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Prediction of Land Cover Model for Central Ambon City in 2041 Using the Cellular Automata Markov Chains Method

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Abstract: The Ambon city center area based on the 2021-2041 RDTR is a center of economic, educational and cultural activities, this makes economic and population growth focused in this region. This also triggers the arrival of residents from other areas to Ambon City and will have an impact on increasing the provision of land for settlements. This condition is expected to trigger land conversion in this area. This study aims to analyze land cover changes in Ambon City in 2001, 2011, 2021 and predict land cover in 2041. This study uses Cellular Automata Markov Chains modeling to predict land cover in the central area of Ambon City in 2041. The results show that the type of built-up land cover and open land continued to increase in area, while agricultural and non-agricultural areas continued to experience a decrease in area and water bodies did not experience a decrease in area. The results of this study are expected to be used as a reference in managing the development of sustainable residential areas and as an effort to arrange land use in the Ambon City center area in the future based on ecological aspects.

Keywords: Ambon City, Cellular Automata, Land Cover, Markov Chains

1. INTRODUCTION

Land cover changes are landscape phenomena that play a very important role in environmental changes at the local, national, and global levels (Wu et al., 2021). Changes in land cover as a form of dynamic interaction process between human activities and land resources, which are spatially distributed (Sugandhi et al., 2022). In particular, the fastest changes in land cover can be seen around urban areas (Sapena & Ruiz, 2019). Land cover changes can also be said to be the switching of land functions with each other that are directly or indirectly related to certain goals in an effort to meet the needs of human life (He et al., 2018; Rakuasa & Somae, 2022). Population growth in line with the increase in human activities in various sectors, especially the economic sector, has triggered a faster rate of land use change / land cover from year to year in the central area of Ambon City (Salakory & Rakuasa, 2022).

Each region has a variety of different types of land cover that vary (Al-Hameedi et al., 2021). This variation is identified from the types of land use that grow and develop in the use of the land (Masiliūnas et al., 2021). Usually, variations in the type of land use in accordance with its designation. However, it does not rule out the possibility that there are also types of land use that are not in accordance with its designation. This discrepancy that causes the process of controlling the utilization of space must be considered more deeply in the form of rules of space utilization (Rakuasa et al., 2022).

Changes in land cover have a significant effect on regional development planning and also on ecosystem functions at all spatial scales, from global to local (Talukdar et al., 2021), It is therefore important to understand the relationship between social phenomena and natural phenomena that occur (Rienow et al., 2022), especially in urban areas to improve the sustainability of dynamic landscapes and to predict the effects of land use planning (Mallick, 2021). This will lead to increased competition in land use, so that economic and social needs will always be a priority in land use change in one region (Sun et al., 2022).

The central area of Ambon City based on the Spatial Detail Plan (RDTR) 2021-2041 is a center of economic, educational and cultural activities, this makes economic growth and population focused in this region. It also triggers the arrival of residents from other regions to Ambon City to settle and have economic activity in Ambon City and will have an impact on increasing the provision of land for settlements. This condition is expected to trigger the transfer of land functions in this area (Liping et al., 2018). Therefore, the utilization and efficiency of urban land cover must be improved based on rational land cover planning with sustainable development goals (Sun et al., 2022), so that there needs to be an increase and management of the potential development of the region (Mohamed & Worku, 2020). Because one of the keys to sustainable development in urban areas is planning and structuring spaces in accordance with the regulations that have been made (Liu et al., 2020).

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Cellular Automata is believed to be an excellent method for predicting future spatial change patterns (Ghosh et al., 2017). Markov Chains has a good ability to statistically predict the probability of change while Cellular Automata is believed to be a powerful method of reading spatial and temporal change pattern (Rakuasa et al., 2022). Cellular Automata Markov Chains modeling it is the most reliable, accurate, and useful model for accurately simulating and predicting future changes in land cover (Rakuasa et al., 2022). This modeling can be used in spatial decision-making for more effective and efficient simulation, prediction and future land use planning (Fitawok et al., 2020).

Cellular Automata Markov Chains method used to make a model of prediction of land cover in the central area of Ambon City in 2041 which will be compared to the RDTR of the central area of Ambon City in 2041 and the results of this modeling are expected to provide solutions in the structuring of land use in Ambon city in the future that are sustainable based on ecological aspects and can support land use planning and proper land use allocation in addition to conducting conservative activities as a preventive effort in ecologically based land use. Therefore, it is necessary to handle and manage land wisely and sustainably. The study aims to spatially determine land cover changes in the central area of Ambon City in 2012, 2017, 2021 and predict land cover by 2041.

2. RESEARCH MATERIALS AND METHODS

This research was conducted in the central area of Ambon City, Maluku Province, Indonesia which has a total area based on the spatial detail plan (RDTR) 2021-2041 which is an area of 2,168.89 ha. (Figure 1). To conduct analysis and prediction of land cover in the central city of Ambon, data collection is needed in three ways, namely literature studies, institutional studies, and field surveys. The type of data and the source can be seen in Table 1 below.

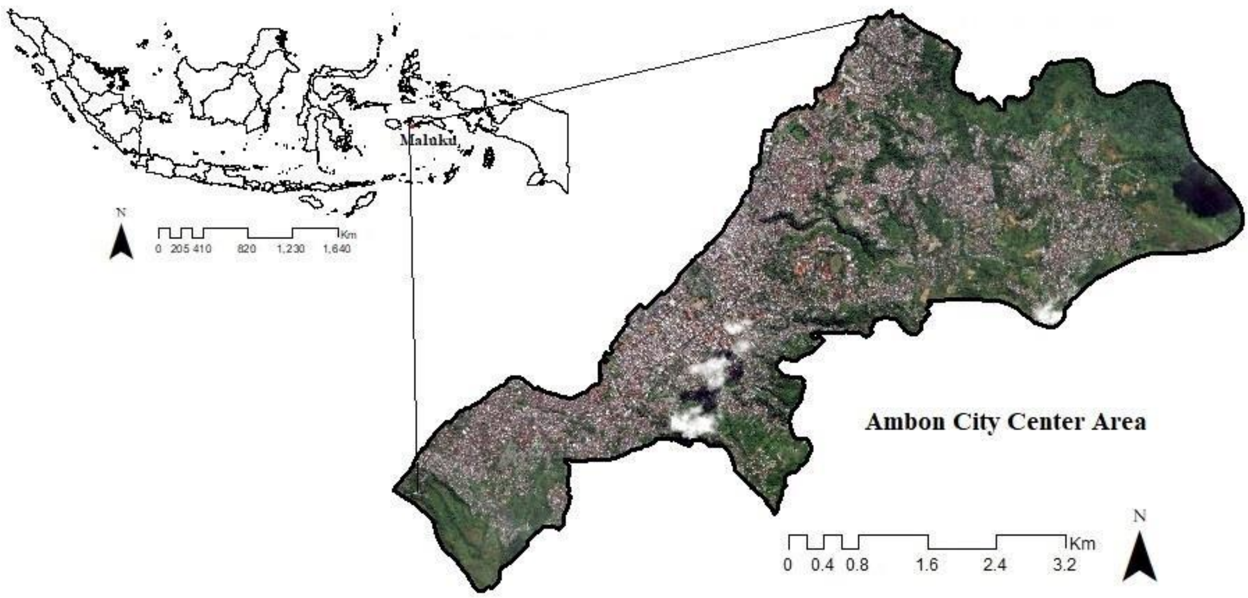

Figure 1. Research Location

Table 1. Research Data

No	Data Components	Source
1	IKONOS Satellite Image in 2001 & 2011 and SPOT 6 image in 2021	Ambon City Builder Planning Agency
2	RDTR Map of central area of Ambon City in 2021-2041	Ambon City Builder Planning Agency
3	Road Network	Geospatial Information Agency
4	River Network	Geospatial Information Agency
5	Coastline	Geospatial Information Agency
6	Land Height	Geospatial Information Agency
7	Slope	Geospatial Information Agency

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The multitemporal satellite imagery data used in the study consists of a 2001 IKONOS satellite image, IKONOS satellite imagery in 2011 and SPOT 6 satellite imagery in 2021 used to interpreting and classify land cover in the third year, while the data used to be a factor driving the development of settlements, namely, elevation, slope, distance from the road, distance from the river and distance from the coastline (Figure 2).

The process of interpretation and classification of land cover is carried out by manually digitizing the land cover class in each multitemporal image data with reference to SNI 7645:2010 (Badan Standarisasi Nasional, 2010), which is divided simply into 5 classes of land cover, namely, residential land, open land, agricultural areas, non-agricultural areas and waters. Processing and analysis of data in this study consists of Interpretation, classification of land cover in 2001, 2011 and 2021, processing of driving factors and making land cover models in 2041 which will be compared to RDTR map of the central area of Ambon city in 2021-2041. Multitemporal land cover data process and data processing factors driving in this study using ArcGIS 10.8 software and the process of making a land cover prediction model in 2041 using IDRISI Selva 17.0 software. Each driving factor has a different influence on each type of land cover change so weighting or weighting is done (Table 2), to calculate the power of driving factor.

Table 2. Classification of Driving Factor.

No	Parameters	Classification	Weight
		0 – 3 %	4
		3 – 15 %	3
1	Slope	15-40 %	2
		>40 %	1
		0-7 msl	2
		7-25 msl	3
2	Elevation	25-100 msl	4
		100-500 msl	5
		>500 msl	1
		0-100 m	1
		101-200 m	2
3	Distance from the river	201-300 m	3
		301-500 m	4
		>500m	5
		<100 m	3
		100-2000 m	2
4	Distance from coastline	>2000 m	1
		0-25 m	5
		25-50	4
		0-25 m	5
		25-50	4
5	Distance from the road	50-100	3
		100-1000	2
		>1000	1

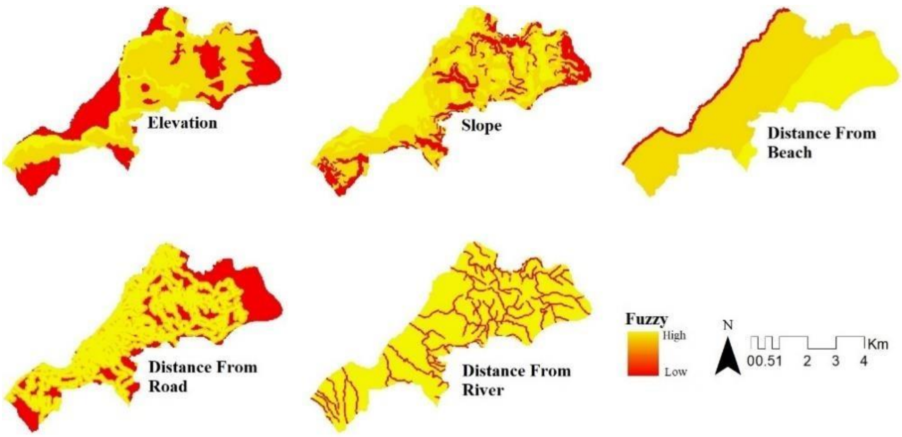

Figure 2. Driving Factors for Settlement Development

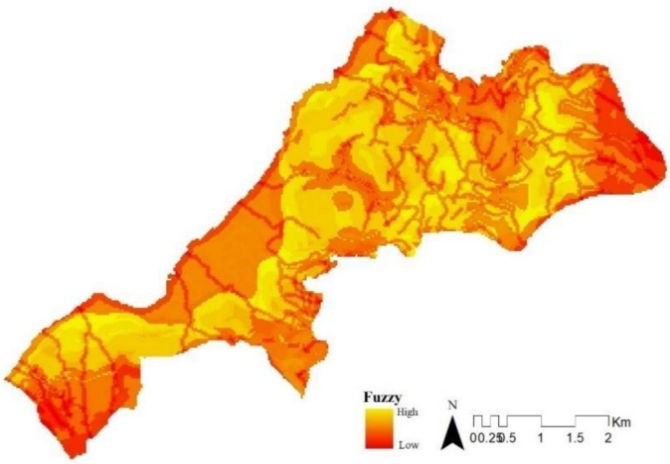

Figure 3. Overlay Driving Factors

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Driving factor data is classified and analyzed in Arc Map software using fuzzy overlay tools (Figure 3). Fuzzy is a logical system that aims to formalize the approximate to reasoning represented in the form of interest levels that have a value range of 0-1 (Boolean) (Zadeh, 1994). According to (Ghosh et al., 2017), fuzzy logic is an excellent thing to interpret data that occurs continuously effectively and efficiently, this is a good way to do cellular automata-based modelling because it uses parallel computing consisting of cells that are interconnected and have continuous value, so that in this study the author processed driving factors data using the concept of fuzzy logic. Fuzzy logic values are shown in red-yellow. The five driving factors are then overlayed using fuzzy overlay tools in the Arc Map software to combine all the data. The classification of each driving factors parameter in this study can be seen in Table 2 and the results of fuzzy analysis on driving factors can be seen in Figure 2 while driving factors that have been overlayed can be seen in Figure 3.

The Markov Chain model produces a Transition Probability Matrix which is a transition matrix of changes from the previous year to the projected year (Sugandhi et al., 2022) . The Markov equation is constructed using land-use distributions at the beginning and end of the observation period presented in a vector (one-column matrix), as well as a transition matrix (Kim et al., 2019). Next, validate the model. Validate the model here that we do. For this reason, there are also projections in the actual year (2021), based on data in 2001 and 2011. After that, the model accuracy test using K - Standard (Kappa Coefficient) calculations until the value reaches >70% or passes the accuracy test and can be predicted for 2041. Then the results of the simulation in 2041 compared to using RDTR data of central area of Ambon city in 2021-2041 are seen how many matches from the simulation data and RDTR data expected by the Ambon city government. More details of this research workflow described in Figure 4 below.

3. RESULTS AND DISCUSSION

3.1. Land Cover Development in downtown Ambon City area in 2001, 2011 and 2021

Built-up land and open land in the central area of Ambon City in the 2001-2021 period continued to experience a significant increase in area, in contrast to types of non-agricultural and agricultural land cover which experienced a reduction in area. This is influenced by the increase in the number of residents in Ambon City in line with the increase in human activities in various sectors, especially the economic sector, so that the need for land resources will also continue to increase. The high population increase in the central area of Ambon city can increase the need for land that is realized in the form of physical development, economic facilities or social facilities. Spatially the area of land cover changes in the central area of Ambon city in 2001, 2011 and 2021 can be seen in Figure 5 and Figure 6.

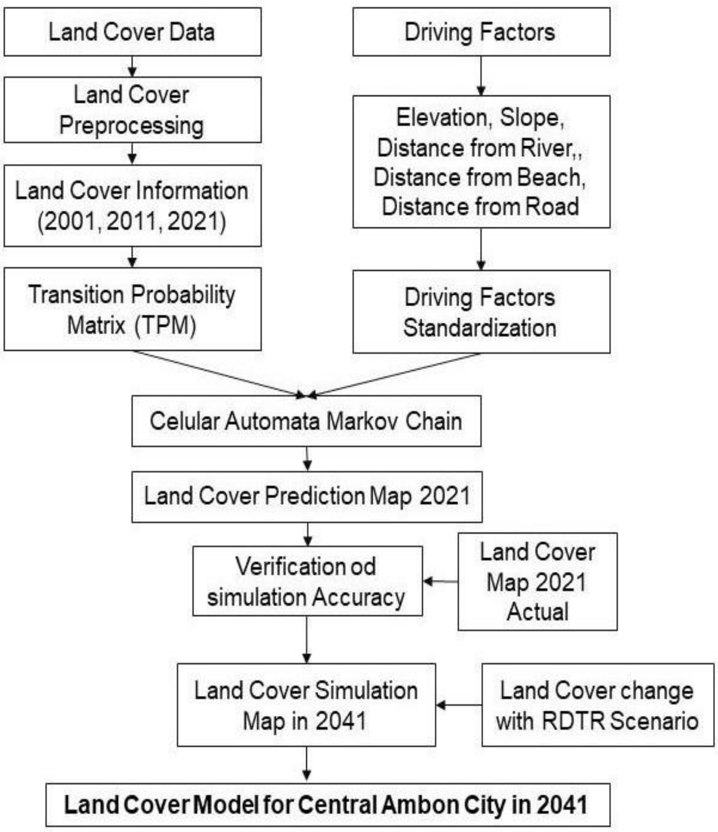

Figure 4. Research Workflow

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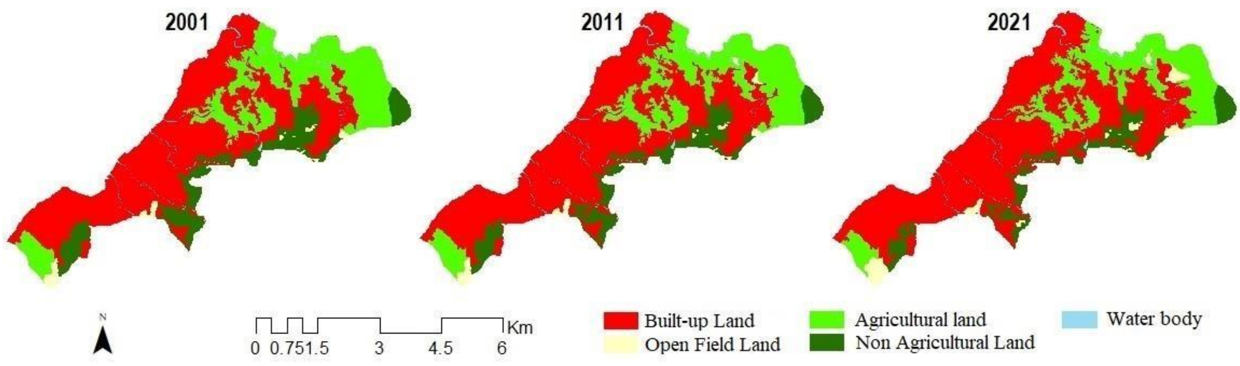

Figure 5. Land cover in 2001, 2011 and 2021

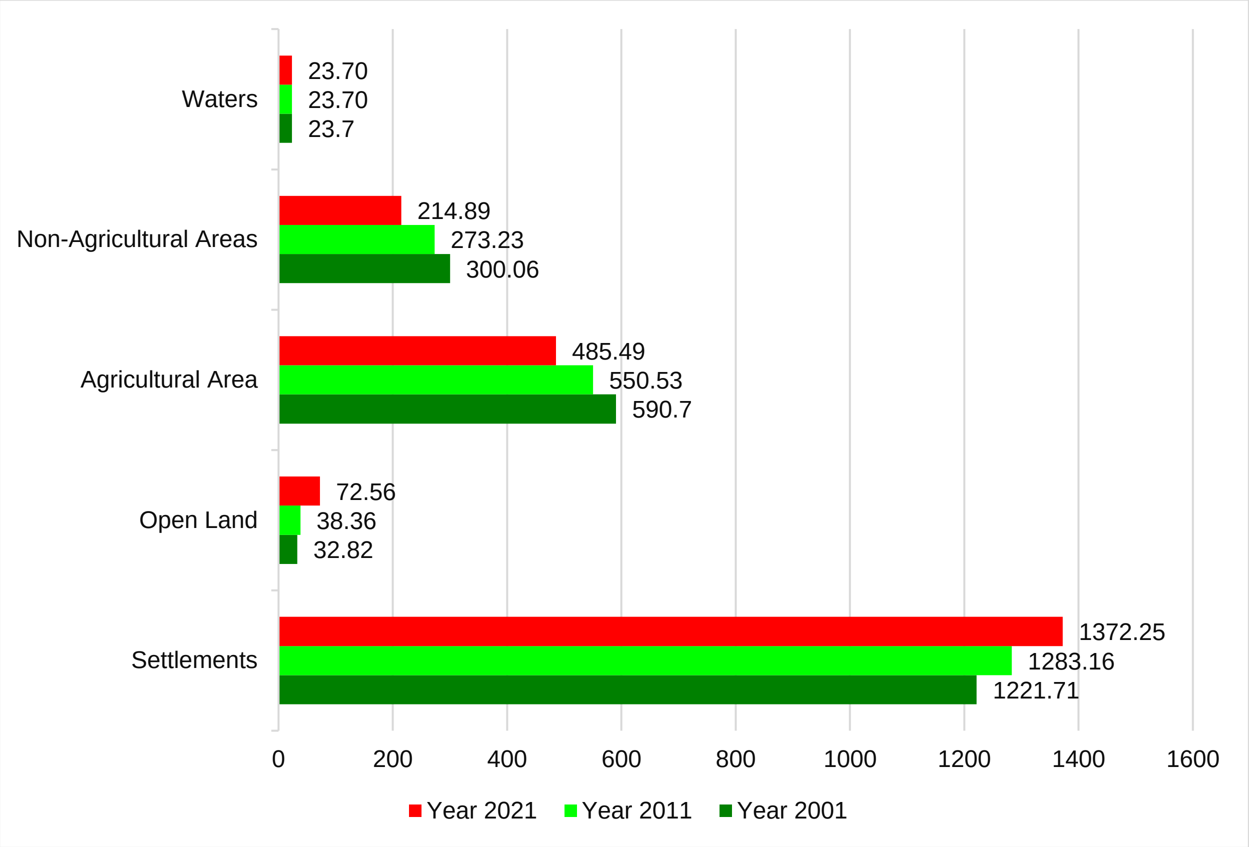

Figure 6. Composition of Ambon City Land Cover in 2001, 2012 and 2021

3.2. Land Cover Simulation Model 2021

Modeling the prediction of land cover change in Ambon City in this study was carried out twice, the first modeling was carried out to see the accuracy of the driving factors given to the 2021 land cover model which aims to see the selection of driving factors. The first modeling will produce (Kappa value), where if the kappa value is ≥70% then the modeling can be done for the second modeling. For the second modeling is done to predict land cover in 2041 using the same driving factors as the first modeling. The Transition Probability Matrix (TPM) in table 4 is the possibility of changing one land cover class to another.

Rows in the probability matrix in Table 3 indicate the origin of land cover, while the columns indicate the purpose of land cover changes. The value of the TPM in Table 3 is in the range of 0-1. The greater the probability value of the destination land cover, the greater the possibility of simple land cover. It can be seen that agricultural land cover has a higher probability of turning into settlements with a TPM value of 0.1977, while the number 1 for the type of water body land cover indicates no change. The results of the 2021 land cover model are shown in Figure 7.

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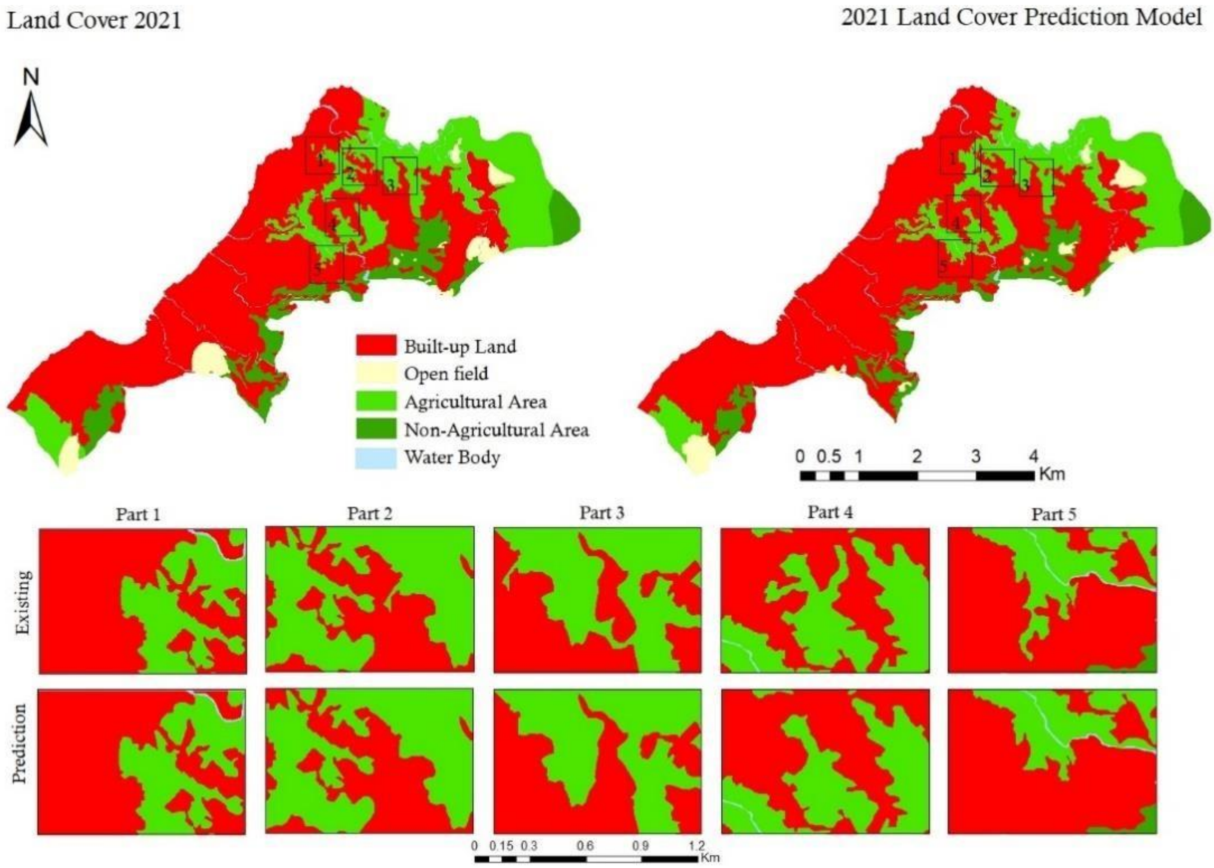

Figure 7. Comparison of existing land cover in 2021 and prediction 2021

Table 3. Transition Probability Matrix (TPM) from 2001 – 2021

	Settlements	Open Land	Agricultural Area	Non-Agricultural Areas	Waters
Settlements	0.8500	0.1375	0.0375	0.0375	0
Open Land	0.1613	0.8387	0	0	0
Agricultural Area	0.1977	0.0309	0.9739	0	0
Non-Agricultural Areas	0.2281	0	0	0.7719	0
Waters	0	0	0	0	1

In Figure 7, the results of the 2021 land cover modeling on residential land classes are wider than the existing 2021 land cover results, which are different from other land cover types where the area is wider than the 2021 land cover modeling results.

The results of the 2021 land cover model are then tested for accuracy. The model accuracy test is very important to do to find out whether the first generated model can be applied to produce the second predictive model. Accuracy tests were carried out using existing land cover data for 2021 as reference data (Latue & Rakuasa, 2022) and land cover prediction model data for 2021 as a comparison image. The accuracy test results obtained a kappa value (standard K) of 0.9557 or 95.57% which indicates that this accuracy value is proven to be large and can be applied to model land cover in the central area of Ambon City in 2041.

3.3. Land Cover Simulation Model 2041

The complete transition probability matrix to 2041 can be seen in Table 4. Just like the first modeling, the value of the TPM in Table 4 is a safe transition probability assuming the possibility that pixels from a certain land cover class will change to another class (or remain the same). in the next time period. The Markov value of the TPM is constructed using the distribution of land cover at the beginning and end of the observation period which is represented in a vector (one pond matrix), as well as a transition matrix. The value of the TPM is in the range of 0-1. The number 0 indicates that there is no change in land cover from one area to another. Number 1 indicates that the land cover is fixed and does not change to other land covers. The greater the probability value on the destination land cover, the greater the possibility of land cover changing.

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Table 4. Transition Probability Matrix (TPM) from 2021 – 2041

	Settlements	Open Land	Agricultural Area	Non-Agricultural Areas	Waters
Settlements	0.8173	0.1198	0.0092	0.0393	0
Open Land	0.5375	0.8500	0.0375	0.0375	0
Agricultural Area	0.6337	0.0977	0.7653	0	0
Non-Agricultural Areas	0.0375	0.0375	0.0375	0.8500	0
Waters	0	0	0	0	1

Agricultural areas have a higher probability of turning into settlements compared to other land cover classes with a TPM value of 0.6337. The number 1 for the type of aquatic land cover indicates that the land cover will remain the same and will not change to other land covers.

Based on the results of land cover modeling of the central area of Ambon City in 2041 using the Cellular Automata Markov Chains method can be seen in Figure 8 that there is an increase in area in the type of residential land cover and open land and vice versa there is a decrease in the area of land cover of agricultural areas and non-agricultural areas while the type of water land cover does not increase or decrease the area. One of the factors that are very influential in the increase in the area of settlement land in 2041 is accessibility or distance from the road. The higher the level of accessibility of a city for its people, the higher the productivity level of the city then the possibility of the city will become fast forward, and vice versa if accessibility is low then most likely in that location the development will be slow.

Predictions of land cover changes in the central area of Ambon City in 2041 were made to compare with RDTR land cover of the central Ambon city area in 2021-2041 (Figure 9). In the Ambon City RDTR PERDA, the government focuses more on the development of one of which realizes Ambon city as a waterfront city pilot city, based on cellular automata predictions, in 2041 the area of build-up Land in the central area of Ambon city is 1,463.60 ha, Open Field (69.46 ha), Agricultural Area (405.51 ha), Non-Agricultural Areas (206.61 ha), and Water Body (23.70 ha,) (Figure 8).

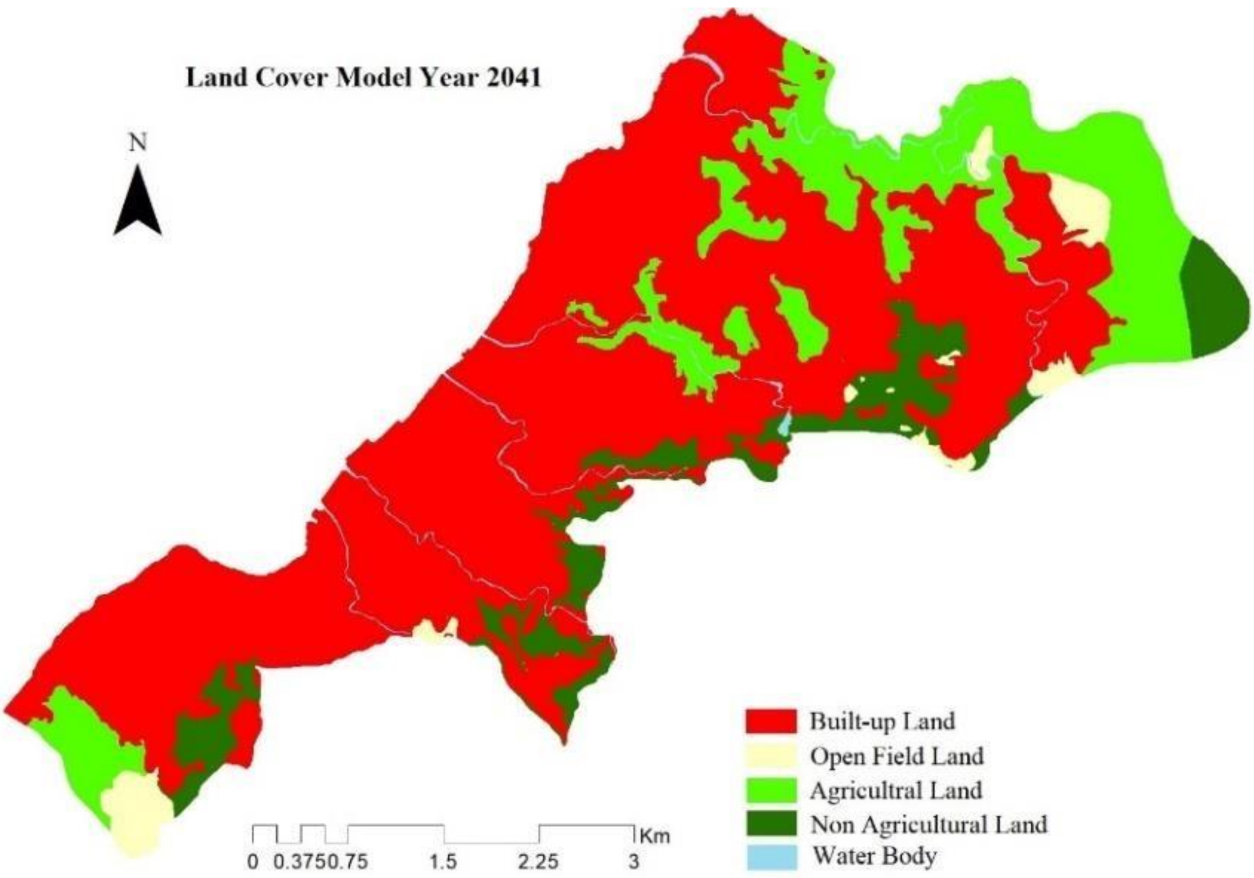

Figure 8. Land Cover Model of Ambon City central area in 2041

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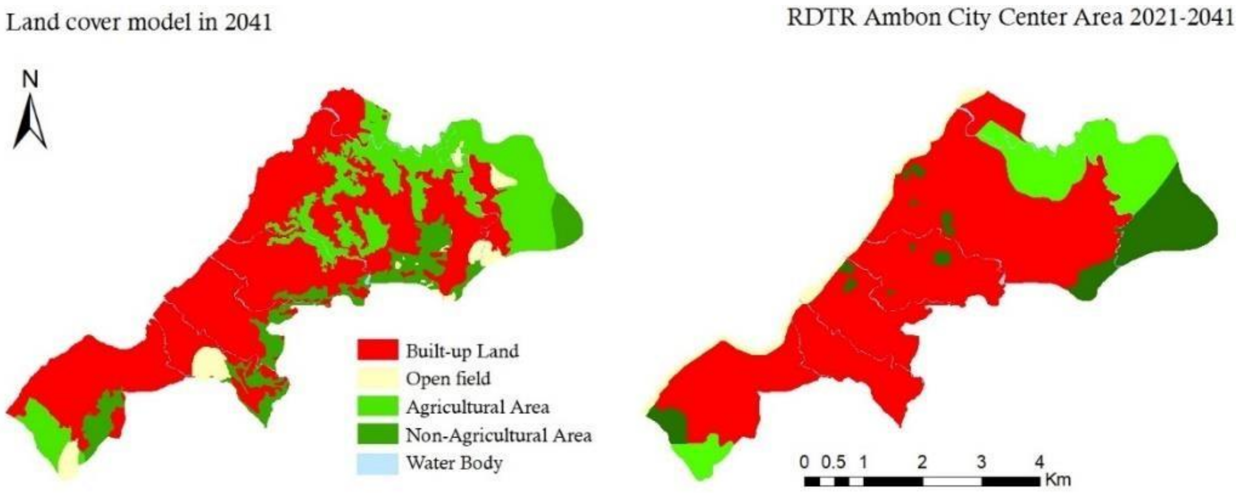

Figure 9. Comparison of Land Cover Model in 2041 and RDTR in 2041

The results of the prediction of land cover in 2041 were then tested for accuracy using the RDTR for the Ambon City Center area in 2011-2041 which had been generalized based on land cover class. The results of the accuracy test show that the model year 2041 has an accuracy value of 0.7643 or 76.43%. This means that the land cover prediction model in 2041 is said to be very good to be used in the next analysis.

Increasing the area of residential land in the Central Region of Ambon City from year to year will cause a decrease in the carrying capacity of the environment (Salakory & Rakuasa, 2022) and environmental damage (Kang & Kanniah, 2022). Therefore, the results of the analysis and prediction of land cover changes can provide a solution in structuring the land use of the Ambon City Center in the future that is sustainable based on ecological aspects and conservation efforts to support land use planning and appropriate land use allocation in addition to carrying out conservative activities as preventive efforts in ecologically based land use.

4. CONCLUSION

It can be concluded that spatially the land cover in the Central Area of Ambon City has undergone significant changes. From 2001, 2011 and 2021, built-up land has continued to increase and increase in area, as well as open land which has increased in area. The direction of development of built-up land tends to follow the topography and road network. In contrast to the cover of agricultural and non-agricultural land, it continues to change into built-up land due to the increasing need for land every year. The prediction results in 2041 show that built-up land will continue to increase in area along with increasing population and demand for land, therefore the results of this study are very useful and can be used as material and input in making policies related to spatial planning and use in the central area of Ambon City in the future.

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