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[Research Article]

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Prediction of Land Cover Change in Wae Heru Watershed Ambon City Using Celular Automata Markov Chain

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Abstract

Land cover change in the watershed area in Ambon City has an impact on land degradation, water pollution, flooding and erosion. Therefore, the utilization and efficiency of land cover in the watershed area must be improved based on sustainable land cover planning. This study aims to analyze land cover changes in the Wae Heru watershed, Ambon City in 2013, 2018, and 2023 and predict land cover in 2028. This study used the CA-Markov method to predict land cover in 2028. The results showed that in 2013 the built-up land had an area of 74.25 ha, in 2018 an area of 79.30 ha and in 2023 an area of 88.00 ha and the results of the 2028 prediction of built-up land were 116.96 ha, this is certainly influenced by the increasing number of residents who continue to grow every year. Agricultural land, non-agricultural land and open land continue to decrease in area. The results of this prediction are very useful for the government in making policies related to sustainable spatial planning in the future.

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Abstrak

Perubahan tutupan lahan pada kawasan DAS di Kota Ambon berdampak pada degradasi lahan, pencemaran air, banjir dan erosi. Oleh karena itu, pemanfaatan dan efisiensi tutupan lahan di wilayah DAS harus ditingkatkan berdasarkan perencanaan tutupan lahan yang berkelanjutan. Penelitian ini bertujuan untuk menganalisis perubahan tutupan lahan di DAS Wae Heru, Kota Ambon pada tahun 2013, 2018, dan 2023 serta memprediksi tutupan lahan pada tahun 2028. Penelitian ini menggunakan metode CA-Markov untuk memprediksi tutupan lahan pada tahun 2028. Hasil penelitian menunjukkan ditahun 2013 lahan terbangun memiliki seluas 74,25 ha, ditahun 2018 seluas 79,30 ha dan ditahun 2023 seluas 88,00 ha dan hasil predisk 2028 lahan terbangun seluas 116,96 ha, hal ini tentunya dipengaruhi oleh bertambahnya jumlah penduduk yang terus bertambah setiap tahunnya. Lahan pertanian, lahan non pertanian dan lahan terbuka terus mengalami penurunan luas. Hasil prediksi ini sangat berguna bagi pemerintah dalam membuat kebijakan terkait tata ruang yang berkelanjutan di masa yang akan datang.

INTRODUCTION

Land cover change is an important issue in environmental studies and natural resource management (Demissie, 2022; Achmadi et al., 2023). Fallati et al. (2017), explained that land cover change is the increase of a land cover from one cover to another followed by a decrease in another type of land cover over time, or a change in the function of a land in different periods of time. Based on previous research conducted by Somae et al. (2023), on spatial modeling of land cover change in Teluk Ambon Baguala Sub-district, the Wae Heru Watershed has experienced land cover change in 2014, 2018, 2022.

The phenomenon of land cover change that occurs in Ambon City is influenced by political/policy and socio-economic factors, causing soil and water degradation that has an impact on ecosystems, biodiversity, and climate change can be modeled through land cover change modeling (Mohamed & Worku, 2019; Saha et al., 2021; Rakuasa et al., 2023). Rapid economic development can also lead to land use change, resulting in contrasting variations of different land use and land cover classes that can be identified through land cover maps (Dutta et al., 2019; Wang et al., 2022; Latue et al., 2023) According to Somae et al. (2023), the influence of political, policy, and socio-economic factors has contributed to land cover change in the Wae Heru watershed. Kamboj & Ali, (2021), added that, population growth, urbanization, and agricultural and industrial activities have changed the face of the Wae Heru watershed, with significant implications for the ecosystem and local communities.

In the face of this challenge, Cellular Automata-Markov Chain (CA-MC) has become an effective method for forecasting land cover change (Rahnama, 2021). This approach combines the concept of cellular automata (CA) to represent spatial and temporal changes with Markov chains (MC) that describe transitions between land cover categories (Mustafa et al., 2021). Through this model, land cover change can be predicted by considering the complex interactions between various factors that influence land use (Rakuasa et al., 2022). In this study, land cover change may include conversion from forest to agricultural land or settlement. The study by Mwabumba et al. (2022), highlights the importance of understanding this type of change and its implications. Predictions of land cover change, both within a given time period and in the future, are relevant in sustainable land management planning (Wang et al., 2022)

Thus this research aims to explore the phenomenon of land cover change in the Wae Heru watershed, Ambon City, with an emphasis on the influence of political, policy, and socio-economic factors. The CA-MC approach will be applied to forecast future land cover change, which will provide a deeper understanding of the environmental dynamics in this region.

METHOD

This research was conducted in Wae Heru watershed, Ambon City, Maluku Province. This research uses RBI (Rupa Bumi Indonesia) vector data and Ternate City National DEM data obtained from InaGeoportal which is the official website of the Geospatial Information Agency: https://tanahair.indonesia.go.id/portal-web. Landsat 5 satellite image data in 2013 and 2018 and Landsat 8 in 2023 obtained from EarthExplorer which is the official website of the United States Geological Survey (USGS) were used to analyze the land cover of the Wae Heru watershed. Land cover in the Wae Heru watershed is classified based on SNI 7645-2010 on Land Cover Classification which consists of built-up land, non-agricultural areas, agricultural areas, open land, and water bodies.

This research uses the CA-MC method. Cellular Automata (CA) Markov is one of the methods that can be used to predict land cover change. This method uses mathematical models and spatial data to generate predictions about future land cover change patterns (Ajeeb et al., 2020). The CA-Markov method works by utilizing the principle of probabilistic change that takes into account the possibility of change from one type of land cover to another (Tian et al., 2016).

This method uses several parameters such as transition matrix, transition probability, and the influence of external factors to predict land cover change (Ghosh et al., 2017). By using the CA-Markov method, it is possible to predict land cover change with high accuracy. This will be very useful in planning more effective and sustainable land use and in making decisions related to appropriate and sustainable spatial planning.

This study uses variables that drive the development of built-up land in the Wae Heru watershed, including slope, land elevation, and distance from roads consisting of health facilities and educational facilities. The use of the above drivers in this study is based on similar studies and the physical conditions of the research location. Gentle and flat slopes and elevations are highly calculated for the development of built-up land or building settlements, this is inversely proportional to areas that have steep slopes.

According to Sugandhi et al. (2022), slope is one of the factors that influence the development of built-up land or buildings in an area. Steep slopes can limit the development of built-up land because it complicates the construction process and can increase the risk of natural disasters such as landslides and floods (Rakuasa et al., 2022). According to Supriatna et al. (2016), people tend to build settlements close to roads and public facilities, namely health facilities and education facilities. Distance from roads, education and health centers can affect the development of built-up land. The closer built-up land is to roads, education and health centers, the more likely it is to be accessible and more attractive for people to live or do business in the area (Latue et al., 2023). On the other hand, the farther the built-up land is from roads, education, and health centers, the more difficult it will be to access and less attractive it will be for people to live or do business in the area (Sapena & Ruiz, 2019). Thus, distance from roads, education, and health centers has a significant influence on the development of built-up land. The driving factors of land cover change in this study can be seen in Figure 1.

Figure 1. Driving Factors

The closer built-up land is to roads, education and health centers, the more attractive it is for people to live or do business in the area and the potential for rapid development (Zhou et al., 2022) . The four variables of driving factors were then overlaid using the Fuzzy Overlay technique. The results of the driving factor overlay show the highest fuzzy value of 1 and the lowest is 0. The highest value (1) indicates that the area is very suitable for built-up land development, on the contrary to (0) the lowest value which is not suitable for built-up land development. Landsat 5 and 8 satellite image data processing starts from radiometric correction, geometric correction then interpretation, digitization and classification based on SNI 7645-2010 on Land Cover Classification consisting of built-up land, non-agricultural areas, agricultural areas, open land, and water bodies (Badan Standarisasi Nasional, 2010). The driving factors used are slope, land elevation, distance from the road and Point of Interest (POI) consisting of health facilities and educational facilities based on the research of (Attaallah, 2018; Ajeeb et al., 2020; Supriatna et al., 2022).

Land cover prediction was conducted using IDRISI Selva and Arc GIS software. ArcGIS is a software platform developed by the company Esri (Environmental Systems Research Institute) for geographic mapping and spatial analysis. The name "ArcGIS" actually covers several different software products that work together to provide various functions in the fields of mapping, geographic analysis, spatial data processing, and geographic information visualization. This research uses the ArcMap software product for land cover analysis and analysis of drivers of developed land development.

IDRISI Selva is a software developed by Clark Labs for spatial analysis, environmental modeling, and geographic mapping. The name "Selva" comes from the Spanish word for "forest," illustrating the software's focus on environmental and biodiversity analysis. IDRISI Selva is part of the broader IDRISI family of software products used in various fields of environmental science, geography, and earth science.

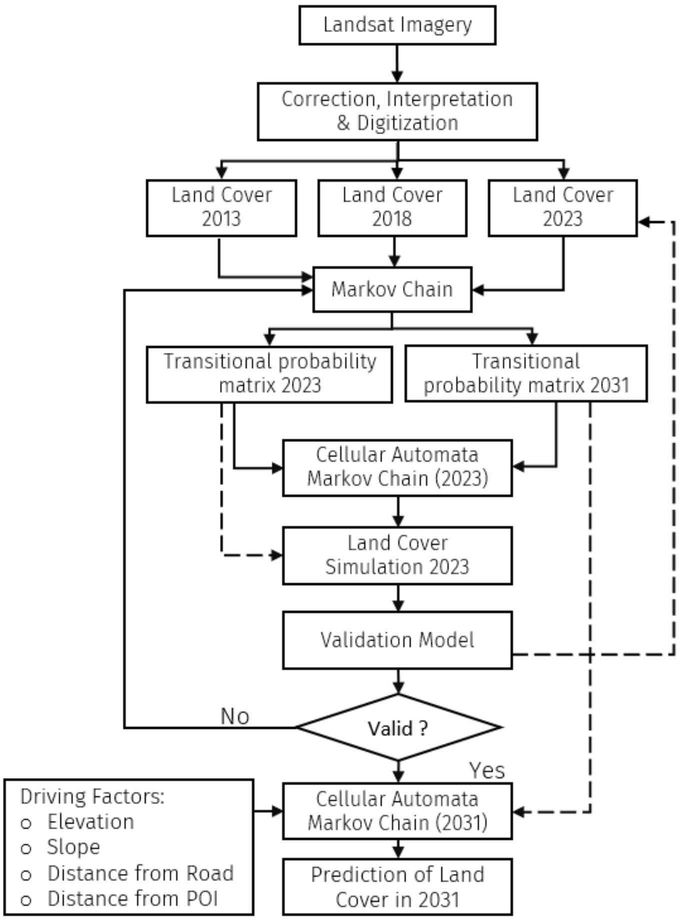

Figure 2. Workflow

Land cover prediction was conducted in IDRISI Selva software using Markov tools by simulating land cover in 2028 which was then validated using existing land cover in 2028. The validation test was conducted using Kstandard (Kappa Coefficient), if the simulation accuracy results reached >75% then there is no need to repeat the accuracy process and can proceed to the next modeling process (Irawan et al., 2019). The research workflow can be seen in Figure 2.

RESULT AND DISCUSSION

Land cover change of Wae Heru watershed in 2013, 2018 and 2023

Land cover change is defined as a change in land use from one type of land cover to another, either caused by natural or human factors. Examples of land cover change include changes from forest land to agricultural land, changes from agricultural land to settlements, or changes from open land to forest. Land cover change can have significant impacts on the environment and human life, so it is important to pay attention to and sustainably manage land cover change to minimize its negative impacts (Talukdar et al., 2020).

The results of the analysis show that built-up land cover in the Wae Heru watershed in 2013, 2018 and 2023 continues to increase in area. In 2013, built-up land had an area of 74.25 ha, in 2018 it was 79.30 ha and in 2023 it was 88.00 ha. Open land in 2013 had an area of 6.54 ha, experiencing an increase in area in 2018 of 6.73 ha and in 2023 of 7.49 ha. Agricultural land in the Wae Heru watershed also experienced an increase in area each year due to the conversion of non-agricultural land into agricultural land, where in 2013 agricultural land was 210.85 ha, in 2018 it was 341.40 ha and in 2023 it was 387.03 ha. In contrast to non-agricultural land which experienced a decrease in area, namely in 2013 covering 329.66 ha in 294.05 and in 2023 covering 238.79, this is different from water bodies which did not experience an increase or decrease in area where water bodies had an area of 8.31 ha. Based on research conducted by Somae et al. (2023), population growth is the factor that most influences land cover change in the Wae Heru watershed and its surroundings. The land cover change map of Wae Heru watershed in 2013, 2018 and 2023 can be seen in Figure 3.

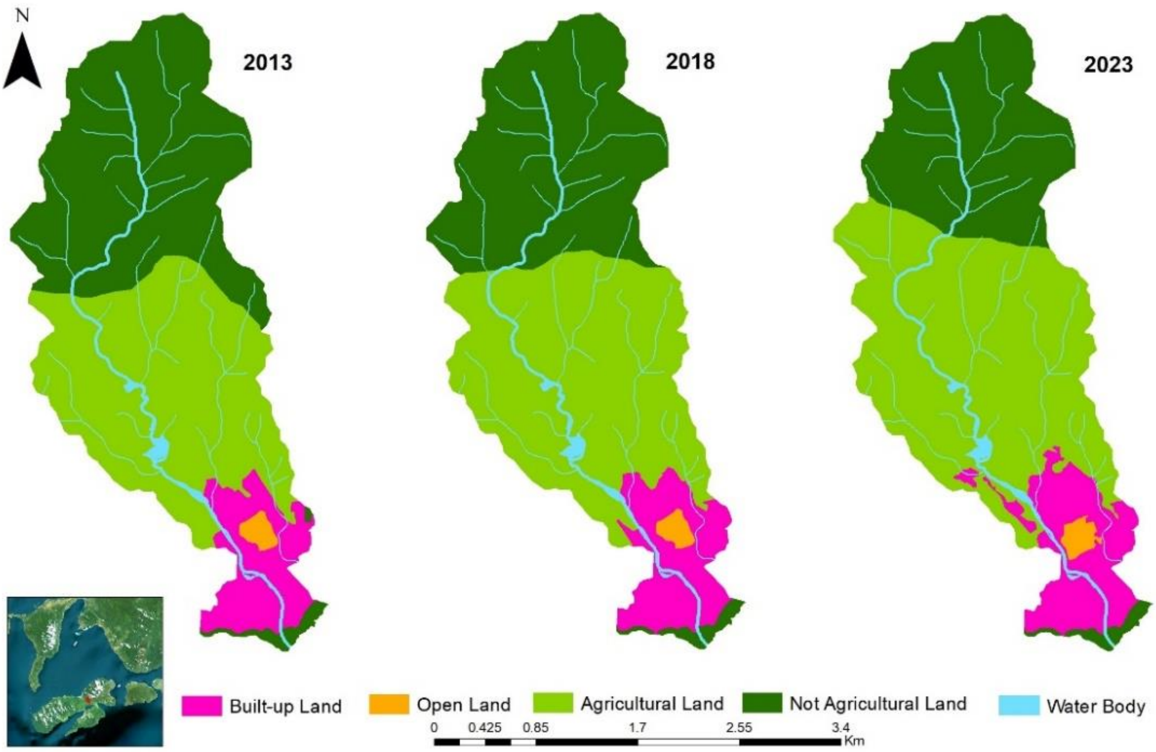

Figure 3. Land Cover in 2013, 2018 and 2023

Simulation of Land Cover of Wae Heru Watershed in 2023

CA Markov analysis produces Transition Probability Matrix (TPM) from 2018-2023 and from 2023-2028. Transition Probability Matrix (TPM) in CA Markov analysis in IDRISI Selva software is a matrix that shows the probability of movement or change from one type of land cover to another in one time period to the next time period. This matrix is used in CA Markov analysis to model land cover change over time. The resulting TPM matrix can be used to predict land cover change in the next time period using the CA Markov model. By taking into account the probability of moving from one land cover type to another, the CA Markov model can generate different scenarios of future land cover change.

The Transition Probability Matrix (TPM) for 2018-2023 can be seen in Table 1. The value of the Transition Probability Matrix (TPM) in Table 1 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 open land cover has a higher probability of turning into settlements with a TPM value of 1.1619, while the number 1 in the type of water body land cover indicates that land cover will remain and do not change to other land covers. The results of the 2023 land cover model can be seen in Figure 4.

Table 1. Transition probability matrix (TPM) for 2018-2023

	C1	C2	C3	C4	C5
C1	0.8496	0	0.0501	0.1003	0
C2	0.0375	0.8500	0.0375	0.0375	0
C3	0.1619	0	0.8381	0	0
C4	0.0054	0	0.2364	0.7582	0
C5	0	0	0	0	1

Descriptions: CL.1= Built-up Land, CL.2= Open Land, CL.3= Aricultural Land, CL.4= Not Agricultural Land, CL.5= Water Body

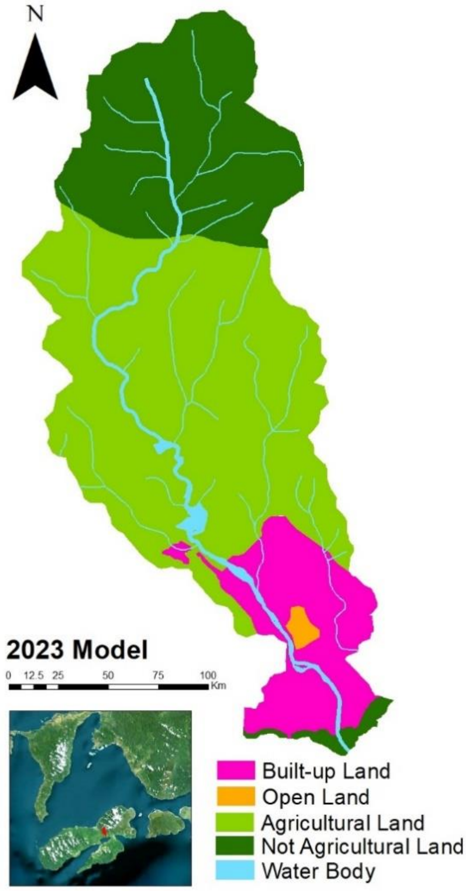

Figure 4. Land Cover Simulation in 2023

The results of the 2023 land cover simulation were then tested for accuracy using the Kappa test. The validation test was conducted using the K-standard (Kappa Coefficient), if the simulation accuracy results reached >75% then there is no need to repeat the accuracy process and can proceed to the next modeling process (Figure 5). The validation test shows a Kappa or K-standard value of 0.8380 or 83.80%, meaning that the accuracy test results are very good for predicting land cover in 2032.

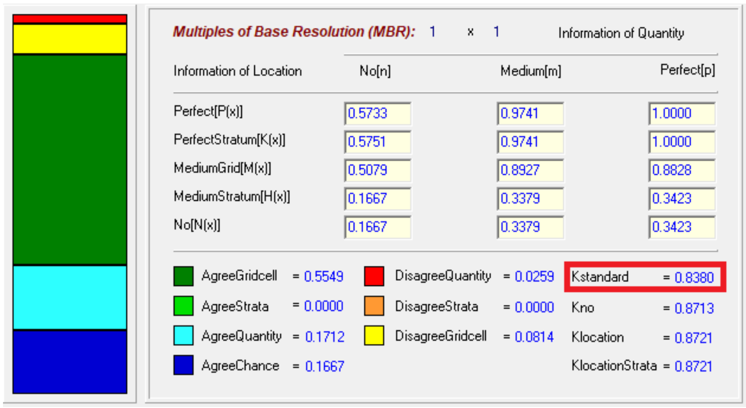

Figure 5. Validation Test of the 2023 Land Cover Model

Land Cover Model of Wae Heru Watershed in 2028

Just like the Transition Probability Matrix (TPM) in Table 1, it also produces TPM values for the period 2023-2028. The magnitude of the TPM value in Table 2 is in the range of 0-1. The greater the probability value on the destination land cover, the greater the likelihood of simple land cover. It can be seen that open land cover has a higher probability of changing into settlements with a TPM value of 0.1755, while the number 1 on the water body land cover type indicates that the land cover will remain and not change to other land covers. The Transition Probability Matrix (TPM) for 2023-2028 can be seen in Table 2.

Tabel 2. Transition probability matrix (TPM) tahun 2023-2028

	C1	C2	C3	C4	C5
C1	0.8212	0.1418	0.0362	0.0008	0
C2	0.0062	0.6938	0	0	0
C3	0.1755	0	0.8245	0	0
C4	0	0	0.3097	0.6903	0
C5	0	0	0	0	1

Description: CL.1= Built-up Land, CL.2= Open Land, CL.3= Aricultural Land, CL.4= Not Agricultural Land, CL.5= Water Body

The results of the prediction of land cover in 2028 in the Wae Heru watershed show that built-up land has an area of 116.96 ha or 16.03%, open land covering 10.81 ha or 1.48%, agricultural land covering 403.93 ha or 55.36%, non-agricultural land covering 189.61 ha or 25.99% and water bodies covering 8.31 ha or 1.14%. According to Latue et al. (2023), population growth in the Wae Heru watershed can significantly affect the increase in built-up land area in the region.

Population growth is usually followed by the need for land for housing, infrastructure, and economic activities. This encourages the conversion of agricultural land, forests, or vacant land into built-up land such as settlements, offices, shopping centers, or industries (Kisamba & Li, 2022). An increase in the area of built-up land can have important consequences, both in environmental and social, economic terms (Wang et al., 2020). Spatial land cover in the Wae Heru watershed can be seen in Figure 6.

The results of the prediction of land cover of the Wae Heru watershed in 2028 are very useful, including for more targeted regional development planning, sustainable natural resource management, agrarian conflict control, local economy-based business development, provision of basic data for research and development.

According to Latue & Rakuasa, (2023), by predicting future land cover, local governments and related stakeholders can plan more targeted and measurable regional development. This can reduce the risk of errors in planning and help optimize the utilization of available land resources. Permatasari et al. (2021), explained that by predicting future land cover, the government and relevant stakeholders can develop sustainable natural resource management strategies and prevent environmental degradation. This will help maintain environmental sustainability and minimize the negative impacts of regional development (Rakuasa & Somae, 2022). According to Wang et al. (2021), by predicting future land cover, the resulting data and information can form the basis for further research and development. This will help improve understanding of the dynamics of land cover change and encourage the development of innovative solutions to address land cover-related issues in the area. Munthali et al. (2020), added that land cover prediction can help prevent future agrarian conflicts. By understanding the changes in land cover that will occur, the government and related stakeholders can take preventive actions to prevent conflicts. Thus, land cover prediction has great importance in sustainable regional development and effective natural resource management. The results of this research are expected to be useful for the government, academics, and the community in the future.

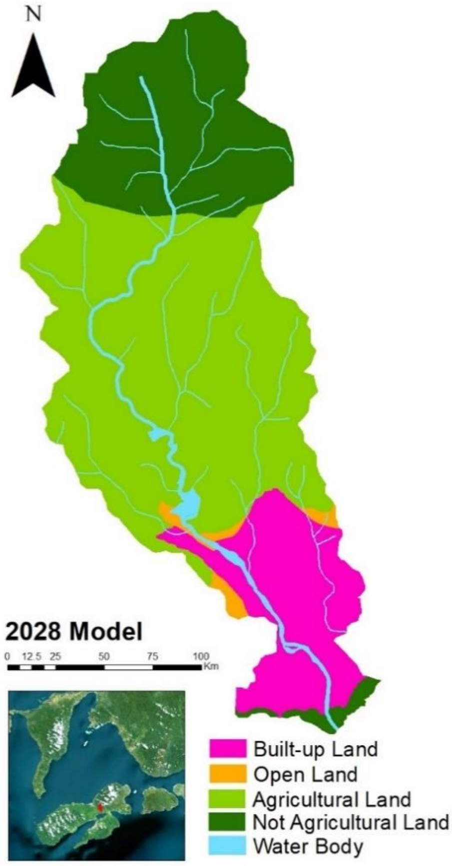

Figure 6. Land Cover Model of the Wae Heru Watershed in 2028

CONCLUSION

Over the last 15 years from 2013, 2018 and 2023, the area of built-up land has continued to increase, in contrast to other types of land cover. The results showed that in 2013 the built-up land had an area of 74.25 ha, in 2018 it was 79.30 ha and in 2023 it was 88.00 ha. The prediction results of land cover in 2028 show that built-up land in the Wae Heru watershed continues to increase in area by 116.96 ha as the population increases every year. The results of this study provide important implications in natural resource management, spatial planning, and future disaster mitigation efforts in the Wae Heru watershed.

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