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# CELLULAR AUTOMATA MARKOV CHAIN APPLICATION FOR PREDICTION OF LAND COVER CHANGES IN THE WAE BATU GANTUNG WATERSHED, AMBON CITY, INDONESIA

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**ABSTRACT**

The development of built-up land over the last 15 years in Ambon City has affected changes in land cover in the Wae Batugantung watershed. This is due to increasing population growth, and the increasing need for residential land. Changes in land cover in the Wae Batu Gantung watershed have an impact on land degradation, water pollution, flooding, and erosion, which will increase in the future. This study aims to analyze land cover changes in the Wae Batu Gantung watershed in 2012, 2017, 2022, and predict land cover in 2027, and 2031. The Cellular Automata Markov Chain method was used in this study to predict the spatial dynamics of land cover change. The results of the study show that from 2012, 2017, 2022, and predictions for 2027, and 2031 residential land, and open land in the Wae Batutangan watershed continue to expand, in contrast to non-agricultural land cover, and agricultural land which is decreasing. The results of this study are expected to be input into policy making related to spatial utilization in the Wae Batugantung Watershed in the future.

*Reseach Paper*

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**Keywords:** Cellular Automata, Markov Chain, Wae Batu Gantung.

## INTRODUCTION

Human activities in carrying out daily economic, social, and cultural life have an impact on changes in land cover. Land cover is simply defined as the biophysical appearance of the earth's surface (Gbedzi et al., 2022; Latue & Rakuasa, 2023). Land cover refers to the surface cover on land, whether vegetation, urban infrastructure, water, open land or others (Velasquez-Montoya et al., 2021). Changes in land cover in an area are a reflection of human efforts to utilize and manage land resources to meet their daily needs (Rakuasa, Supriatna, et al., 2022). According to Kuma et al., (2022), land cover is the result of complex interactions between humans, and biophysics with driving forces that take place over a wide range of spatial, and temporal scales (Rakuasa & Pakniany, 2022). Thus, land cover change is also a complex process caused by the interaction between humans, and nature which results in different forms of land cover.

The increase in population will be followed by an increase in the demand for residential land in watersheds, so that many forest areas are converted into agricultural land, plantations, settlements, and other

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cultivation lands, causing land conversion (Rakuasa, 2022). The human need for space causes land cover changes that tend to damage the hydrological function of the watershed, increase land degradation, erosion,, and encourage sedimentation processes (Ni et al., 2021; Rakuasa et al., 2022).

Wai Batu Gantung is one of the watersheds that has experienced significant land cover changes in Ambon City. In this watershed there has been a reduction in the area of non-agricultural, and agricultural land. Also vice versa, residential land, and open land have increased. Changes in land cover in the Wai Batu Gantung watershed greatly affected the decrease in monthly flow rates, baseflow, and annual interflow. It also has an impact on the increase of erosion rate in the watershed, which reaches 73.20 tones/year with total sediment of 56.06 tones/year, and a decrease in environmental quality (Jacob, 2013; Salakory & Rakuasa, 2022). Land cover changes need to be controlled and monitored to ensure the function of the watershed ecosystem. Detection of land cover change is essential for a better understanding of landscape dynamics over a given period to determine sustainable management policies (Nguyen & Ngo, 2018).

Spatial dynamics analysis, and prediction of land cover change in the Wae Batu Gantung watershed was carried out using the Cellular Automata Markov Chain (CA MC) method, which is the most reliable, accurate, and useful model for accurately simulating, and predicting spatial, and temporal land cover change in future (Nguyen & Ngo, 2018; Ajeeb et al., 2020; Latue & Rakuasa, 2022; Sugandhi et al., 2022).

CA MC modeling was chosen because it has very good, and accurate spatial-temporal, and statistical prediction capabilities (Wang et al., 2022 ;Rakuasa et al.,2022). Based on the background above, this study aims to analyze the spatial dynamics of land cover change in 2012, 2017, 2022, 2027, and 2031 in the Wae Batu Gantung watershed. This research is expected to be useful for local governments in spatial planning by paying attention to ecological, and environmental sustainability in the Wai Batu Gantung Watershed in the future.

## LITERATURE REVIEW

Spatial Dynamic refers to the dynamic changes and interactions between spatial entities within a system. Spatial entities can include geographic locations, areas, buildings, roads, and other spatially defined elements (Supriatna et al., 2016). Land cover is a type of land that describes all the physical conditions on the earth's surface. The physical conditions on the land surface can be in the form of vegetation cover, water and soil (Munthali et al., 2020). Land cover is all physical material on the earth's surface such as bodies of water and natural vegetation (Permatasari et al., 2021). Land cover refers to various land surface covers in the form of vegetation, urban infrastructure, water, bare soil and so on (Kapitza et al., 2022; Rakuasa & Pakniany, 2022).

The phenomenon of land cover change that occurs due to the influence of political/policy and socio-economic factors causing soil and water degradation which impacts ecosystems, biodiversity, and climate change can be modeled through land cover change modeling (Rakuasa, 2022b). Rapid economic development can also cause changes in land use resulting in contrasting variations of various land use classes and land cover which can be identified through land cover maps (Latue & Rakuasa, 2023).

Land cover change can involve conversion of land classes such as conversion from forest land cover to agricultural land use or transition from forest to settlement (Kafy et al., 2020). The phenomenon of change is seen over a certain period of time until predictions of future changes (Wang et al., 2021). Thus, the land cover change model is a model that presents changes in land use and land cover within a certain period of time and predictions of changes in land use and land cover in the future.

## METHODS

This research was conducted in the Wai Batu Gantung watershed (area: 1,089.84 ha), geographically located in Ambon City, Maluku Province, which has rapid residential land development. Spatially, the research location is presented in **Figure 1**. The data used for this research consisted of IKONOS satellite imagery for 2012, and SPOT 6 for 2017 and 2022 obtained from the Ambon City Development Planning Agency. The National Digital Elevation Model (DEM) datasheets 2612-23 and 2612-24 obtained from the Geospatial Information Agency were used to delineate watershed boundaries, classify land elevation, and slope. The road distance and Point of Interest variables were obtained based on the RBI map of Ambon City from the Geospatial Information Agency.


**Figure 1 Research Location**

The process of interpretation and digitization is carried out to classify land cover in the Wai Batu Gantung watershed which refers to SNI 7465:2010 (Badan Standarisasi Nasional, 2010), namely settlements, agricultural areas, non-agricultural areas, open land, and waters. The driving factor data used in this study consisted of the slope, land elevation, distance from the main road and distance from Points of interest (POI) which consisted of health facilities and educational facilities (**Figure 2**). The driving factor in this study is some of spatial variables that can affect changes in land cover in a location (Xu et al., 2022). Each driving factor has a different effect on each type of land cover change, so it is weighted (**Table 1**) to calculate the strength of these driving factors.

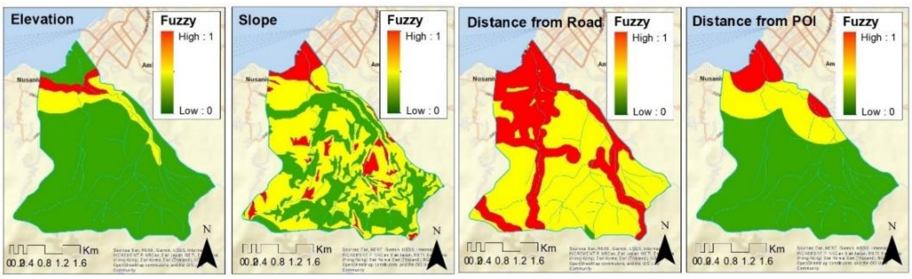


**Figure 2 Driving factor**

**Table 1 Driving Factors Scoring**

| No | Parameters | Classification | Weight | Suitability |
|---|---|---|---|---|
| 1 | Slope | < 3 % | 3 | Very Suitable |
| | | 4 – 15 % | 2 | Suitable |
| | | >15 % | 1 | Not Suitable |
| 2 | Elevation | < 7 mdpl | 1 | Not Suitable |
| | | 8-25 mdpl | 3 | Very Suitable |
| | | 26-100 mdpl | 2 | Suitable |
| | | >100 mdpl | 5 | Not Suitable |

| | | | | |
|---|---|---|---|---|
| | | 0-100 m | 3 | Very Suitable |
| 4 | Distance from the road | 101-1000 m | 2 | Suitable |
| | | >1000 m | 1 | Not Suitable |
| | | <400 | 3 | Very Suitable |
| 5 | Distance from the POI | 401-1000 m | 2 | Suitable |
| | | >1000 m | 1 | Not Suitable |

Source: (Latue & Rakuasa, 2022; Sugandhi et al., 2022)

In this study, scoring was given to each driving factor (**Table 1**) in determining the suitability of settlement development in the area. Suitable area will be given a high score and areas that are not suitable will be given a low score. The lower the score, the lower the development of a settlement, conversely, the higher the score, the higher the development of residential land cover in the region (Latue & Rakuasa, 2022; Sugandhi et al., 2022).

Land cover prediction in 2027 and 2031 is carried out using the Cellular Automata Markov Chain (CA MC) method. Before predicting the 2027 and 2031 land cover models, it is necessary to create a 2022 land cover model to test the accuracy of the model and the driving factors used. Processing of the initial land cover model in 2022, 2027, and 2031 will be carried out by the IDRISI Selva software. Cellular Automata Markov Chain modeling basically combines two different methods, namely Markov Chain which is an empirical/statistical model, while Cellular Automata is a dynamic model included in the GIS platform (Ildoromi et al, 2015).

The Cellular Automata Markov Chain process for predicting land cover change in 2027 and 2031 assumes patterns of land cover change or transitional probability that have occurred in the last five years, namely from 2012 to 2017 and from 2017 to 2022 can be used to predict the pattern of change from 2022 to 2027, and 2031. Then, validation of the 2022 cover model was carried out using the existing land cover data for 2022 and if the model accuracy test (Kappa coefficient) was > 75%, predictions could be made for 2027 and 2031 (Irawan et al., 2019).

## RESULTS AND DISCUSSION

### Land Cover Change

The types of land cover for settlements and open land in the 2012-2022 period continued to experience an increase in area, in contrast to the types of land cover in the agricultural and non-agricultural land cover which experienced a decrease. The continued escalation influences this in the number of people living in watersheds, resulting in a higher demand for built-up land/settlements. Spatially, the land cover changes in the Batu Gantung watershed can be seen in Figure 4, and the area of each land cover class can be seen in **Table 2**.

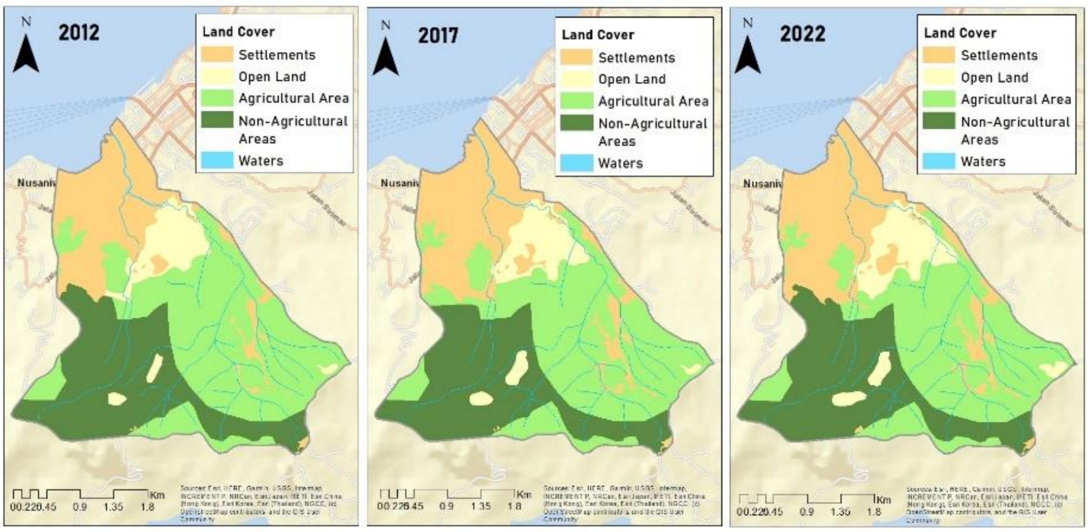


**Figure 3 Land Cover in Batu Gantung Watershed**

Based on **Table 2** and **Figure 2**, it is known that the type of settlement cover has increased by 21.49% of the total area in 2012 to 24.39% in 2017, and 26.23% in 2022. Open land cover types also continue to experience an increasing percentage area from 7.45% in 2012 increased to 7.98% in 2017, and 8.53% in 2022, in contrast to the types of agricultural land cover which continued to experience a decrease in area presentation, namely 42.26% in 2012 to 40, 35% in 2017, and will continue to decrease in 2022 to 38.31%.

**Table 2 Area of Land Cover in Batu Gantung Watershed**

| LU/LC | 2012 | | 2017 | | 2022 | |
|---|---|---|---|---|---|---|
| | (ha) | % | (ha) | % | (ha) | % |
| Settlements | 234.24 | 21.49 | 265.82 | 24.39 | 285.85 | 26.23 |
| Open Land | 81.15 | 7.45 | 86.93 | 7.98 | 92.97 | 8.53 |
| Agricultural Area | 460.53 | 42.26 | 439.8 | 40.35 | 417.50 | 38.31 |
| Non-Agricultural Areas | 312.30 | 28.66 | 295.66 | 27.13 | 291.89 | 26.78 |
| Waters | 1.63 | 0.15 | 1.63 | 0.15 | 1.63 | 0.15 |
| **Total Areas** | 1089.84 | 100.00 | 1089.84 | 100.00 | 1089.84 | 100.00 |

Types of non-agricultural land cover also continue to experience a decrease in area, namely 28.66% in 2012 to 27.13% in 2017, and continue to decrease, namely 26.78% in 2022, while land cover for water bodies does not decrease or increase in area.

**Land Cover Prediction**

Land cover prediction in this study was carried out twice; the first was a simulation to see the accuracy of the driving factors given to the model, aiming to calibrate the selection of driving factors. In this first simulation, it will produce an accuracy value (Kappa value) so that it can be seen whether the driving factors in the first simulation can be used in the second simulation. The second simulation was carried out to see the condition of land cover in 2027 and 2031 using the same driving factors as the first simulation.

The simulation is carried out using Markov Chain Cellular Automata, by using the driving factors that have been made in the previous stage, the magnitude of the probability of a change in a land cover is called the transition probability matrix (TPM) or commonly called the Markov Chain value, the magnitude of the number in TPM shows the possibility of one land cover changing into another land cover.

**Table 3 Transition Probability Matrix (TPM) 2017 to 2022**

| | **Settlements** | **Open Land** | **Agricultural Area** | **Non-Agricultural Areas** | **Waters** |
|---|---|---|---|---|---|
| **Settlements** | 0.8498 | 0 | 0.1502 | 0 | 0 |
| **Open Land** | 0.3027 | 0.6913 | 0.0059 | 0 | 0 |
| **Agricultural Area** | 0.1269 | 0.1213 | 0.7519 | 0 | 0 |
| **Non-Agricultural Areas** | 0.0276 | 0.0785 | 0.0991 | 0.7948 | 0 |
| **Waters** | 0 | 0 | 0 | 0 | 1 |

Probability values range from 0-1, where 0 indicates there is no possibility of land *cover* change, while 1 indicates *land cover* change. In the transition probability matrix, in **Table 3** it is known that open land has the highest probability value of 0.3027 which has the potential to turn into settlements, and waters have a transition probability value of 0, meaning it will not change into other types of land cover.

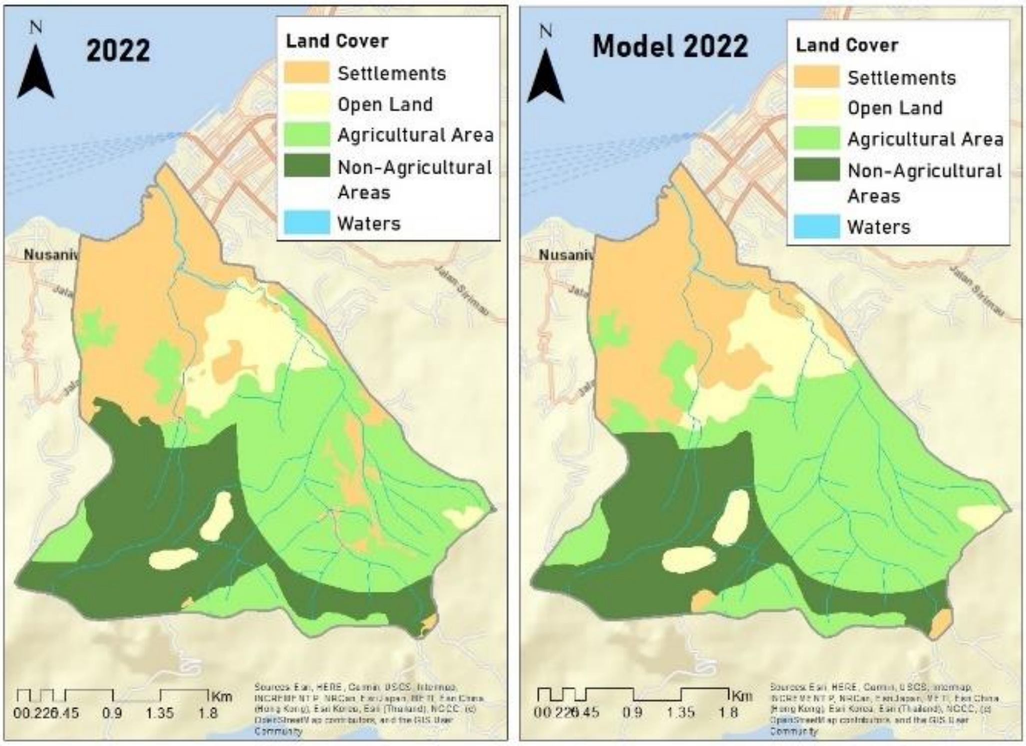


**Figure 4 Comparison between model and existing results of 2022 land cover**

After making the 2022 model, the model must be tested for accuracy. An accuracy test was conducted to find out whether the first generated model could be applied to produce the second predictive model. Accuracy tests were carried out using existing land cover data for 2022 as reference data and predicted land cover data for 2022 as a comparison (Ghalehteimouri et al., 2022). A comparison between the 2022 model results and the 2022 existing land cover can be seen in **Figure 3**. The results of the accuracy test obtained a Kappa value (standard K) of 0.92 or 92.67% which indicates that this accuracy value is proven to be large and can be applied to modeling land cover in the Batu Gantung Watershed for the years of 2027 and 2031. The results of the accuracy test carried out in the IDRISI Selva software can be seen in **Figure 4**.

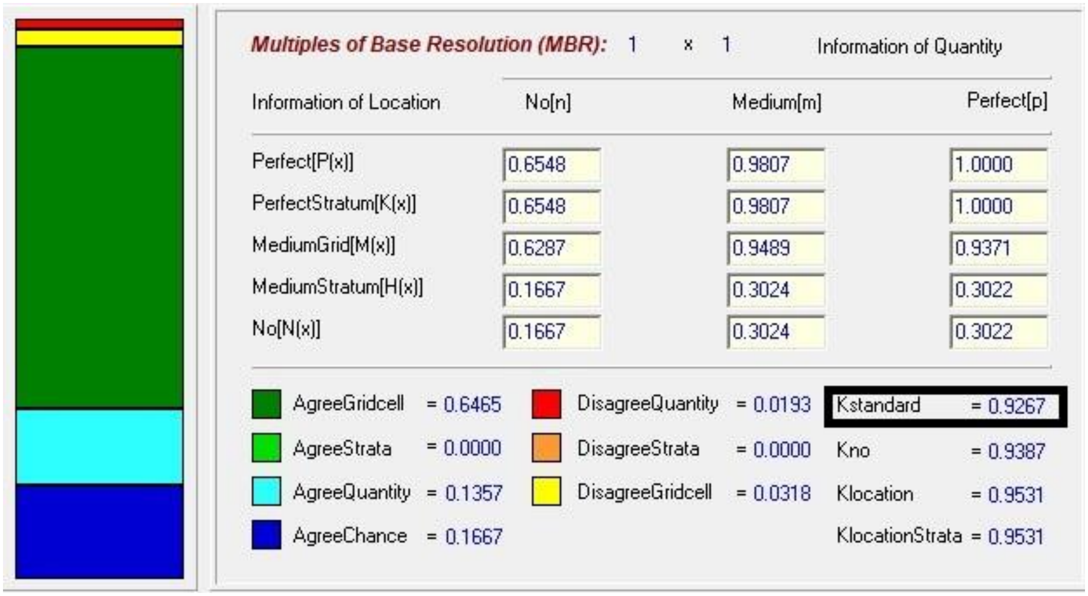


**Figure 5 Results of the Kappa Value Accuracy Test for the 2022 LC model**

Prediction of land cover in 2027 is carried out by analyzing the transition probability to see the possibility of changes in land cover, the same as in the first simulation. The transitional probability matrix from 2022 to 2027 can be seen in **Table 4**. The value of this transitional probability matrix shows that open land areas have the highest probability value of 0.1779 to turn into settlements. The transitional probability matrix from 2027 to 2031 in **Table 5** shows that open land areas have the highest probability value of 0.4039 to turn into settlements. Based on **Table 4** and **Table 5**, it can be concluded that the open land cover type has the highest probability value every year to turn into residential land.

**Table 4 Transition Probability Matrix (TPM) 2022 to 2027**

| | Settlements | Open Land | Agricultural Area | NonAgricultural Areas | Waters |
|---|---|---|---|---|---|
| **Settlements** | 0.8499 | 0 | 0.1501 | 0 | 0 |
| **Open Land** | 0.1779 | 0.8221 | 0 | 0 | 0 |
| **Agricultural Area** | 0.0815 | 0.1137 | 0.8049 | 0 | 0 |
| **Non-Agricultural Areas** | 0.0206 | 0.0921 | 0.0481 | 0.8391 | 0 |
| **Waters** | 0 | 0 | 0 | 0 | 1 |

**Table 5 Transition Probability Matrix (TPM) 2027 to 2031**

| | Settlements | Open Land | Agricultural Area | Non-Agricultural Areas | Waters |
|---|---|---|---|---|---|
| **Settlements** | 0.8486 | 0 | 0.1514 | 0 | 0 |
| **Open Land** | 0.4039 | 0.5961 | 0 | 0 | 0 |
| **Agricultural Area** | 0.0528 | 0.2220 | 0.7252 | 0 | 0 |
| **Non-Agricultural Areas** | 0.0439 | 0.1248 | 0.1560 | 0.6754 | 0 |
| **Waters** | 0 | 0 | 0 | 0 | 1 |

Based on the results of processing predictions of land cover models in 2027 and 2031 using the Cellular Automata Markov Chain, it is known that the types of residential land cover and open land cover continue to experience an increase in area, for types of agricultural land cover and non-agricultural land cover types continue to experience a decrease in area, and types of land cover of water bodies does not experience an increase or decrease in area.

The results of modeling predictions for watershed land cover in Ambon City in 2027 and 2031 are very important because they can be used as a basis for making policies related to spatial planning and utilization. It also can optimize sustainable watershed management, and as a first step in efforts to mitigate natural disasters. Spatially, the results of land cover predictions for 2027 and 2031 can be seen in **Figure 5**.

Increasing the area of settlement land in Ambon City, especially in the Watershed (DAS) from year to year will not only cause a decrease in the carrying capacity of the environment Salakory & Rakuasa (2022), but also cause environmental damage (Shang & Wu, 2022). Therefore, the results of the analysis and prediction of land cover change can provide a solution in structuring sustainable Ambon City land use in the future based on ecological aspects and conservation efforts to support land use planning and appropriate land use allocation (Rakuasa & Somae, 2022). This is in addition to carrying out conservative activities as a preventive measure in ecologically based land use.

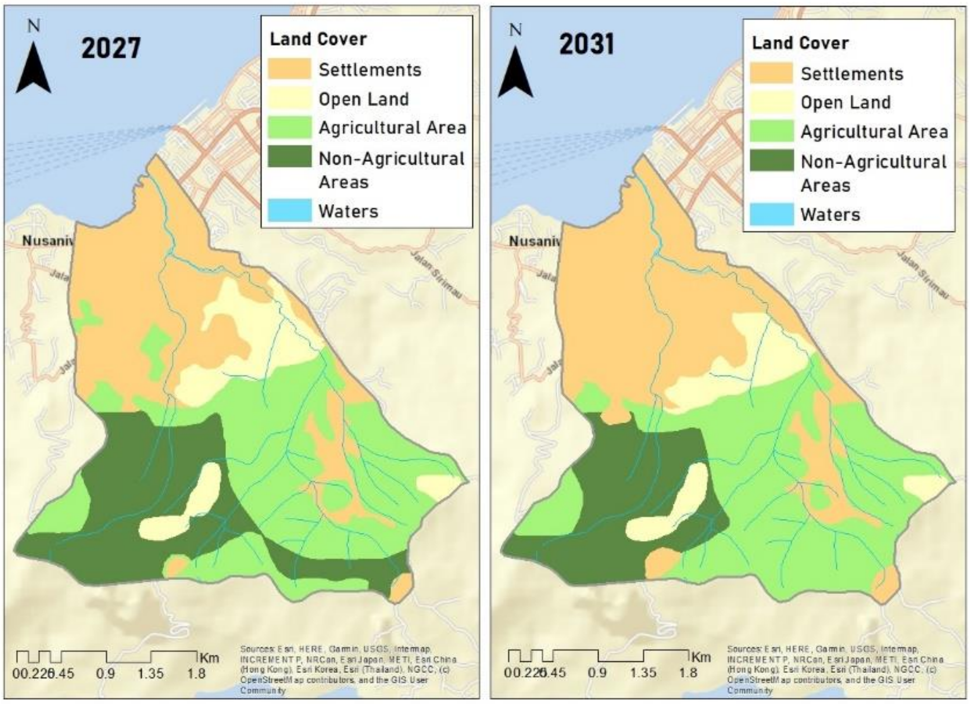


**Figure 6 Land cover models in 2027 and 2031**

## CONCLUSION

Residential land area in the Wai Batu Gantung watershed continues to increase every year. The prediction results for 2027 and 2031 also show the same conditions where the type of built-up land cover in the Batu Gantung watershed area continues to increase very quickly. This increase in line with population growth and high demand for land for settlements. Therefore, the analysis and prediction of changes in land cover in the Wai Batu Gantung watershed is very important and useful. It can be used as material in making policies related to spatial planning and optimizing sustainable watershed management.

### Author's declaration

### Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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### Availability of data and materials

All data are available from the authors.

### Competing interests

The authors declare no competing interest.

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