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Land Cover Modeling in 2034 in Waiheru Watershed, Ambon City, Indonesia Using CA-Markov

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Abstract

The increasing demand for land due to population growth and community activities in Ambon City certainly has an impact on land cover changes in the Waiheru Watershed. Therefore, it is important to model future land cover as a sustainable environmental planning material. This study aims to analyze land cover changes in 2014, 2019, 2024 and model land cover in 2034 with the Cellular Automata Markov Chain (CA-Markov) approach. This method integrates historical land cover data and factors driving land use change, elevation, slope, distance from road, distance from river, population, distance from point of interst. The results show a trend of conversion of mixed agricultural land into residential areas, which certainly has the potential to exacerbate ecosystem vulnerability in the Waiheru watershed. Settlement land cover continues to increase in area, namely 68.78 ha in 2014, 77.73 ha in 2019, 96.72 ha in 2024 and the modeling results in 2034 show that settlement land has an area of 138.65 ha, this is in contrast to the forest area which has decreased due to the expansion of population settlements.These findings are expected to provide insights for policy makers and urban planners in formulating sustainable land management strategies, as well as maintaining a balance between development needs and environmental conservation in the Waiheru watershed.

Keywords: Cellular automata, land cover, Markov Chain, Waiheru

1. Introduction

Land cover change is a global phenomenon that has significant impacts on ecosystems and the environment. In Indonesia, as an archipelago with high geographical diversity, land cover change is a crucial issue, especially in areas experiencing rapid growth such as Ambon City (Salakory & Rakuasa 2022). The Waiheru watershed in Ambon City is the focus of attention because of its vital role in providing water resources and maintaining the ecological balance of the region. In the context of sustainable development, a deep understanding of the dynamics of land cover change is necessary for effective planning and management of the region (Fitriana et al. 2021; Maurya et al., 2022). Predicting future land cover change is a valuable tool for policy makers and urban planners in anticipating environmental and socio-economic challenges that may arise (Ildoromi et al., 2015; Beroho et al. 2023). Therefore, modeling land cover in 2034 in the Waiheru watershed is a strategic step in efforts to manage a sustainable environment in Ambon City.

The use of Cellular Automata-Markov (CA-Markov) method in land cover modeling has been proven effective in various previous studies (Ghosh et al. 2017; Balist et al. 2021; Ghalehteimouri et al. 2022). This method combines the advantages of Markov analysis, which is able to predict changes based on historical trends, with the ability of Cellular Automata to model spatial and temporal interactions (Ghosh et al. 2017). This approach allows for a more accurate simulation of how land cover patterns will evolve over a period of time, taking into account drivers of change such as the physical condition of the area, accessibility, spatial policies, population growth, and economic development (Weslati, Bouaziz, and Sarbeji 2023; Selmy et al. 2023). The Waiheru watershed, as one of the important watersheds in Ambon City, faces various pressures due to population growth and infrastructure development (Rakuasa and Latue 2023). Land cover change in this area can affect water quality and quantity, soil erosion, and biodiversity (Manakane et al. 2023). Therefore, land cover modeling is crucial to identify areas vulnerable to change and its potential impact on the watershed ecosystem.

This study aims to produce a predictive model of Waiheru watershed land cover in 2034 using the CA-Markov method. The selection of 2034 as the

projection point considers the time period sufficient to see significant changes, but still within the range that can be anticipated by medium-term policies. The results of this modeling are expected to provide a clear picture of the direction of land cover change in the future, so that it can be the basis for better spatial planning and more effective environmental impact mitigation strategies. Land cover modeling using CA-Markov also enables policy-based scenario analysis (Subiyanto and Amarrohman 2019). By considering various development and conservation scenarios, the model can help stakeholders to visualize the long-term consequences of current spatial decisions (Rakuasa et al. 2022). This is particularly important given the unique characteristics of Ambon City as a coastal city vulnerable to climate change and natural disasters.

In addition, this study also aims to identify key factors influencing land cover change in the Waiheru watershed. Understanding these drivers of change is important for developing land management strategies that are adaptive and responsive to the social-ecological dynamics in the region. By integrating historical data, current conditions, and future projections, this research is expected to make a significant contribution to sustainable watershed management in Ambon City. The results of the study are expected to be an important instrument in supporting evidence-based decision-making for spatial planning and environmental management in Ambon City. This study is not only relevant for the local context, but can also provide valuable insights for watershed management in other regions in Indonesia that face similar challenges in balancing economic development with environmental conservation.

2. Research Methodology

This research was conducted in the Waiheru watershed located on Ambon Island, Indonesia (Figure 1). This research is a quantitative study that integrates Remote Sensing and Geographic Information System technologies. The method used in this research is the Cellular Automata-Markov Chain (CA-MC) method to predict future land cover in the Waiheru watershed. This research used SPOT 6 satellite image data in 2014, 2019 and 2024, which was then subjected to interpretation and digitization processes to obtain land cover data for the Waiheru watershed in the 2014, 2019 and 2024 periods. Land cover data is classified into five classes, namely, settlements, open land, mixed plantations, forests and rivers. The driving factor data used in this study are elevation, slope, distance from river, distance from road, population, and distance from Point of Interest (POI) which consists of distance from education and health centers

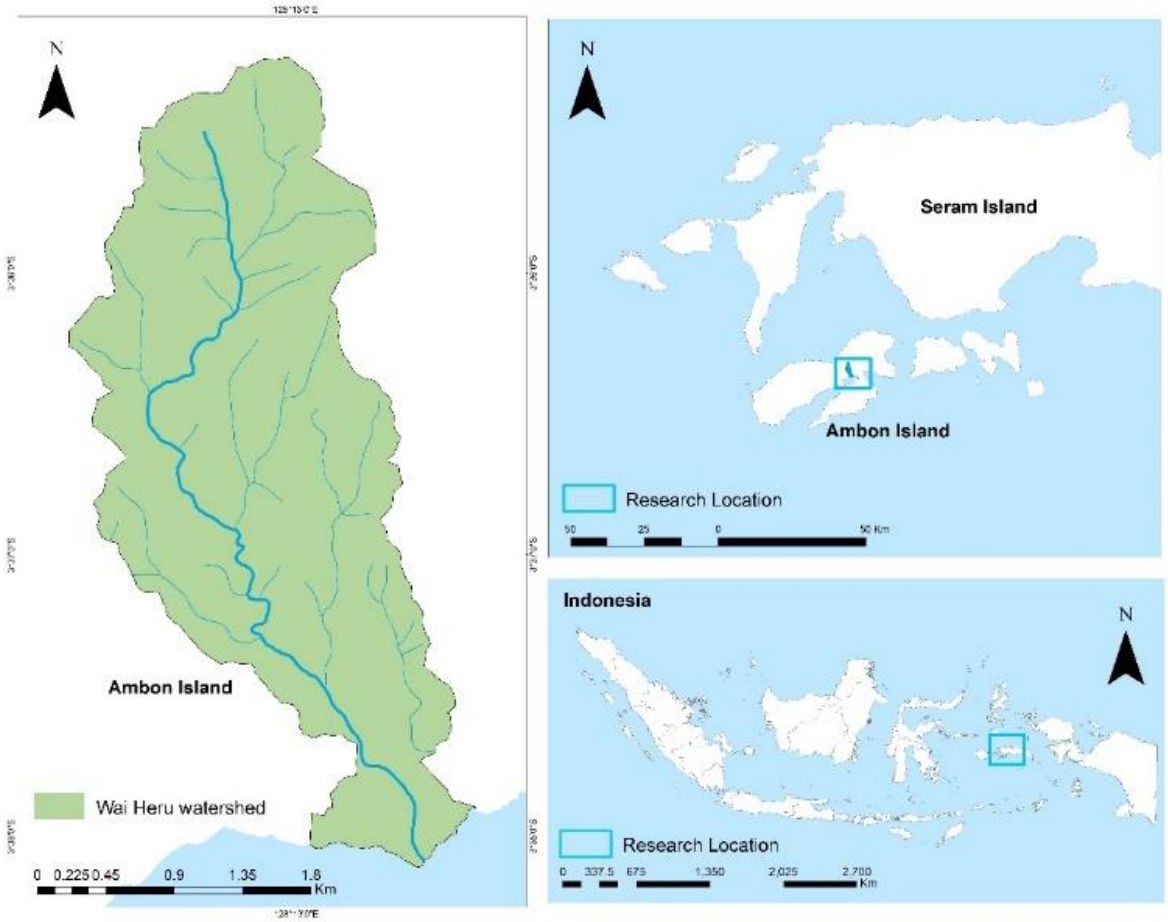

Fig 1. Research Location

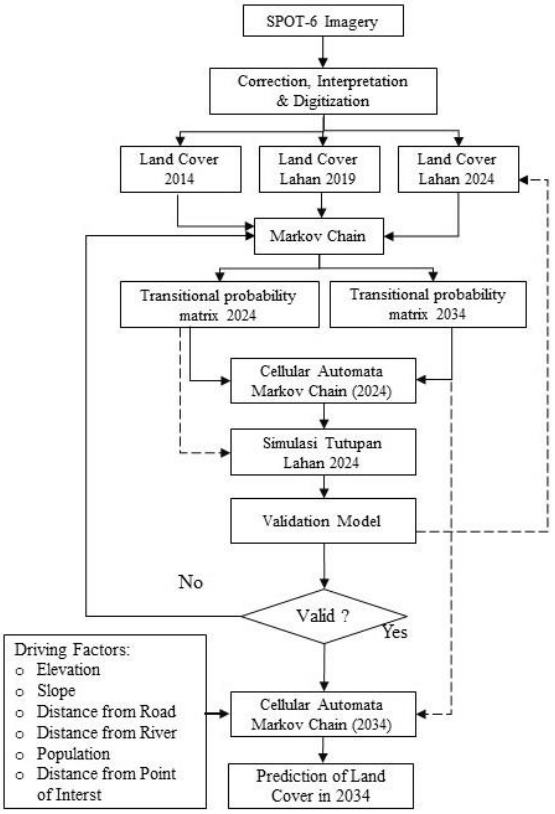

Fig 2. Workflow

The driving factors that affect land cover change with different levels of influence. This data was processed using ArcMap 10.4.1 with fuzzy overlay technique. Fuzzy is a good logic system to describe continuous data in Cellular Automata method. Each driving factor was combined using gamma fuzzy logic. The result of the Markov Chain model is a probability matrix showing land use change. The model was created based on the distribution of initial and final land cover, then validated by comparing the 2024 land cover from the digitization and field observation using Kappa Coefficient. The model accuracy test refers to the K-Standard (Kappa Coefficient) value with a value of >70% (valid) so that it can continue to be the basic land cover in predicting land cover in 2034. The detailed workflow of this research can be seen in Figure 2.

3. Result and Analysis

3.1. Land Cover in 2014, 2019 and 2024

Land cover development in the Waiheru Watershed, Ambon Island, Indonesia, showed significant changes between 2014, 2019 and 2024. In 2014, the settlement area was recorded at 68.78 ha, which increased to 77.73 ha in 2019, and is expected to reach 96.72 ha in 2024. This increase reflects the rapid population growth and urbanization in the area, where new settlements are built to meet the needs of the growing population. This growth is in line with urbanization trends occurring in many cities in Indonesia, where new settlements are often built in areas that were previously open land or agricultural land [15]. Spatial changes in land cover can be seen in Figure 3 and Table 1.

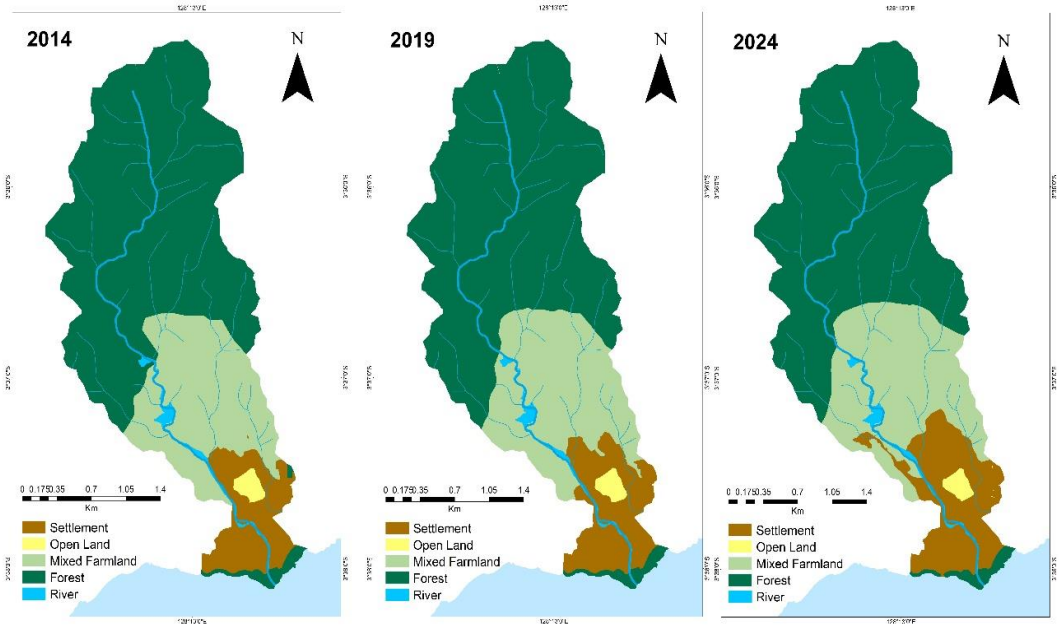

Fig 3. Land cover of the Waiheru watershed, Indonesia

Open land showed stability at 6.54 ha from 2014 to 2019, but decreased to 5.86 ha in 2024. This decline may be due to the conversion of open land to other uses, such as settlements or agricultural land. On the other hand, mixed agricultural land increased from 169.83 ha in 2014 to 174.77 ha in 2019, and continued to increase to 177.21 ha in 2024. This shows that despite settlement growth, agriculture remains an important part of land use in the Waiheru watershed, supporting local food security. However, the decline in forest area from 476.14 ha in 2014 to 462.25 ha in 2019, and continuing to decline to 441.51 ha in 2024, indicates that deforestation needs to be watched closely. This decline could negatively impact local ecosystems and the sustainability of natural resources. Reduced forests can reduce the region's ability to sequester carbon and maintain ecosystem balance (Kusratmoko, et al.,2017; Latue & Rakuasa

2023). Therefore, it is important to implement sustainable land management strategies in order to maintain the balance between development and environmental preservation in the Waiheru watershed.

Table 1. Land Cover Area of the Waiheru Watershed, Indonesia

Land Cover Type	Area (ha)		
	2014	2019	2024
Settlement	68.78	77.73	96.72
Open Land	6.54	6.54	5.86
Mixed Farmland	169.83	174.77	177.21
Forest	476.14	462.25	441.51
River	8.31	8.31	8.31
Total	729.61		

3.2. Land Cover Simulation in 2024

Based on Table 2 the Transition Probability Matrix (TPM) from 2014 to 2024 illustrates the probability of land cover change in the Waiheru watershed. This matrix shows the likelihood of each land cover type to change into another land cover type or remain in the same condition during the 10-year period. Based on the TPM, it can be seen that settlements and open land have the highest probability (0.8500) of remaining in the same condition, indicating the relative stability of these two land cover types. Mixed agricultural land has a 0.7107 probability of remaining unchanged, but also has a significant probability (0.2893) of changing to residential. Forest shows a tendency to remain as forest (0.8200), but also has a probability of changing to mixed farmland (0.1728).

Rivers have a probability of 1 to remain unchanged, indicating no change is expected for this type of land cover over the period. These patterns reflect the dynamics of land cover change in the Waiheru watershed, with indications of settlement and agricultural expansion potentially reducing forest area. The accuracy test results show a kappa (Kstandard) value of 0.9284 or 92.84% which means the model shows very good accuracy and can be the basis for predicting land cover in 2034.

Table 2. Transition Probability Matrix (TPM) from 2014 – 2024

Land Cover Type	Settlement	Open Land	Mixed Farmland	Forest	River
Settlement	0.8500	0.0375	0.0375	0.0375	0
Open Land	0.0375	0.8500	0.0375	0.0375	0
Mixed Farmland	0.2893	0	0.7107	0	0
Forest	0.0072	0	0.1728	0.8200	0
River	0	0	0	0	1

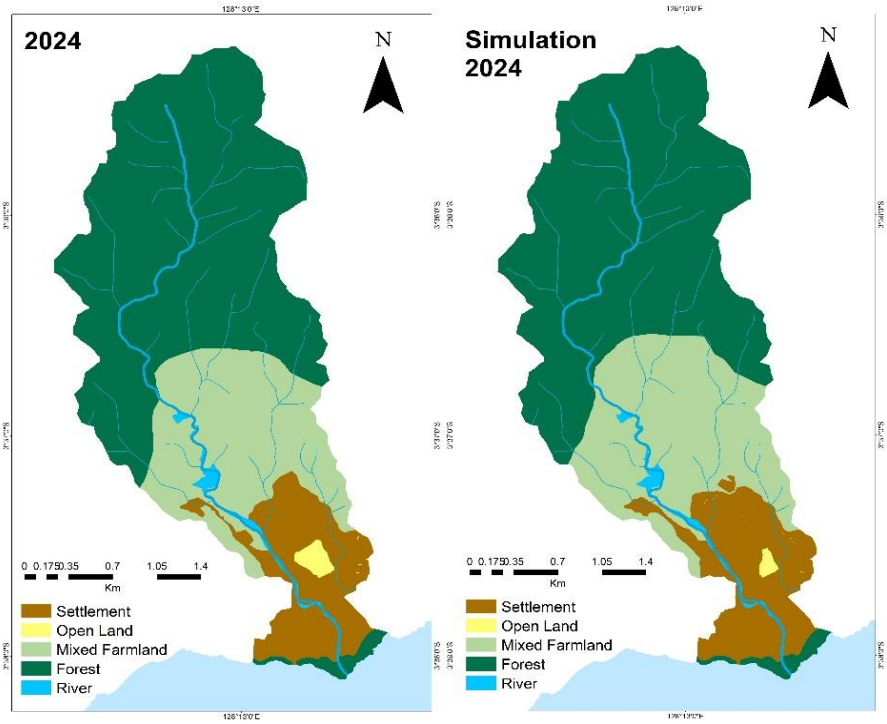

Figure 4. Land cover in 2024 and 2024 Simulation results of Waeheru Watershed

Table 3. Land Cover Area in 2024 and simulation results 2024

Land Cover Type	Area (ha)	
	2024	Simulation 2024
Settlement	96.72	103.19
Open Land	5.86	2.32
Mixed Farmland	177.21	193.17
Forest	441.51	422.61
River	8.31	8.31
Total	729.61	

In Table 3 and Figure 5 the simulation results show some changes compared to the actual data. Settlements and mixed agriculture are projected to increase in area, from 96.72 ha to 103.19 ha for settlements and from 177.21 ha to 193.17 ha for mixed agriculture. In contrast, open land and forest are projected to decrease in area, with open land decreasing from 5.86 ha to 2.32 ha and forest from 441.51 ha to 422.61 ha. River area remains constant at 8.31 ha. These changes indicate a trend of urbanization and conversion of natural land to built or agricultural land in the Waiheru watershed.

3.3. Land Cover Simulation in 2034

Table 4 shows the Transition Probability Matrix (TPM) for land cover change in the Waiheru watershed, Ambon City, Indonesia from 2024 to 2034. This matrix illustrates the probability of change from one type of land cover to another over a 10-year period. The values in the matrix indicate the probability that an area with a particular land cover will remain the same or change to another land cover. Some interesting trends can be seen: settlements have a high probability (0.8489) of remaining as settlements, but there is also a possibility of changing to open land (0.1511). Open land has a 0.7516 probability of remaining as open land, but also has a 0.2484 probability of turning into a settlement. Mixed farmland shows a tendency to change to settlement (0.3675) or remain as mixed farmland (0.6323). Forest has a high probability of remaining as forest (0.7831), but there is also a possibility of changing to mixed farming (0.1728). River has a probability of 1 to remain as river, indicating no change is expected for this land cover.

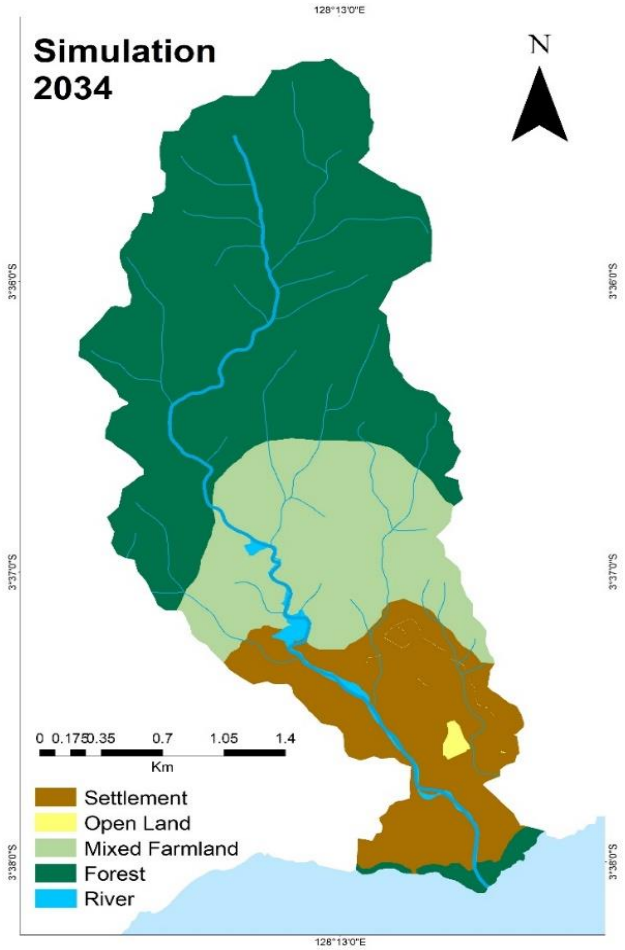

Fig 5. Land Cover Simulation Results in 2034 Waiheru Watershed, Indonesia

Table 4. Transition Probability Matrix (TPM) from 2024 – 2034

Land Cover Type	Settlement	Open Land	Mixed Farmland	Forest	River
Settlement	0.8489	0.1511	0	0	0
Open Land	0.2484	0.7516	0	0	0
Mixed Farmland	0.3675	0	0.6323	0.0002	0
Forest	0.0045	0	0.1728	0.7831	0
River	0	0	0	0	1

Based on the results of the 2034 land cover modeling in the Waeheru watershed in Figure 5, the settlement area is expected to increase significantly to 138.81 ha, reflecting the continuing trend of urbanization in the area. This increase indicates that settlements will become one of the main land uses, along with population growth and the need for more housing. On the other hand, open land is expected to shrink to 2.35 ha, indicating the conversion of open land to other uses, most likely for settlements or agricultural land. Mixed agricultural land is predicted to decrease slightly to 163.01 ha, while forest also decreases to 417.12 ha. This decrease in forest area indicates deforestation or conversion of forest land to other uses, which could have a negative impact on the local ecosystem. River area remained stable at 8.31 ha, indicating that there was no significant change in this land cover. The total land cover area is predicted to remain the same at 729.61 ha, but changes in the distribution of land cover types indicate challenges in future natural resource management.

There is a consistent upward trend in the residential area, starting from 68.78 ha in 2014, increasing to 77.73 ha in 2019, and reaching 96.72 ha in 2024. This increase reflects the continued population growth and urbanization in the area, where the need for housing is increasing as the number of residents increases. Predictions for 2034 show that the settlement area will increase significantly to 138.81 ha. This sharp increase indicates that settlements will become one of the main land uses in the Waiheru watershed, which could impact other land uses and the balance of the ecosystem. This growth in settlement area also signals the need for better spatial planning to ensure sustainable management of natural resources and reduce negative impacts on the environment in the future

4. Conclusion

This research successfully identifies and analyzes land cover change in the Waiheru Watershed, Indonesia, which shows a significant upward trend in settlement area between 2014, 2019, 2024 and 2034, and its impact on ecosystem balance. Using the Cellular Automata-Markov Chain (CA-MC) method, this study not only provides a clear picture of the future direction of land cover change, but also highlights the importance of spatial planning that is adaptive and responsive to social-ecological dynamics. The results of this research are expected to be an important instrument in evidence-based decision-making for sustainable natural resource management and environmental impact mitigation in Ambon City, Indonesia.

5. References

Balist, Jahanbakhsh et al. 2021. 'Detecting Land Use and Climate Impacts on Water Yield Ecosystem Service in Arid and Semi-Arid Areas. A Study in Sirvan River Basin-Iran'. *Applied Water Science* 12(1): 4. https://doi.org/10.1007/s13201-021-01545-8.

Beroho, Mohamed et al. 2023. 'Future Scenarios of Land Use/Land Cover (LULC) Based on a CA-Markov Simulation Model: Case of a Mediterranean Watershed in Morocco'. *Remote Sensing* 15(4): 1162. https://www.mdpi.com/2072-4292/15/4/1162.

Fitriana, A. et al. 2021. 'Land Change Prediction in Bondowoso Regency Using Automata Markov Method'. *{IOP} Conference Series: Earth and Environmental Science* 311(4): 100321. https://doi.org/10.1088/1755-1315/311/1/012073.

Ghosh, Pramit et al. 2017. 'Application of Cellular Automata and Markov-Chain Model in Geospatial Environmental Modeling- A Review'. *Remote Sensing Applications: Society and Environment* 5: 64–77. https://www.sciencedirect.com/science/article/pii/S2352938516300258.

Ildoromi, A., Nori, H., Naderi, M., Amin, S. A., & Zeinivand, H. 2015. 'Land Use Change Prediction Using Markov Chain and CA Markov Model (Case Study: Gareen Watershed)'. *journal of watershed management research* 8(16): 232–40. http://jwmr.sanru.ac.ir/article-1-919-en.html.

Jafarpour Ghalehteimouri, Kamran et al. 2022. 'Predicting Spatial and Decadal of Land Use and Land Cover Change Using Integrated Cellular Automata Markov Chain Model Based Scenarios (2019–2049) Zarriné-Rūd River Basin in Iran'. *Environmental Challenges* 6: 100399. https://linkinghub.elsevier.com/retrieve/pii/S2667010021003735.

Kusratmoko, E, S D Y Albertus, and Supriatna. 2017. 'Modelling Land Use/Cover Changes with Markov-Cellular Automata in Komering Watershed, South Sumatera'. *{IOP} Conference Series: Earth and Environmental Science* 54: 12103. https://doi.org/10.1088/1755-1315/54/1/012103.

Latue, P. C., & Rakuasa, H. 2023. 'Analysis of Land Cover Change Due to Urban Growth in Central Ternate District, Ternate City Using Cellular Automata-Markov Chain'. *Journal of Applied Geospatial Information* 7(1): 722–28.

Manakane, Susan E, Philia Christi Latue, Glendy Somae, and Heinrich Rakuasa. 2023. 'Prediction of Land Cover Change in Wae Heru Watershed Ambon City Using Celular Automata Markov Chain'. *Journal of*

Geographical Sciences and Education 1(1): 1–11. https://journal.pubsains.com/index.php/jgs/article/view/52.

Maurya, Nitesh Kumar, Sana Rafi, and Saima Shamoo. 2022. 'Land Use/Land Cover Dynamics Study and Prediction in Jaipur City Using CA Markov Model Integrated with Road Network'. *GeoJournal* 88(1): 137–60. https://link.springer.com/10.1007/s10708-022-10593-9.

Rakuasa, Heinrich et al. 2022. 'Spatial Dynamics Model of Earthquake Prone Area in Ambon City'. *IOP Conference Series: Earth and Environmental Science* 1039(1): 012057. https://iopscience.iop.org/article/10.1088/1755-1315/1039/1/012057.

Rakuasa, Heinrich, and Philia Christi Latue. 2023. 'Analisis Spasial Daerah Rawan Banjir Di DAS Wae Heru, Kota Ambon'. *Jurnal Tanah dan Sumberdaya Lahan* 10(1): 75–82. https://jtsl.ub.ac.id/index.php/jtsl/article/view/845.

Salakory, M., Rakuasa, H. 2022. 'Modeling of Cellular Automata Markov Chain for Predicting the Carrying Capacity of Ambon City'. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan (JPSL)* 12(2): 372–87.

Selmy, Salman A. H. et al. 2023. 'Detecting, Analyzing, and Predicting Land Use/Land Cover (LULC) Changes in Arid Regions Using Landsat Images, CA-Markov Hybrid Model, and GIS Techniques'. *Remote Sensing* 15(23): 5522. https://www.mdpi.com/2072-4292/15/23/5522.

Subiyanto, S, and F J Amarrohman. 2019. 'Analysis of Changes Settlement and Fair Market Land Prices to Predict Physical Development Area Using Cellular Automata Markov Model and {SIG} in East Ungaran Distric'. *{IOP} Conference Series: Earth and Environmental Science* 313: 12002. https://doi.org/10.1088/1755-1315/313/1/012002.

Supriatna, Supriatna et al. 2022. 'CA-Markov Chain Model-Based Predictions of Land Cover: A Case Study of Banjarmasin City'. *Indonesian Journal of Geography* 54(3). https://journal.ugm.ac.id/ijg/article/view/71721.

Weslati, Okba, Samir Bouaziz, and Mohamed Moncef Sarbeji. 2023. 'Modelling and Assessing the Spatiotemporal Changes to Future Land Use Change Scenarios Using Remote Sensing and CA-Markov Model in the Mellegue Catchment'. *Journal of the Indian Society of Remote Sensing* 51(1): 9–29. https://link.springer.com/10.1007/s12524-022-01618-4.