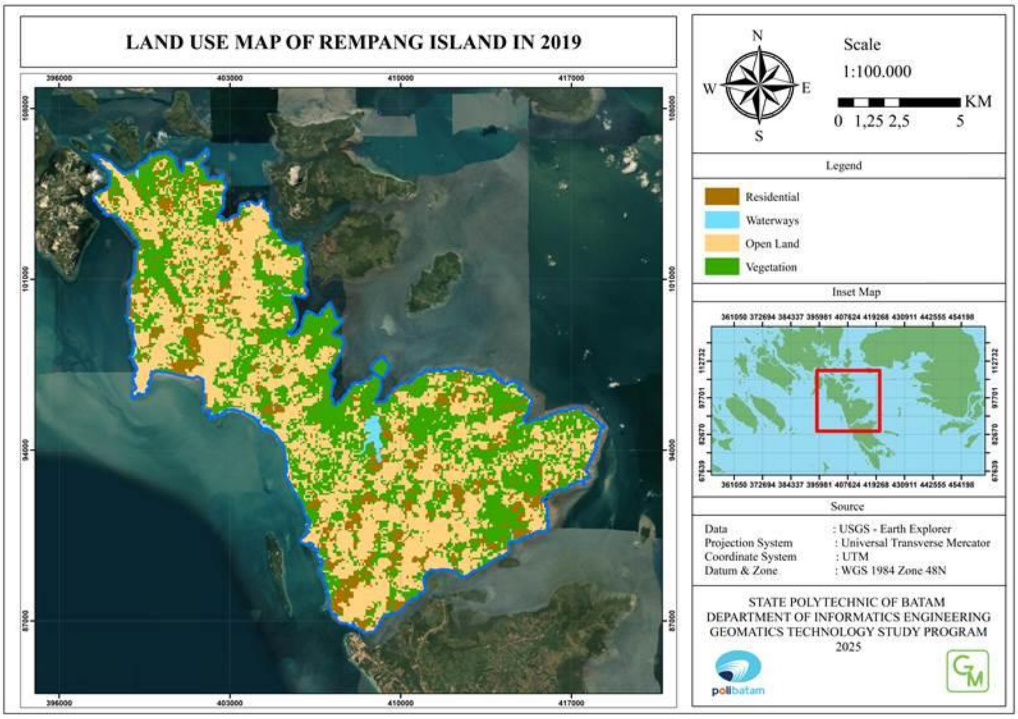

Figure 4. *Land Use in 2019*

This map depicts land use distribution on Rempang Island in 2019 at a scale of 1:100,000 and a spatial resolution of 30 meters. The colors on the map represent the following categories: brown for residential (2,078.93 Ha), blue for waterways (196.71 Ha), cream for open land (7,310.75 Ha), and green for vegetation (5,877.41 Ha).

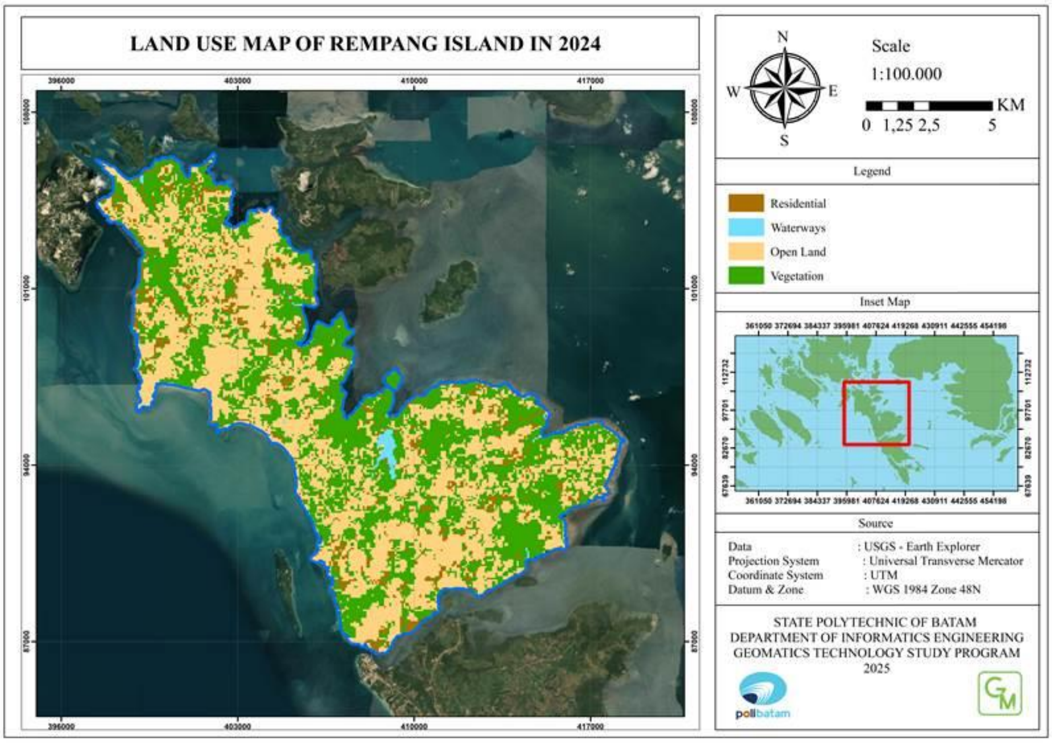

Figure 5. *Land Use in 2024*

This map depicts land use distribution on Rempang Island in 2024 at a scale of 1:100,000 and a spatial resolution of 30 meters. The colors on the map represent the following categories: brown for residential (1,285.36 Ha), blue for waterways (167.31 Ha), cream for open land (7,578.41 Ha), and green for vegetation (6,432.72 Ha).

1) Land Use in 2014–2019
   As a result of land conversion into and open land, the area of vegetation decreased by 3.0% (from 6,055.93 ha to 5,877.41 ha), while the area of water decreased by 16.6% (from 235.86 ha to 196.71 ha). This decline was influenced by the increasing demand for developed land, which

was supported by population growth. Based on BPS data, the population of Rempang Island increased to 3,515 in 2019. This has led to an increase in demand for residential land and resulted in increased land conversion. This can be proven by satellite imagery observations, which show that the area of land converted to residential use has increased by 32.6% (from 1,567.59 ha to 2,078.93 ha).

2) Land Use in 2014–2024
The area of settlements decreased by 18.0% (from 1,567.59 ha to 1,285.36 ha) due to land conversion for the Rempang Eco City project. The area of vegetation increased by 6.2% (from 6,055.93 ha to 6,432.72 ha) due to climate change. Overall, land use changes during this period showed an expansion of vegetation areas and a decrease in residential areas, open land (a small decrease of -0.3%, from 7,604.41 ha to 7,578.41 ha), and water areas (a decrease of 29.0%, from 235.86 ha to 167.31 ha).

3) Land Use in 2019–2024
Land use changes over the past five years show an upward and downward trend. The area of open land increased by 3.7% (from 7,310.75 ha to 7,578.41 ha) due to land conversion and the impact of climate change, while the area of water decreased by 15.0% (from 196.71 ha to 167.31 ha). Conversely, the area of residential land decreased by 38.2% (from 2,078.93 ha to 1,285.36 ha) as a result of a development project planned by the Indonesian government to develop Rempang Island through a project called Rempang Eco City.

b. Slope

The topographical characteristics of an area can be identified based on its slope. Areas with flat slopes are more suitable for residential development. On Rempang Island, flat slopes dominate with an area of 5,431.65 hectares, followed by gentle slopes with an area of 3,851.78 hectares, moderately steep slopes with an area of 3,793.86 hectares, steep slopes with an area of 2,207.17 hectares, and very steep slopes with an area of 179.34 hectares.

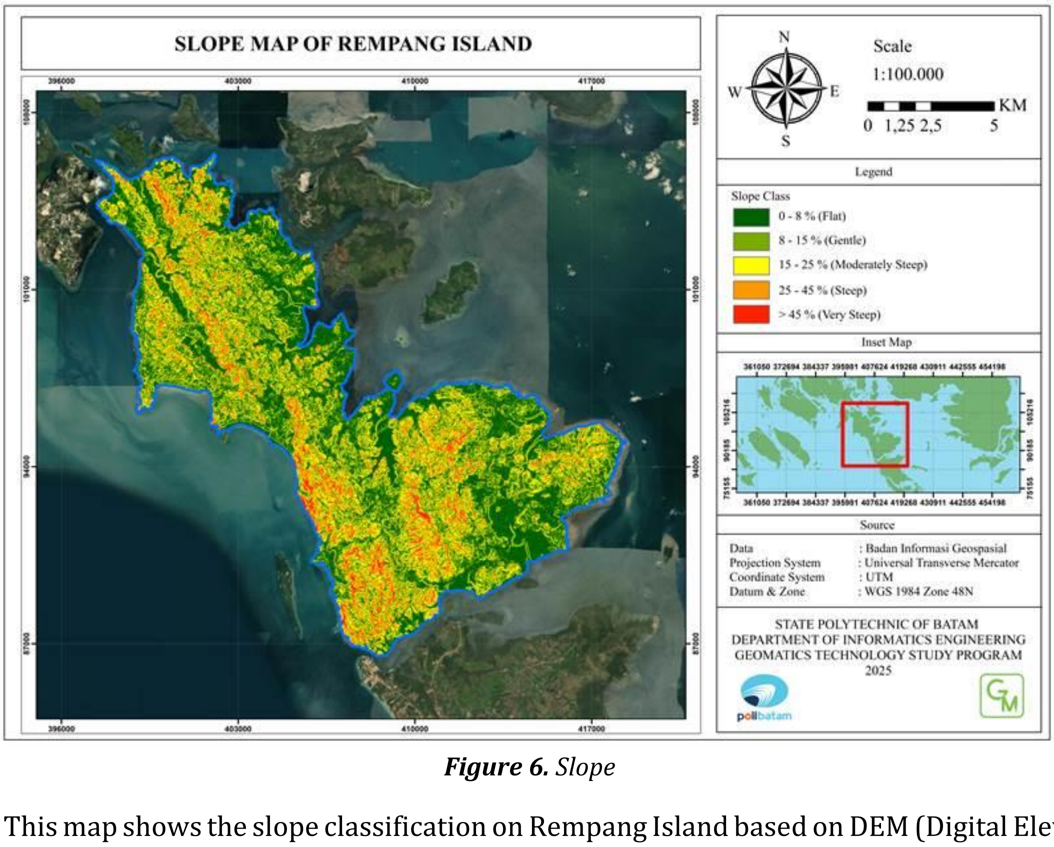

Figure 6. *Slope*

This map shows the slope classification on Rempang Island based on DEM (Digital Elevation Model) data with a resolution of 30 meters. Light green indicates a flat slope (0-5%), which dominates 5,431.65 Ha, while red indicates a very steep slope (> 45%), which is only 179.34 Ha. This map is used as a driving variable in the CA-ANN model to predict land conversion risk.

c. Disaster Risk

Rempang Island is relatively safe for habitation because it is dominated by low-risk areas. The low-risk area for flooding covers 12,332.91 hectares, the moderate-risk area covers 2,078.12 hectares, and the high-risk area covers 1,052.77 hectares. For the risk level of landslides on Rempang Island, the low risk area covers 13,167.25 hectares, the medium risk area covers 974.51 hectares, and the high risk area covers 1,465.25 hectares.

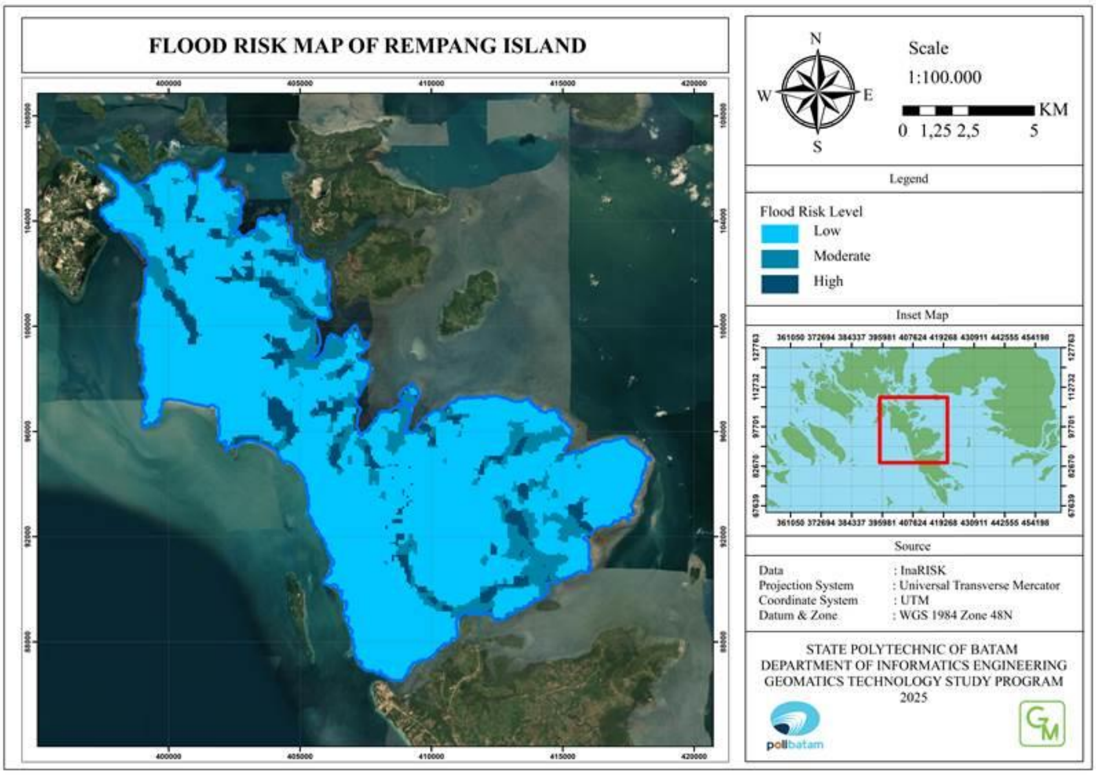

***Figure 7.** Flood Disaster Risk*

This map depicts the flood risk levels on Rempang Island based on hydrological analysis using rainfall and elevation data. Low-risk areas cover 12,332.91 hectares, moderate-risk areas cover 2,078.12 hectares, and high-risk areas cover 1,052.77 hectares. This map is important for integration into predictive models, as flood risk influences land use patterns.

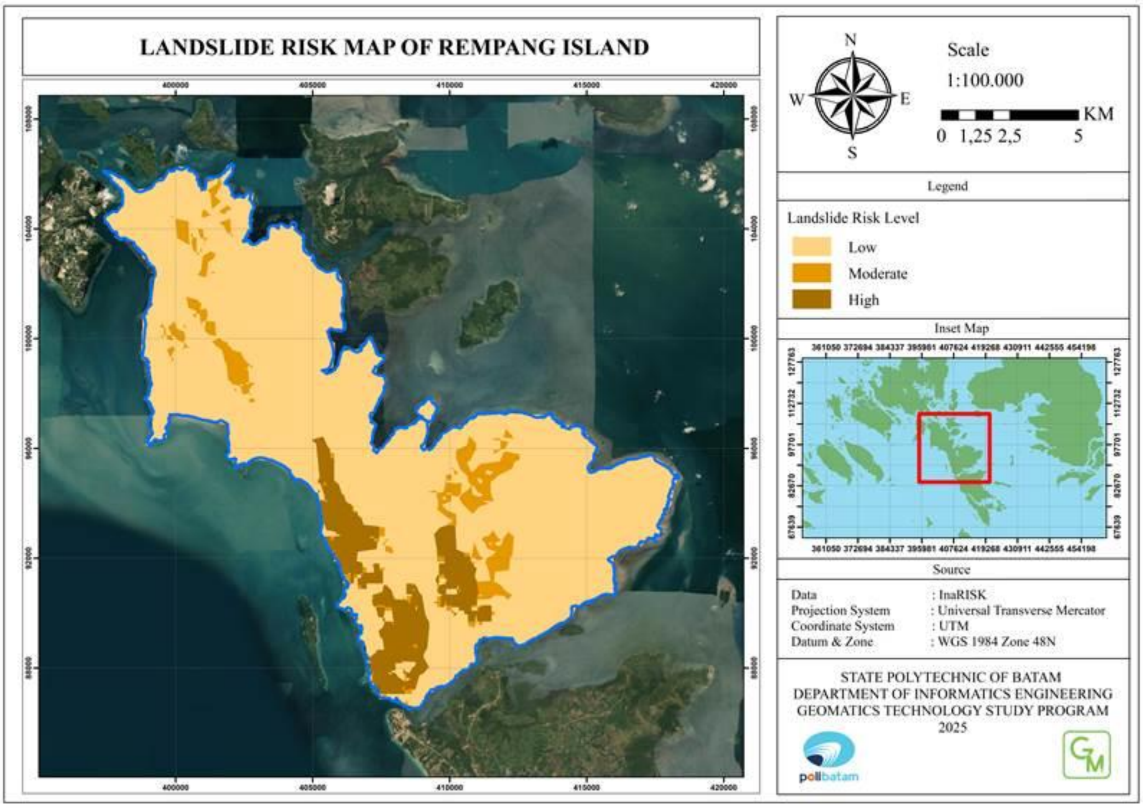

***Figure 8.** Landslide Disaster Risk*

This map shows landslide risk based on slope, soil type, and rainfall. Low-risk areas dominate with 13,167.25 hectares, moderate risk areas cover 974.51 hectares, and high-risk areas cover 1,465.25 hectares. This data is used to assess the impact of development on disaster vulnerability, with a focus on steep areas prone to landslides.

d. Land Use Designation

The Land Use Designation Map serves to assist in the management and conservation of natural resources, as a reference in planning land use and infrastructure development. There are 19 land use designations on Rempang Island, as follows:

***Table 6**. Designation of the Rempang Island Area*

Land Use Designation	Area (Ha)
Mangrove Ecosystem Area	175.76
Public Facilities and Social Facilities Area	1.40
Protected Forest Area	4,365.42
Protected Forest Area/Office Area	6.53
Protected Forest Area/Green Open Space	0.47
Convertible Production Forest Area	42.42
Convertible Production Forest Area/Public and Social Facility Area	37.30
Convertible Production Forest Area/Tourism Area	1,302.10
Convertible Production Forest Area/Trade and Services Area	428.44
Convertible Production Forest Area/Residential Area	4,512.35
Convertible Production Forest Area/Industrial Area	1,138.93
Convertible Production Forest Area/Transportation Area	101.17
Convertible Production Forest Area/Green Open Space	18.18
Tourism Area	138.00
Trade and Services Area	28.44
Residential Area	172.96
Water Resources Area	192.07
Hunting Park Area	2,684.38
Transportation Area	117.48

This table presents the area size for each land use based on the Batam City Spatial Plan. The data shows the dominance of Convertible Production Forest Area/Residential Area (4,512.35 hectares), which is relevant to the Rempang Eco City project. The figures in hectares are calculated from official spatial data and are used for land suitability analysis.

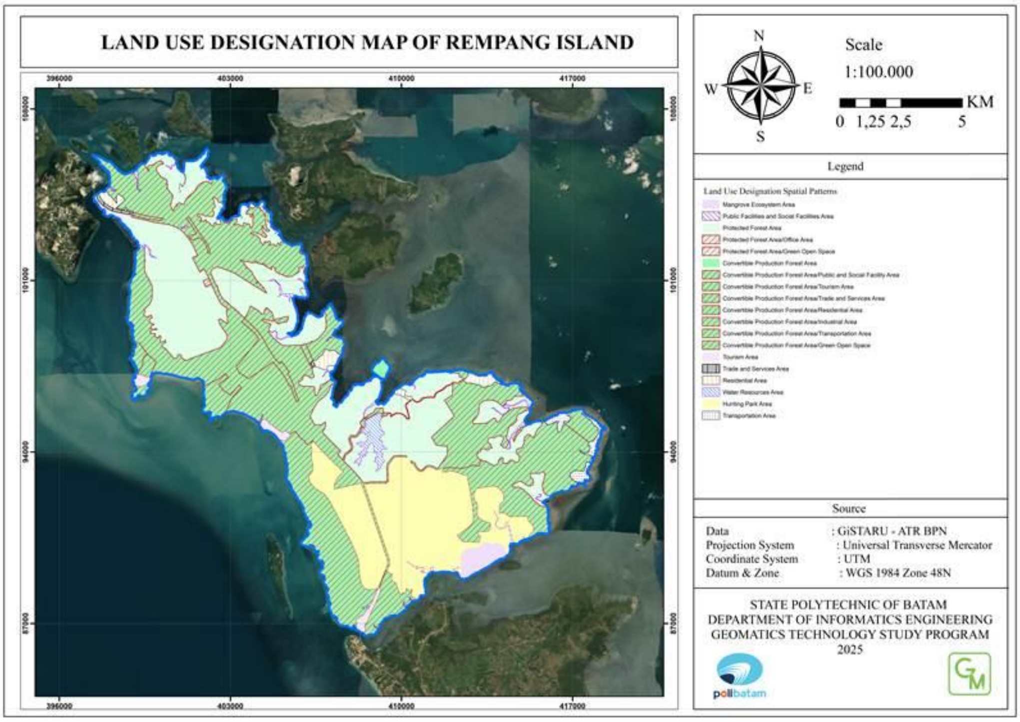

***Figure 9.** Land Use Designation based on the Batam City Spatial Plan*

This map depicts land use on Rempang Island at a scale of 1:100,000. It serves as a basis for predicting the impact of development on land use.

e. Land Use Prediction Results for 2029

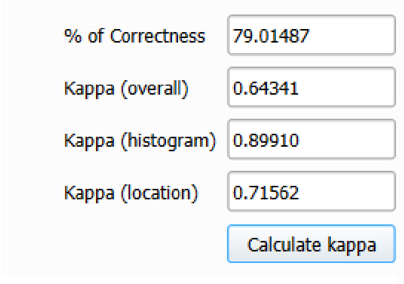

Figure 10. *Validation results*

This image shows the validation of the CA-ANN model using MOLUSCE. A Kappa value of 0.64 indicates a strong interpretation, with an accuracy of 79.01% reflecting the model's ability to project land use changes. This validation was carried out by comparing the 2024 predictions with actual data, ensuring the reliability of the model for the 2029 projections.

Table 7. *Predicted Land Use Area in 2029*

Land Use	2029 (Ha)
Residential	1.932,32
Waterways	170,55
Open Land	7.373,78
Vegetation	5.987,15

This table summarizes the results of the CA-ANN model projections for 2029. The figures in hectares show an increase in settlements of 1,932.32 Ha, reflecting the impact of the Rempang Eco City project. This data was calculated based on model simulations and validated for accuracy.

The prediction results show that the dominant land use on Rempang Island will be open land with an area of 7,373.78 hectares. The area of residential land and waterways is predicted to increase. The area of residentials will increase from 1,285.36 hectares in 2024 to 1,932.32 hectares, and the area of water bodies will increase from 167.31 hectares to 170.55 hectares. Conversely, the area of vegetation and open land is expected to decrease. In 2024, the area of vegetation is predicted to decrease from 6,432.72 hectares to 5,987.15 hectares, and the area of open land is predicted to decrease from 7,578.41 hectares to 7,373.78 hectares, which is thought to be influenced by development.

Prediction of land use on Rempang Island in 2029 using the CA method –ANN shows its ability to project future land use changes and successfully makes predictions with a "% of correctness" value of 79.01%, which is the accuracy value in percentage, and a Kappa (overall) value that calculates the conformity of the prediction results with land use in 2024 of 0.64. These results show that the predictions generated fall within the strong Kappa value interpretation. According to the prediction results, the area of residential land will increase from 2024 to 1,932.32 hectares.

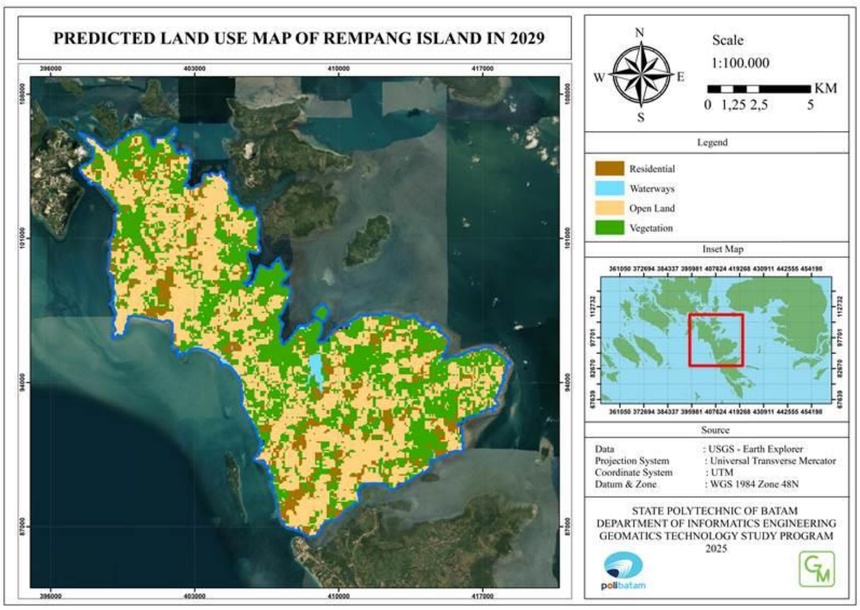

Figure 11. *Land Use in 2029 Based on CA – ANN Predictions*

This map depicts land use projections for 2029 on a scale of 1:100,000. The colors on the map represent the following categories: brown for residential (1,932.32 Ha), blue for waterways (170.55 Ha), cream for open land (7,373.78 Ha), and green for vegetation (5,987.15 Ha). This map was generated using a CA-ANN model and is used to analyze the implications of development.

2. Discussion

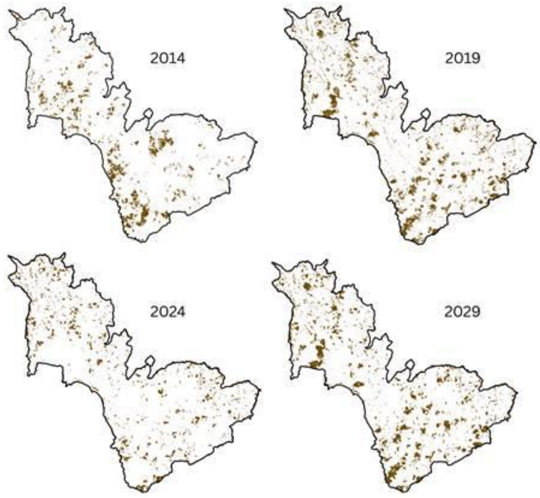

Figure 12. *Patterns of Land Conversion to Residential Areas*

Tabel 8. *Changes in Residential area in 2014, 2019, 2024, and 2029*

Land Use	2014 (Ha)	2019 (Ha)	2024 (Ha)	2029 (Ha)
Residential	1,567.59	2,078.93	1,285.36	1,932.32

The results of this study indicate that the CA-ANN model is effective in projecting land use changes on Rempang Island, particularly in anticipating an increase in residential land due to the development of the Rempang Eco City Project. Spatial analysis of historical data (2014, 2019, and 2024) reveals a significant pattern of change, where the area of residential land increased from 1,567.59 hectares in 2014 to 2,078.93 hectares in 2019, driven by population growth which reached 3,515 people in 2019 (BPS, 2020). However, the decline to 1,285.36 hectares in 2024 shows the impact of land management policies to support the project, which diverted some of the land for industrial and ecotourism purposes. The prediction for 2029 estimates an increase back to 1,932.32 hectares, reflecting residential development in response to the project's infrastructure needs. Driving factors such as slope inclination, land use, and disaster risk play a crucial role in the CA-ANN model, as it relies not only on historical data but also integrates physical and risk variables, resulting in more holistic projections.

To strengthen the validity of these findings, the results of this study were compared with a previous study in Sleman Regency that used the CA-ANN model to predict land use change. That study showed an increase in land use for settlements of 287.342 ha and a decrease in rice fields of 291.93 ha, driven by population and economic growth, which is similar to the pattern of land conversion on Rempang Island due to population growth. However, the accuracy of the model in the Sleman study was much higher, with a Kappa index of 0.95621, a correction of 97.14082%, and a percentage of prediction accuracy with existing data of 93.52%, compared to an accuracy of 79.01% and a Kappa of 0.64 in this study. This difference can be explained by the geographical context: Sleman, as a mainland area with supporting variables such as road data and a more stable distribution of educational institutions, allows for higher accuracy, while Rempang Island, as a small island with complex disaster risks (slope inclination and natural hazards), poses additional challenges in modeling, resulting in more moderate accuracy. Nevertheless, both studies emphasize that CA-ANN is effective in capturing the dynamics of land change due to anthropogenic pressures, with Sleman using data from 2015 and 2017, while this study uses data from 2014, 2019, and 2024 for long-term projections.

The performance of CA-ANN in this study was also compared with other modeling approaches. Compared to Markov Chain models alone, which are often used for temporal land change simulations but are less accurate in capturing spatial interactions, CA-ANN showed superiority with better accuracy due to its ability to integrate cellular rules with artificial neural networks to model non-linear complexity. However, when compared to machine learning-based models such as Random Forest or SVM, CA-ANN has equivalent or slightly lower performance in large datasets, where Random Forest achieves up to 85% accuracy in land prediction. Nevertheless, CA-ANN excels in scenarios with limited data and complex spatial variables, such as on Rempang Island, due to its flexibility in handling local dynamics. Compared to the Sleman study, which used CA-ANN with high accuracy, our performance was lower because the complexity of disaster risks was not fully covered in the model, indicating that CA-ANN needs to be adjusted to region-specific variables for optimal results.

The implications of these findings are important for sustainable development planning on Rempang Island. The predicted increase in residential land highlights the need for disaster risk mitigation strategies, such as strengthening infrastructure in steep slope areas, to prevent uncontrolled land use change. This is in line with the IPCC (2022) recommendation on integrating predictive models into environmental policy, which emphasizes the need for historical data and risk variables for accurate projections. However, this study has several limitations. First, the accuracy of the model is limited by the quality of historical data, which may not fully capture seasonal variations or extreme climate changes. Second, the CA-ANN model relies on subjectively selected parameters, which can affect the results if not extensively validated. Third, this study focuses only on Rempang Island, so generalization to other regions requires adjustment. Fourth, limitations in disaster risk data (such as flood or landslide data) may reduce the accuracy of projections. Fifth, compared to the Sleman study, which has higher accuracy, this study is limited by the small scale of the island, which makes spatial data more difficult to obtain and validate.

Overall, these findings contribute to the literature on cartography and land modeling by demonstrating the effectiveness of CA-ANN in the context of small island development, while highlighting the need for an integrative approach to address environmental challenges. Support from the Sleman study reinforces this interpretation, although the limitations of the study indicate room for further development.

D. Conclusion

Predictions of land use change on Rempang Island using the CA-ANN method resulted in a model accuracy of 79.01% with a strong kappa value, making this model acceptable for future spatial modeling. The main findings show that land use in 2029 will be dominated by open land (7,373.78 hectares), with an increase in residential area from 1,285.36 hectares (2024) to 1,932.32 hectares and water areas from 167.31 hectares to 170.55 hectares, as well as a decrease in vegetation from 6,432.72 hectares to 5,987.15 hectares and open land from 7,578.41 hectares to 7,373.78 hectares. These changes were influenced by driving factors such as the dominance of flat slopes (5,431.65 hectares), the designation of production forest/residential areas (4,512.35 hectares), and low risk of flooding (12,332.91 hectares) and landslides (13,167.25 hectares), with a significant impact from the development of Rempang Eco City.

The limitations of this study include the potential for inaccuracy in the digitization stage, which could affect the accuracy of the classification, as well as the spatial resolution limitations of the satellite images used. Recommendations for further research include improving the accuracy of digitization and using satellite images with higher spatial resolution for more accurate land use classification.

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