FORUM GEOGRAFI
ISSN: 0852-0682 | E-ISSN: 2460-3945

HTTPS://JOURNALS.UMS.AC.ID/INDEX.PHP/FG/

Spatial Dynamics of Land Cover Change in Ternate Tengah District, Ternate City, Indonesia

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Citation:
Rakuasa, H., & Pakniany, Y. (2022) Spatial Dynamics of Land Cover Change in Ternate Tengah District, Ternate City. Forum Geografi. Vol. 36, No. 2.

Article history:
Received: 02 October 2022
Accepted: 29 December 2022
Published: 29 December 2022

Abstract

The phenomenon of urban growth has become an important issue that affects the land use system and land cover in a region for several reasons, such as population growth and the economy. This phenomenon has also become one of the main environmental issues lately because it has devastated urban ecosystems. Ternate Tengah District has the highest population growth rate in Ternate City and has experienced extensive urban development due to several reasons, such as the pace of urbanization, economic growth, and population. Urbanization accelerates the demand to land for living. As a result, there will be gaps or disparities between land needs and available land, a decline in environmental carrying capacity, and potential environmental harm in the future. Spatial modeling of future land covers is needed to provide data on policy-making. GIS and remote sensing methods have been widely introduced, but the most effective one is CA-Markov. This model has been used in various areas worldwide, but its application to predicting land use change in the populous city of a small island under threat of volcanic hazards like Ternate is limited. This study aims to evaluate and forecast the land-use changes brought on by urbanization in Ternate City's Central Ternate District. We used a cellular automata-Markov chain to examine and forecast land cover changes in 2002, 2012, 2022, and 2032. The findings indicate that residential area development will increase along with population expansion and land demand. The results of this study can support the policy-making related to the future arrangement and utilization of space in The Central Ternate District.

Keywords: cellular automata, Markov chain, land cover, Ternate, volcanic areas

1. Introduction

The phenomenon of urban growth has become an important issue that affects the land use system and land cover in a region for several reasons, such as population growth and the economy (Kisamba & Li, 2022). Urbanization is an essential factor that encourages urban growth (Almdhun *et al.*, 2018). This phenomenon has also become one of the main environmental issues lately because it has devastated urban ecosystems (Wang & Wang, 2017; Alimuddin *et al.*, 2022). Based on previous research conducted by Umanailo *et al.* (2017), two factors are considered to affect changes in land cover in Central Ternate District greatly: population and economic factors. Therefore, it can be concluded that the increasing population of Central Ternate District makes the need for land to settle also increase, as a result of which there will be inconsistencies or inequalities between land needs and available land, the occurrence of a decrease in environmental carrying capacity and environmental damage in the future (Salakory & Rakuasa, 2022; Sugandhi *et al.*, 2022; Rakuasa & Somae, 2022).

The Central Ternate District, in the center of Ternate City and the City Area Section (BWK) II, is the most populous and the destination of urbanization in North Maluku Province. Based on data from BPS Ternate City in 2021, Ternate Tengah District has the highest population growth rate in Ternate City, with a total population in 2021 reaching 53,643 people (BPS, 2021). This area has experienced extensive urban development in recent years due to several reasons, such as the pace of urbanization, economic growth, and population, which led to a decrease in green areas in Central Ternate District. In addition, the geographical condition of the Central Ternate District, which is in the active volcanic area, namely Mount Gamalama, has an impact on the availability of land for settlement in the future. Therefore, predictions of urban development and growth or urban growth need to be carried out, which later the information can be used as a basis and foothold in policy-making related to the arrangement and use of sustainable space and as a first step in efforts to mitigate natural disasters in the future.

There are many GIS and remote sensing models and methods to predict urban growth patterns, including Cellular Automata (CA) model, Land Transformation Model (LTM), and Logistics Regression (LR) (Ajeeb *et al.*, 2020). Furthermore, the utilization of Geographic Information System (GIS) and remote sensing data can be used to develop a sustainable urban planning system in the future (Mohamed & Worku, 2020). Dynamic spatial modeling also plays an important role in predicting urban growth patterns, which has many advantages compared to the other methods (Han & Jia, 2017; Akbar & Supriatna, 2019; Rakuasa *et al.*, (2022). Therefore, this method is highly recommended for use in the simulation and prediction of urban trends. Dynamic spatial modeling using the CA-Markov method or Celular Automata- Markov Chain has become one of the leading dynamic models used by most studies in geography, environmental science, and urban and regional planning (Rakuasa *et al*., 2022; Getu & Bhat, 2022).

The CA-Markov model has been commonly used in the last five years due to its simplicity and can be easily integrated with other models (Kushwaha *et al.*, 2021). In addition, this model provides ease of use and simplicity of implementation and can add influencing variables to the simulation process. Several influencing variables can be added, for example, statistics such as population and economic variables and dynamic variables such as height and slope. Entering variables of this type produces results that are not only more realistic but also much more accurate (Hegazy & Kaloop, 2015).

The model has been applied in various regions worldwide to predict land use changes (e.g., Fu *et al.* [2022], Wang *et al.* [2022]) as well as Indonesia (e.g., Kurnia *et al.* [2022]), but its application to predicting land use change in the populous city of a small island under threat of volcanic hazard like Ternate is limited. Previous research on land cover changes in Central Ternate District has been carried out in previous studies, such as Umanailo *et al*. (2017), that analyzed land cover changes in 2000, 2005, 2010, and 2015 in 2020. Sarihi *et al*. (2020) also conducted a land use change analysis on Ternate Island in 2019. However, the previous studies analyzed land cover changes without predicting future changes. This research aims to analyze land cover changes in 2002, 2012, and 2022 and predicts land cover in 2032. In this study, the Celular Automata-Markov Chain model was selected to predict urban growth trends and patterns in Central Ternate District using ArcGIS and IDRISI Selva software.

2. Research Methods

This research was conducted in Ternate District, Ternate City, North Maluku Province, which has an area of 1,407.17 ha. The research location can be seen in Figure 1. To analyze land cover changes due to urban growth in Central Ternate District, Ternate City using Celular Automata-Markov Chain. The software used for data processing and analysis in this study consists of Arc GIS 10.8 software for the process of processing land cover data and driving factors, IDRISI Selva software for processing the 2032 land cover model, Microsoft Office 365 software used for the process of analyzing the area of land cover development.

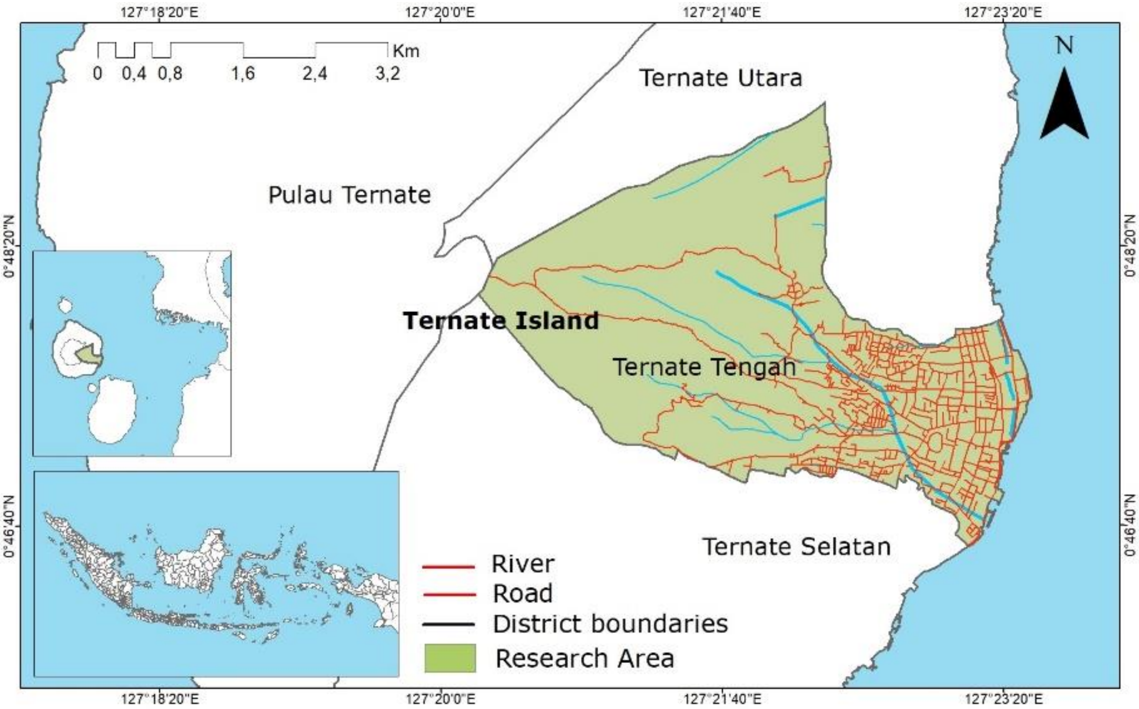

Figure 1. Research Area.

The processing of multi-temporal imagery data of Landsat imagery 2002, 2012, and 2022 was started by downloading data from the USGS. Second, we performed a radiometric correction process to correct the digital number and geometric correction to minimize geometric errors (Sukojo *et al.*, 2017). Third, we musked the imageries based on the administrative boundaries of the Central Ternate District. Afterward, the three images underwent a combination of bands to facilitate the interpretation and digitization processes. We used a combination of band 321 for Landsat 5 and band 432 for Landsat 8. The digitization process was carried out in the Arc GIS 10.8 software with reference to SNI 7465: 2010 for the classification scheme (Badan Standarisasi Nasional, 2010), namely settlements, open land, agricultural areas, non-agricultural areas, and waters.

ArcGIS 10.8 software was used to handle the multitemporal land cover data and the driving factors in this study. IDRISI Selva 17.0 software was used to create a land cover prediction model for the year 2032. Each driving factor has a different influence on each type of land cover change so that weighting is carried out. Table 1 was used to calculate the strength of the driving factor.

Table 1. Driving Factor Classification.

No	Parameter	Class	Score
1	Land Elevation	0-7 mamsl	1
		8-25 mamsl	3
		26-100 mamsl	2
		>100 mamsl	1
2	Slope	0-3 %	3
		4-15 %	2
		>15 %	1
3	Distance from the Road	0-100 m	3
		101-1000 m	2
		> 1000 m	1
4	Distance from POI	<400 m	3
		401-1000 m	2
		>1000 m	1

Source: Sugandhi *et al*. (2022).

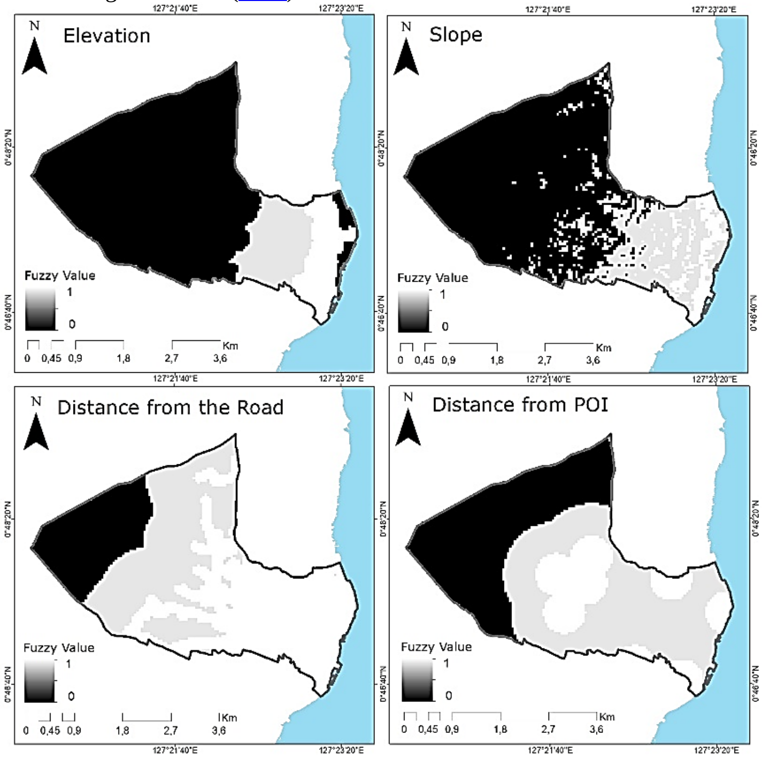

Figure 2. Driving Factors.

Push factor data is processed using the ArcMap 10.8 application using the fuzzy overlay technique and produces output as a push factor (Figure 2). Fuzzy is a logic system that aims to formulate an appraisal estimate reflected in a level of importance with a range of values of 0-1 (Boolean). Fuzzy logic is an excellent method for defining data obtained continuously, effectively and efficiently, which is a great process for performing cellular automata-based modeling, considering that using parallel computing consists of interconnected cells and has continuous values (Ghosh *et al*., 2017). The fuzzy logic value is displayed with a black and white gradation, where the resulting white color gradation is the higher the value, referring to the higher the development of settlements in the area. The five variables that have been carried out fuzzy membership are then overlaid with fuzzy gamma logic in the ArcMap 10.8 application (Figure 3), then a combination of the suitability of all the driving factor variables can be produced.

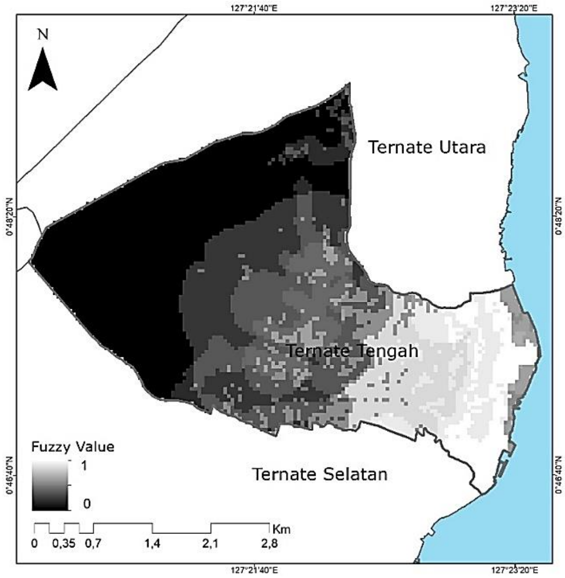

Figure 3. Overlay Results of Factors Driving the Development of Settlements.

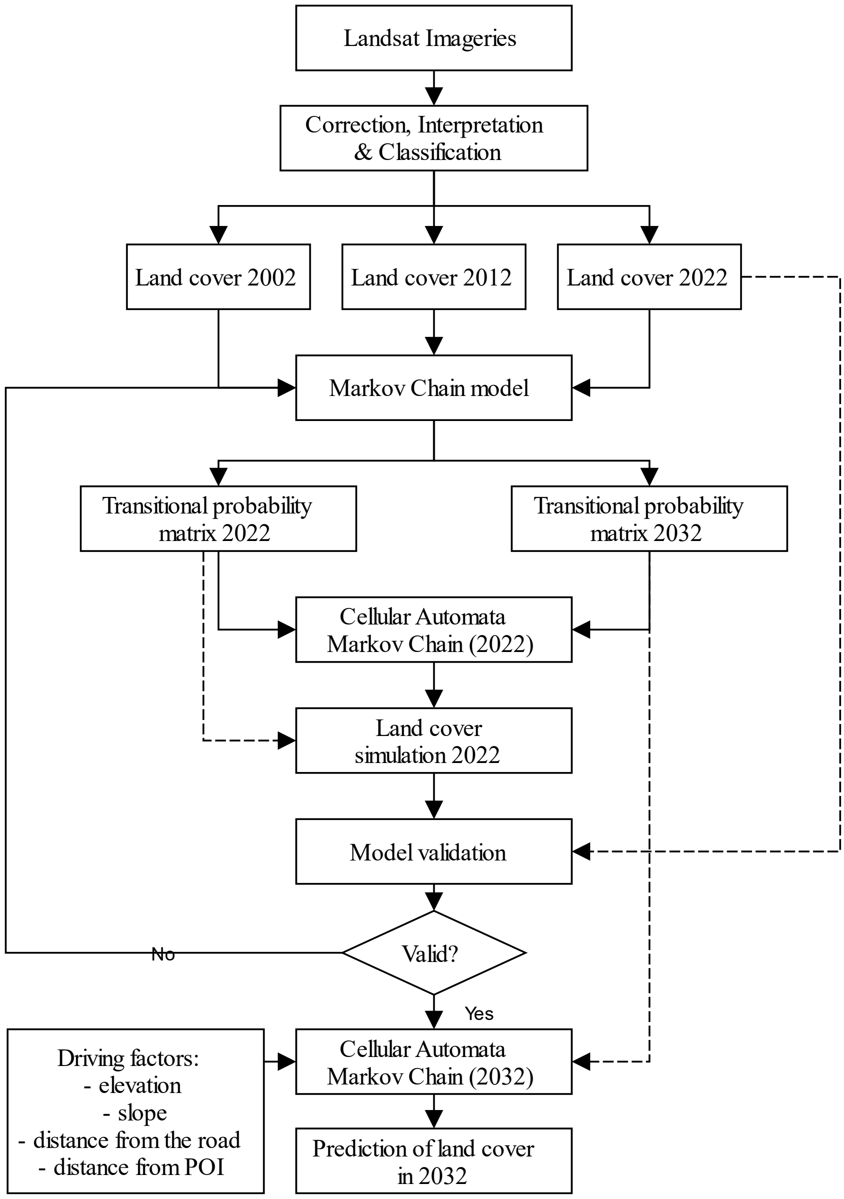

Figure 4. Research Workflow.

Land cover modeling in 2032 was carried out using LCM (Land Change Modeller), Markov, CA Markov, and Validation tools in the IDRISI Selva software. The method used to create a land cover model in 2032, the Cellular Automata Markov Chain method, is a hybrid model that is commonly used to predict land cover changes based on geographic information systems. Cellular Automata Markov Chain combines two different methods: Markov Chain, an empirical/statistical model, while Cellular Automata is a dynamic model included in the GIS platform (Marko *et al.*, 2016). The accuracy of the model was assessed using Kappa Coefficient once the model is generated. If the simulation accuracy result is reached > 75%, there is no need to repeat the accuracy assessment process, and can proceed to the next modeling process (Sugandhi *et al.*, 2022; Latue & Rakuasa, 2022). The complete research workflow can be seen in Figure 4.

3. Results and Discussion

3.1. Land Use and Land Cover (LULC) in 2002, 2012 and 2022

Land Use and Land Cover (LULC) in Ternate Tengah Subdistrict has undergone significant changes from 2002, 2012, and 2022, especially for residential and bare land cover. These land covers continue to increase. This contrasts the type of land cover of agricultural areas and non-agricultural areas that continue to decrease in the area due to uncontrolled urban growth. Land cover growth is influenced by the increase of residents living in Central Ternate District, which raises the need for built/settlement land and impacts the conversion of other functions into residential land. Spatially, the Land Use and Land Cover (LULC) of Central Ternate District in 2002, 2012, and 2022 can be seen in Figure 5, and the area of each land cover class can be seen in Table 2.

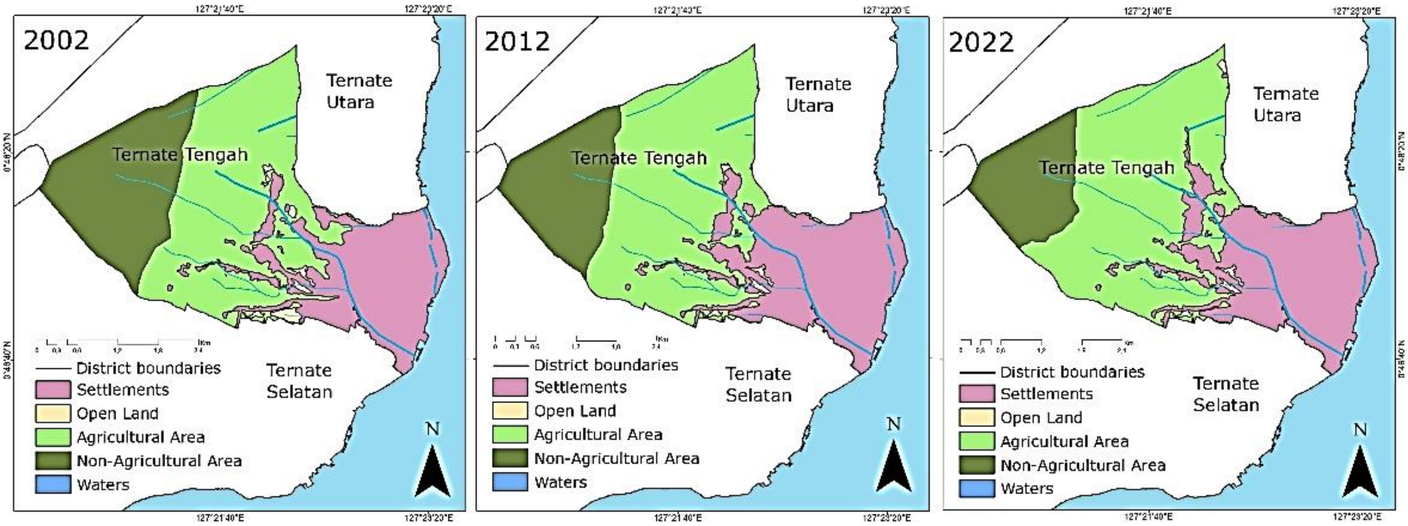

Figure 5. Land Use and Land Cover, Central Ternate District.

Table 2. Land Use and Land Cover Area of Central Ternate District.

Land Use and Land Cover (LULC)	2002		2012		2022	
	hectare	%	hectare	%	hectare	%
Settlements	385.08	27.37	441.91	31.40	459.01	32.62
Open Land	18.21	1.29	10.40	0.74	8.38	0.60
Agricultural Area	648.75	46.10	695.24	49.41	732.49	52.05
Non-Agricultural Area	354.33	25.18	258.83	18.39	206.5	14.67
Waters	0.79	0.06	0.79	0.06	0.79	0.06
Total	1407.17	100.00	1407.17	100.00	1407.17	100.00

Figure 5 shows that the settlement development pattern is heading eastward. The rate of population growth that continues to increase in line with development in all fields has resulted in the emergence of new problems, namely the increasing need for residential land as a demand for living needs in addition to clothing and food needs (Salakory & Rakuasa, 2022). Central Ternate subdistrict, which is the center of Ternate City and the center of education, economy, and government, makes the flow of urbanization that is getting higher every year, the movement of residents from rural to urban. This is certainly one factor that triggers changes in cover in Central

Ternate District. Population movement from rural to urban brings substantial and diverse changes to urban land, both in land use and land cover (Ajeeb *et al.*, 2020). The increase in the number of people is also in line with the increase in human activities in various sectors, especially the economic sector (Salakory & Rakuasa, 2022).

3.2. Land Cover Simulation in 2022

Simulations were carried out using CA-Markov using previously created driving factors. The probability of a change occurring or not is known from the Markovian value (Markov Chains Value) or the Transition Probability Matrix (TPM). The amount from the Markovian value (Markov Chains Value) or the Transition Probability Matrix (TPM). The amount of TPM in the 2022 simulation is shown in Table 3, driving factors that have been made previously.

Table 3. Transition Probability Matrix (TPM) from 2012 – 2022.

LU/LC	Settlements	Open Land	Agricultural Area	Non-Agricultural Area	Waters
Settlements	0.8500	0.0375	0.0375	0.0375	0
Open Land	0.5121	0.4879	0	0	0
Agricultural Area	0.2142	0	0.7858	0	0
Non-Agricultural Area	-	0	0.3789	0.6211	0
Waters	0	0	0	0	1

Ambon City land cover modeling in 2021 was carried out using Markov Chains and driving factors data that had been prepared. The magnitude of the possibility of land cover change is called the Transition Probability Matrix (TPM), while the figures in the SDGs table show the magnitude of the possibility of land cover that has changed into other land covers. The magnitude of the Transition Probability Matrix (TPM) value in the range of 0-1. The number 0 indicates no change in land cover from one area to another. Meanwhile, number 1 indicates that the land cover will be fixed and will not change to other land covers. From Table 3, it can be seen that open land has a higher probability of turning into Settlements with a TPM value of 0.5121. After the 2022 land cover simulation is generated, an accuracy test is carried out on the model to determine whether the model can be used to create a second model. The accuracy test was carried out by comparing the existing land cover data (in 2022) as a ground truth image using Idrisi Selva software where the Kappa (Kstandard) value is 0.8960 or 89.60% which shows that this accuracy value is said to be very good and can be continued to model the land cover of The Central Ternate District in 2032. More details of the kappa test can be seen in Figure 6.

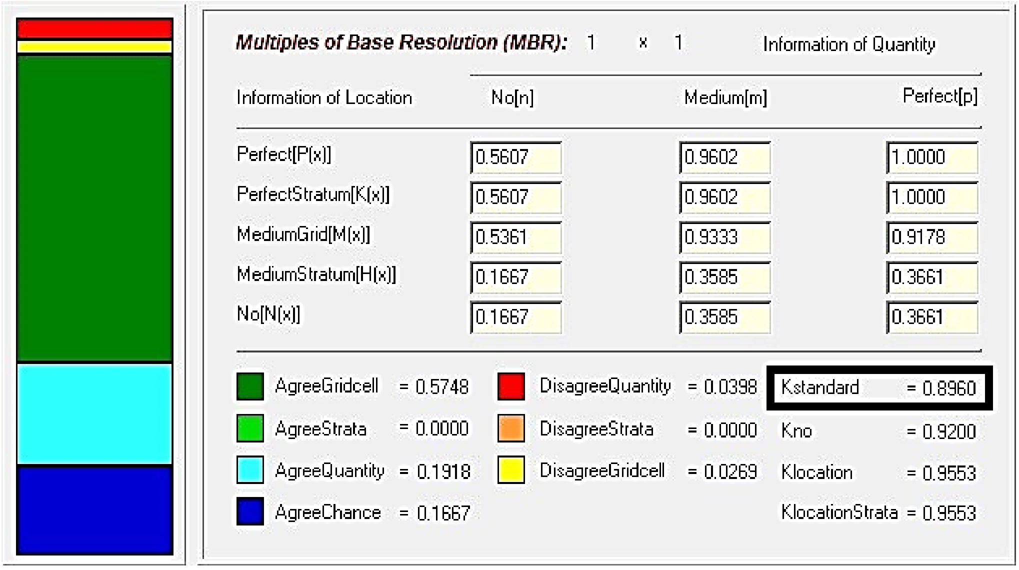

Figure 6. Validation of 2022 Models with Kappa Test.

Based on the results of land cover simulations in 2022, significant changes in land cover are found in residential land cover, whose area has increased. This significant increase in the area of settlements occurred in the central and northern parts of Pariaman City. Meanwhile, land cover that has decreased occurs in agricultural land cover (Figures 7 and 8). From the five land covers, it can be seen that open land has the greatest probability of turning into residential land with a TPM value of 0.4680, followed by the type of Agricultural Area cover with a TPM value of

0.1495. Waterbody has a TPM value of 0, meaning it will not change to other land cover types. Based on the results of land cover simulations (Figure 9), it is known that the type of residential land cover has an area of 503.91 hectares, open land has an area of 7.35 hectares, agricultural areas have an area of 696.46 hectares, non-agricultural areas have an area of 198.65 and types of aquatic land cover have an area of 0.79 hectares.

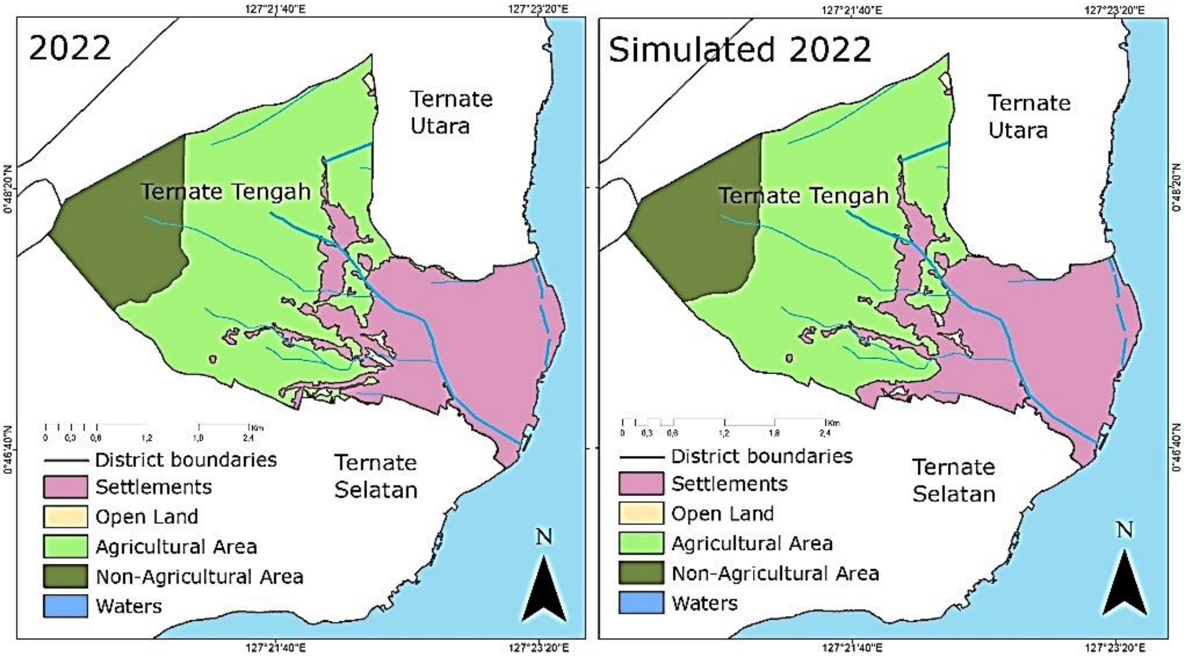

Figure 7. Comparison of simulated and observed land cover results in 2022.

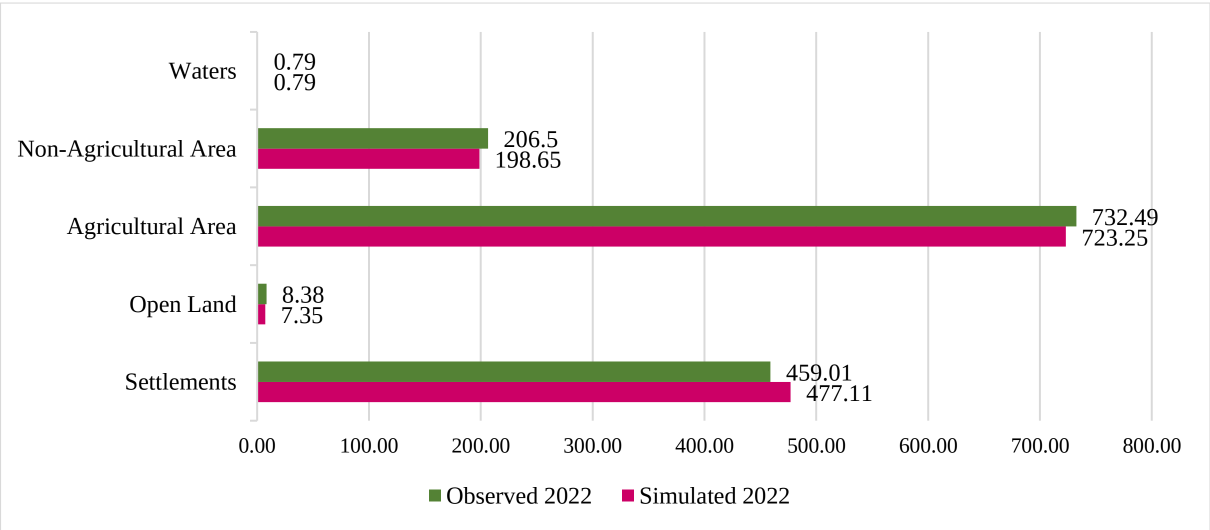

Figure 8. Comparison of the land covers area in 2022 resulting from simulated and observed results.

Table 4. Transition Probability Matrix (TPM) from 2022 – 2032.

LU/LC	Settlements	Open Land	Agricultural Area	Non-Agricultural Area	Waters
Settlements	0.8500	0.0375	0.0375	0.0375	0
Open Land	0.4680	0.5320	0	0	0
Agricultural Area	0.1495	0.0191	0.8314	0	0
Non-Agricultural Area	-	0	0.3231	0.6769	0
Waters	0	0	0	0	1

3.3. Land cover simulation in 2032

The 2032 land cover simulation in Central Ternate District is the second simulation, in this stage using the same driving factors and potential transition accuracy as in the first simulation, but using different macrovian values (Table 4), so that it will produce the 2032 model year. Urban growth in Central Ternate District greatly affects changes in Land Use and Land Cover (LULC), this can be seen from the development of built-up land from 2002, 2012, 2022 and based on the results of modeling in 2032 the area of residential land will continue to experience an increase in area of 503.91 ha. The results of the land cover simulation in 2032 can be seen in Figure 9.

Urban growth in Central Ternate Regency greatly influences Land Use, and Land Cover (LULC) changes. This can be seen from residential land development from 2002, 2012, and 2022. Also, it can be seen from the modeling results in 2032. The area of Residential land will continue to increase by 503.91 hectares. Based on Figure 10, it is known that residential land continues to experience a significant increase every year. In the northern and eastern parts of the residential area, the area has extended from the collector road since there is no longer any non-developed land directly adjacent to the road.

Residential/built-up land will continue to increase in area as population growth increases and demand for land in the region increases (Utami *et al.*, 2018). The results of this study are expected to help estimate or understand future land cover changes based on past trends and their driving variables in Central Ternate District. Furthermore, the results of the analysis and prediction of changes in land cover in Central Ternate District are expected to be used as evaluation material in making policies related to spatial planning and spatial use in Ternate City, especially in Central Ternate District in the future.

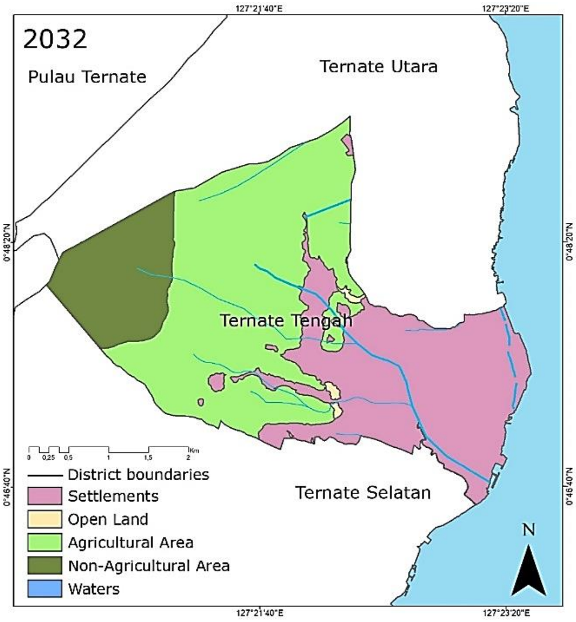

Figure 9. Results of land cover simulation in 2032.

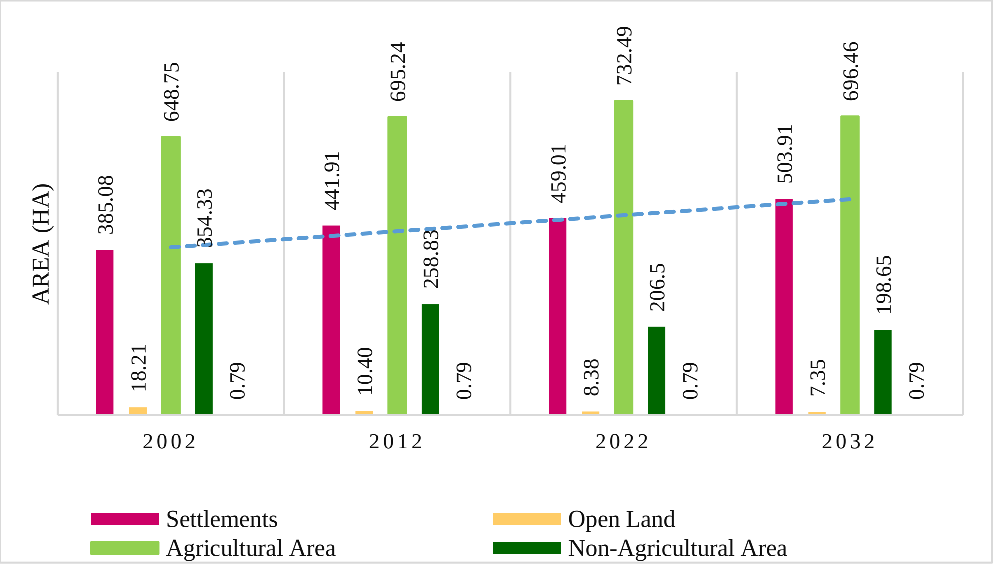

Figure 10. Development of Land Use and Land Cover in Central Ternate District.

4. Conclusion

Over the last 20 years, from 2002, 2012, 2022 and the results of the Celullar Automata Markov Chain model predictions in 2032, land cover changes in Central Ternate District continue to experience an increase in area. Land cover that has consistently increased in the area is found in residential and open land cover. Land cover that has decreased in the area is found in the land cover of agricultural areas and non-agricultural areas. Residential land will continue to experience an increase in area in line with population growth and high demand for land in Central Ternate District. Therefore, the results of this study are expected to be input in policy-making related to the arrangement and utilization of disaster mitigation-based space in Central Ternate District in the future.

Acknowledgments

The authors would like to express our gratitude to anonymous reviewers who gave useful comments to develop this paper.

Author Contributions

Conceptualization: Heinrich Rakuasa & Yamres Pakniany; **methodology**: Heinrich Rakuasa & Yamres Pakniany; **investigation**: Heinrich Rakuasa & Yamres Pakniany; **writing—original draft preparation**: Heinrich Rakuasa & Yamres Pakniany; **writing—review and editing**: Heinrich Rakuasa & Yamres Pakniany; **visualization**: Heinrich Rakuasa & Yamres Pakniany. All authors have read and agreed to the published version of the manuscript.

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