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Land Cover Projection of Jember Irrigation Area Using MOLUSCE QGIS

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Abstract: Jember Regency has the third-largest agricultural area in East Java Province. However, the agricultural area has decreased due to the expansion of built-up areas in line with population growth. This indicates the need for special attention to controlling the expansion of built-up area in Jember Regency. This study focuses on predicting the loss of agricultural areas and the increase in built-up areas in Jember Regency using the Cellular Automata-Markov (CA-Markov) modelling approach through the MOLUSCE plugin in QGIS to perform land cover prediction. Predicting land cover change using Sentinel-2 imagery to obtain land cover data for Jember Regency in 2017 and 2021. The land cover maps for 2017 and 2021 will be used as reference maps to determine land cover in 2025. The obtained 2025 land cover map will validate the model's accuracy by comparing it with the actual 2025 land cover using Kappa Accuracy. The result of this study achieved a kappa accuracy of 91%, indicating a high classification accuracy. The validated model will then be used to predict land cover for 2045 by conducting six iterations. The analysis predicts a reduction in agricultural areas by 5,675 hectares and a predicted increase in built-up areas in irrigated areas by 6,348 hectares from 2025 to 2045. Over the next 20 years, irrigation areas under the regency's authority are expected to experience a growth in built-up areas at 46.1%, under provincial authority predicted to grow by 34.6%, and areas under central authority predicted to grow by 110% of the total agricultural areas in Jember Regency. These findings are important for local governments and stakeholders in land management and urban planning. They also contribute to the monitoring of agricultural land use and the development of effective policy strategies.

Keywords : Land Cover Change; Projection; Sentinel-2; MOLUSCE.

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Introduction

Population growth is one factor that causes changes in land cover. Changes in land cover lead to an increase in the conversion of agricultural land for non-agricultural uses. This will threaten national food security, reduce labor absorption in the agricultural sector, and disrupt communities that have long depended on agricultural land for their livelihoods (Kholik et al., 2024).

Jember Regency has the third-largest agricultural area in East Java Province. Changes in land cover in Jember, particularly the conversion of forest to agricultural use or the conversion of agricultural areas to built-up areas, affect the water balance and could lead to surpluses or shortages of irrigation water (Indarto et al., 2023).

Remote sensing technology is effective for identifying land cover changes and predicting future land cover changes. Esri Living Atlas provides land cover data with a resolution of 10 meters obtained from Sentinel-2 L2A imagery. Esri land cover data has been available since 2017 (Shiri et al., 2024). The map result of a deep learning model trained using over five billion manually labeled Sentinel-2 pixels. This model uses six Sentinel-2 surface reflectance bands: red, green, blue, near infrared, and two shortwave infrared bands. The final map was created using year-round imagery combined into a single, representative map (Karra et al., 2021). Most research on land use change relies on Landsat satellite imagery (Değermenci, 2023), while Sentinel-2 imagery provides better land cover data for making land cover predictions (Bill Donatien et al., 2024).

Projecting land cover changes in agricultural areas is important for developing effective policy strategies.

Geospatial technology and spatial analysis provide effective tools for monitoring and predicting these changes. The MOLUSCE (Modules for Land Use Change Simulation) plugin in QGIS can be used to predict and analyze land cover changes by utilizing the Cellular Automata-Markov (CA-Markov) algorithm, which combines Markov Chain analysis to estimate the transition probabilities of land cover based on historical data and Cellular Automata to simulate spatial patterns and the distribution of changes in future scenarios. The integration of these algorithms allows land cover prediction (Muhammad et al., 2022a).

Predictions of land cover are expected to provide a foundation for more targeted planning and policymaking to maintain the sustainability of agricultural land functions and support efforts to achieve sustainable national food security. Additionally, routine monitoring of land cover changes helps stakeholders anticipate potential risks of land conversion and take preventive actions to protect vital agricultural zones.

Data and Method

Study Area

This research focused on agricultural areas experiencing dynamic changes in land use in Jember Regency, East Java. Jember Regency was chosen because it has the highest rice production (Tuslaela et al., 2024). The Jember Regency is located in the southeastern East Java province. It borders Bondowoso and Probolinggo Regencies to the north. Jember borders Banyuwangi Regency to the east, Lumajang Regency to the west, and faces the Indian Ocean to the south. This study, conducted in 2025, included data collection, modeling, and simulation result validation stages.

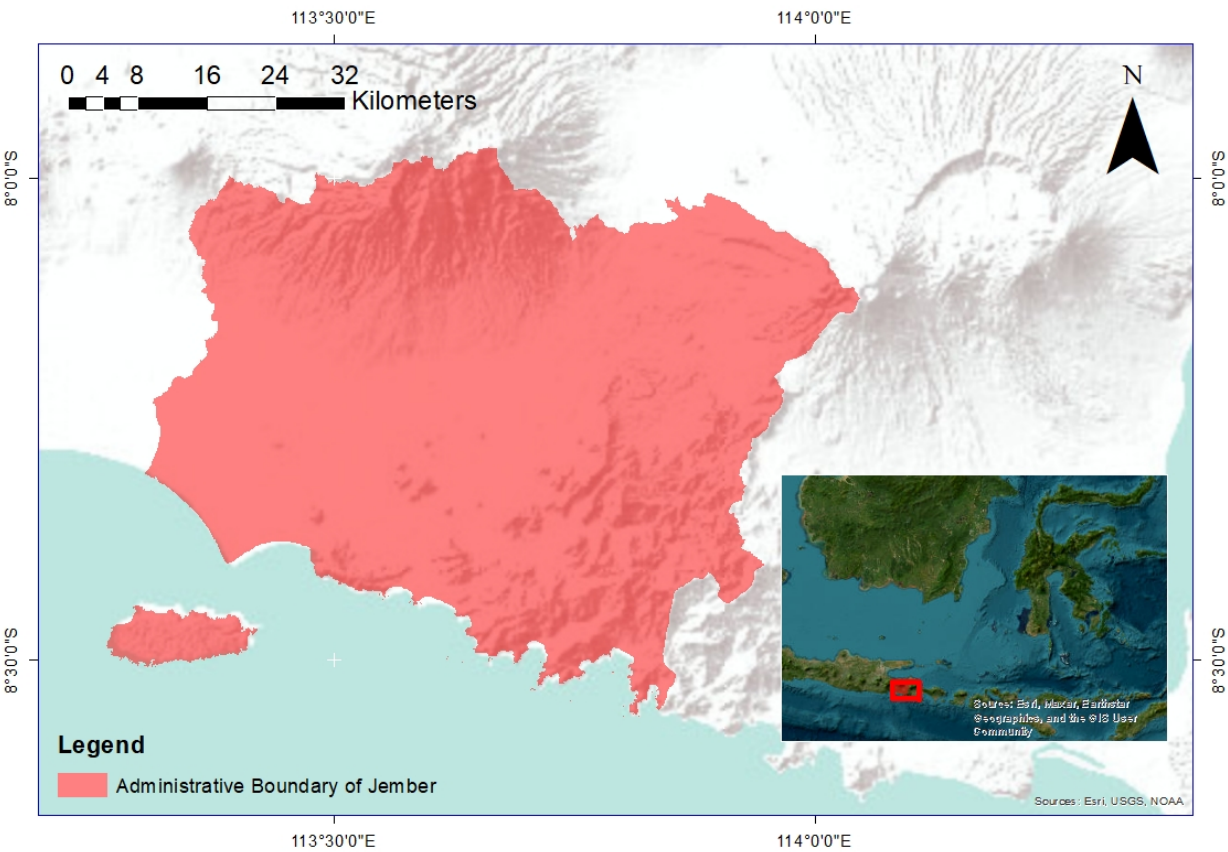


Figure 1. Study Location

Analysis Method

The data used in this study comprised several sources. The land cover maps for the years 2017 and 2021 were obtained from the Esri Living Atlas Cloud. The 2017 and 2021 land cover maps were created using Sentinel-2 imagery, which is highly effective for mapping land cover, especially in agricultural areas (Phiri et al., 2020). The land cover classes used are water, trees, crops, built-up areas, and rangeland areas. The “Trees” group usually consists of dense vegetation, such as forests, plantations, and mangroves. The "Crops" group includes agricultural areas (Karra et al., 2021). The irrigation area boundary maps for Jember Regency were obtained from the Public Works, Highways, and Water Resources Office of Jember Regency. Additional supporting data, such as administrative and road network maps, were gathered from https://tanahair.indonesia.go.id/. The road network map was chosen as the driving factor because the agricultural area in Jember Regency has a relatively flat contour (Santoso & Fitri, 2023). This is based on the fact that changes in land cover in lowlands are greatly influenced by human activities related to road accessibility (Odgaard et al., 2014). In addition to road accessibility, elevation maps are a key factor in detecting changes in land cover (Saputra & Lee, 2019). However, this study only considered road networks due to the limited availability of elevation maps with Sentinel-2 resolution. Figure 2 illustrates the research flow.

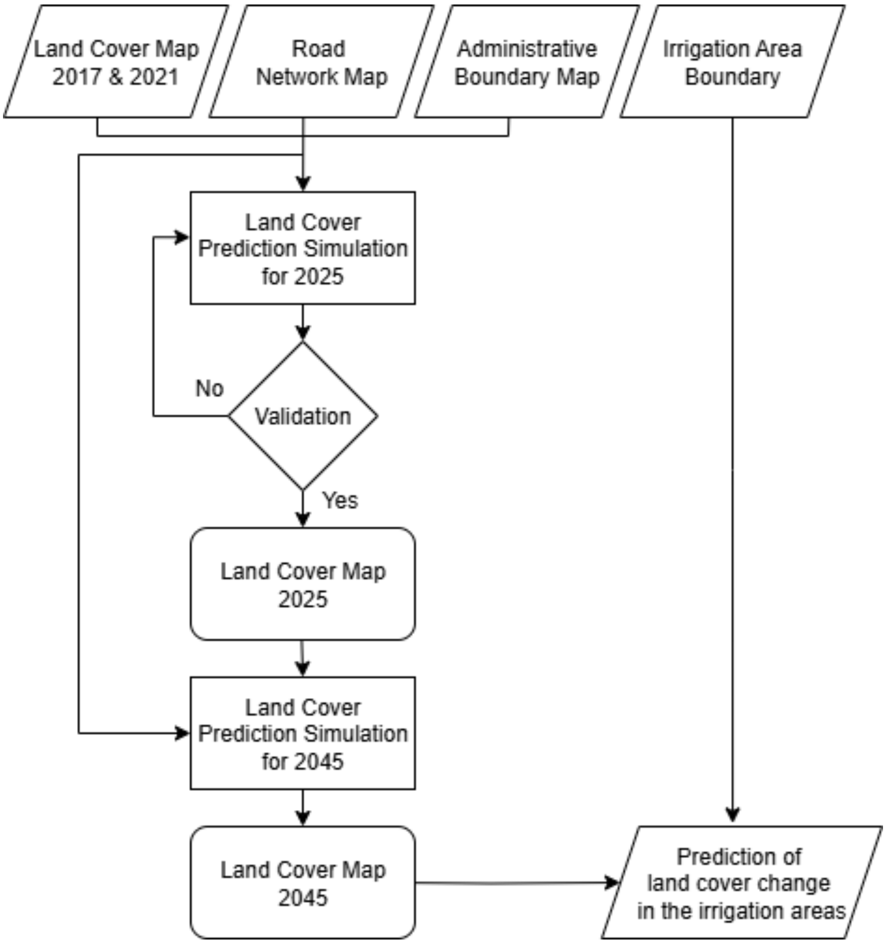


Figure 2. Research Flow

This study began with combining land cover maps from Esri Living Atlas Cloud, which were adjusted to fit the study area. Then, land cover predictions for 2025 were made using land cover maps from 2017 and 2021. The land cover prediction simulation used the MOLUSCE (Modules for Land Use Change Simulation) plugin in the QGIS software program using the Cellular Automata-Markov (CA-Markov) algorithm. MOLUSCE was chosen because it is an open-source plugin directly integrated with QGIS. It allows users to easily perform analyses, modelling, and simulations of land cover changes without additional software. Its simple data input process makes it user-friendly for researchers (Kumari & Roy, 2025; Yadav & Singh, 2024).

These results were validated by comparing the 2025 land cover map with reference data from Google Earth and through direct verification using ground truth in the field. In this study, the modelling process is carried out through several iterations, where land cover predictions for each year are generated from the previous period. Each iteration involves model validation using the kappa accuracy index, and modelling proceeds to the next iteration only if the kappa accuracy validation results are more than 80% (De Raadt et al., 2019).

Validation

Validation was carried out by comparing the 2025 land cover prediction map with reference data from Google Earth. Because some of the Google Earth data were not fully up-to-date, a field survey was conducted to complement and validate the accuracy of the reference data through ground truth checks. Sample points for the accuracy assessment of land cover maps are distributed proportionally according to each land cover class's area, ensuring that the ground truth distribution reflects the overall land cover composition. Land cover classes with larger areas are allocated more sample points than smaller ones. Validation between the prediction map and reference data, including Google Earth and ground truth data, was assessed using kappa accuracy. Kappa accuracy was used to calculate the accuracy level and measure the conformity of the prediction results with the comparative data. If the obtained accuracy value was above 80%, the land cover simulation modelling was deemed suitable for use (Wu et al., 2025). The formula for assessing Kappa Accuracy in land cover classification is as follows:

$$KA = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}X_{+i}}{N^2 - \sum X_{i+}X_{+i}} \quad (1)$$

X_{ii} is the diagonal value of the contingency matrix for row i and column i. N is the number of observation points, and r is the number of land use classes (Feizizadeh et al., 2022).

Irrigation area

In accordance with Ministerial Regulation No. 14/PRT/M/2015 concerning the criteria and determination of irrigation area status, issued by the Ministry of Public Works and People's Housing in 2015. Irrigation areas under 1,000 hectares fall under the authority of the regency; those between 1,000 and 3,000 hectares fall under the authority of the province; and those over 3,000 hectares fall under the authority of the central government.

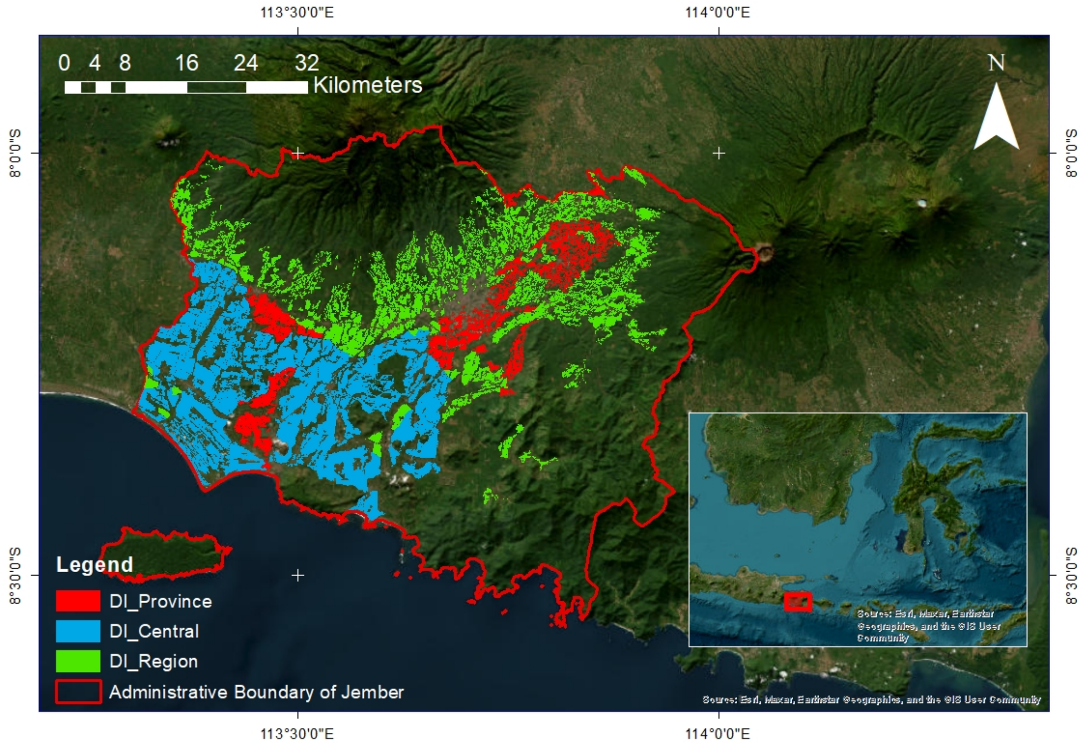


Figure 3. The Irrigation District Authority

Results and Discussion

Land Cover Change Analysis

Changes in land cover between 2017 and 2021 resulted in a transition matrix showing significant land conversion in Jember Regency, particularly in the agricultural areas, which changed to built-up areas. The following transition matrix illustrates the land cover changes from 2017 to 2021.

Table 1. Transition matrix land cover map 2017 and 2021

	Water	Forest	Rangeland	Crops	Built Area
Water	0.81	0.03	0.03	0.1	0.02
Forest	0.0005	0.93	0.0001	0.04	0.01
Rangeland	0.12	0.27	0.33	0.24	0.01
Crops	0.0009	0.04	0.0001	0.90	0.05
Built Area	0.0002	0.041	3.09	0.05	0.90

The transition matrix table shows that forest areas have decreased and been converted into crops 4% and built-up areas 1% from the total forest area in Jember Regency. The built-up areas increased by 5% in the crop area. This data transition matrix will be used as a basis for predicting the land cover map for 2025. The land cover prediction for 2025 Jember Regency was generated by applying Cellular Automata-Markov using the MOLUSCE plugin in QGIS. The following image shows the land cover prediction map for 2025.

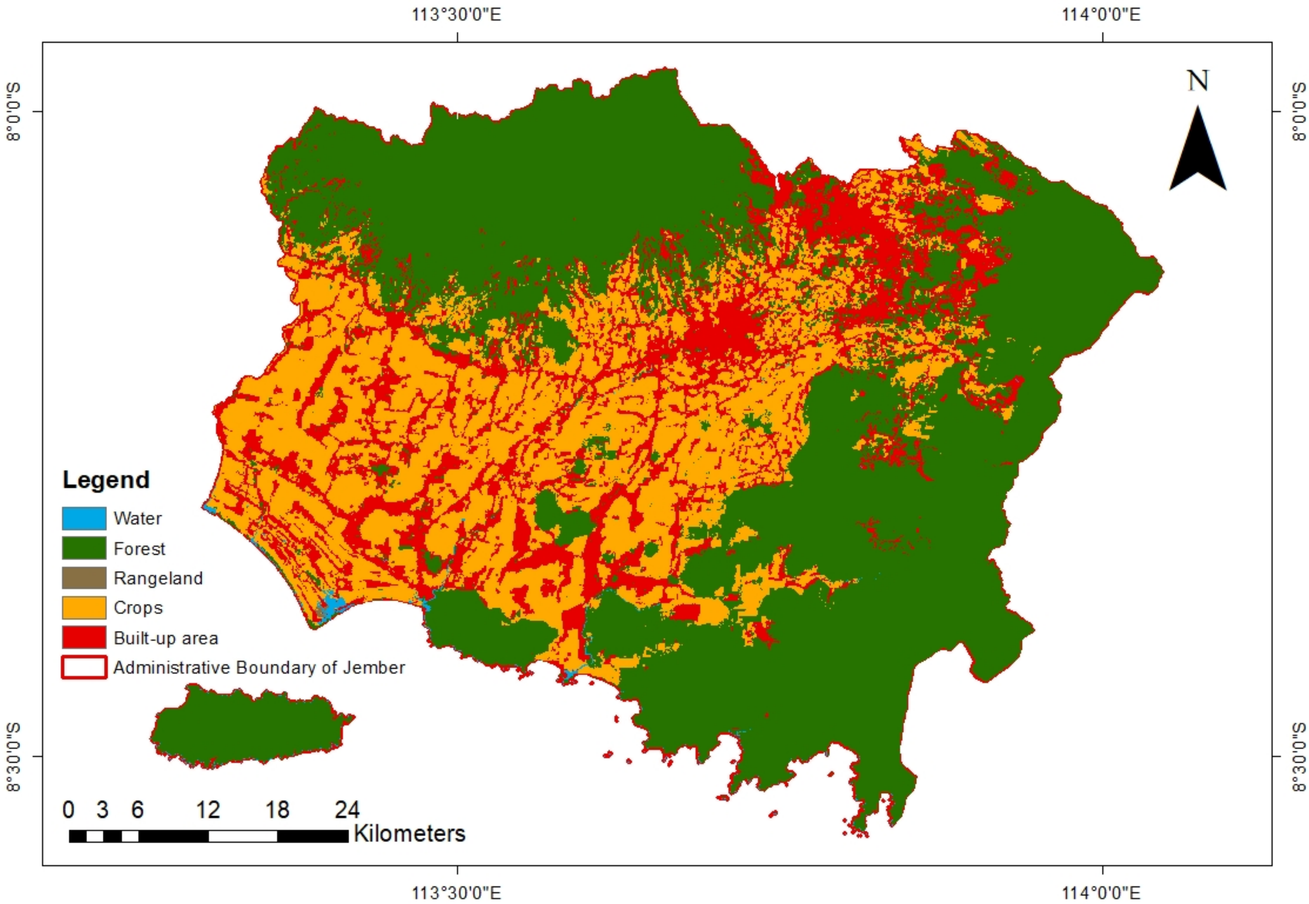


Figure 4. Land Cover Prediction for 2025

From 2021 to 2025, Jember Regency experienced an increase in Built-up area of 598 hectares and a decrease in Crop area of 1,025 hectares.

Model Validation

The 2025 land cover prediction map was validated using Google Earth as the comparative data source. The following random points were used to validate the map.

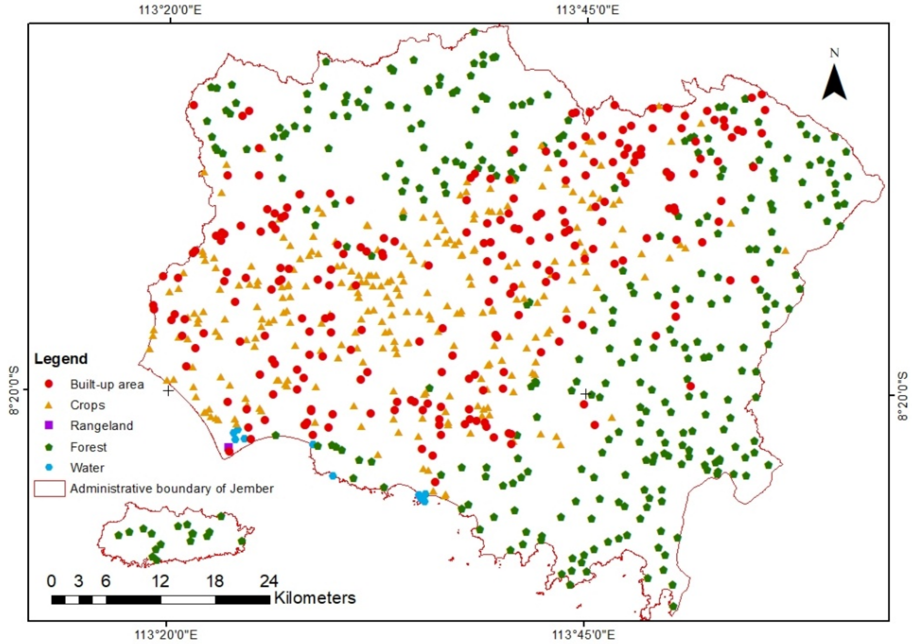


Figure 5. Random Point for Validation Check

The 2025 land cover prediction map was validated by comparing its accuracy at 856 points. Since not all Google Earth data is from 2025, the study also conducted a validation with ground truth at 35 points. Considering the ease of access to the location, this point was selected so that field inspections can be carried out effectively and efficiently. The selection of this point also ensures that the validation data covers the variations of existing land cover conditions. The following points were observed directly in the field.

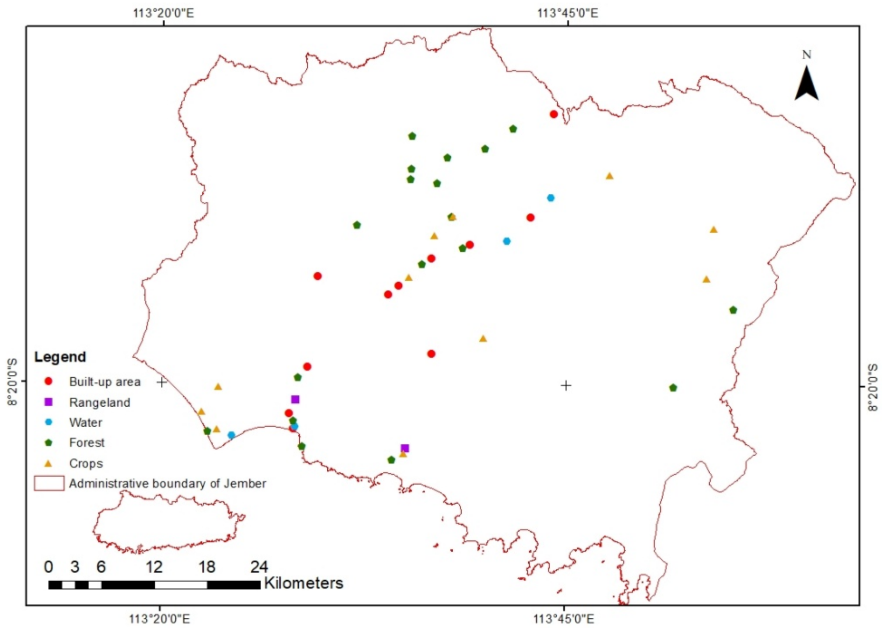


Figure 6. Ground Truth Point for Validation Check

The confusion matrix below contains the agreement between the reference data and the classes classified by the model, representing all types of land cover tested. The model's reliability was validated using Kappa Accuracy, and the results were as follows.

Table 2. Confusion Matrix for Kappa Accuracy

Reference Data	Classified into class					**Total**
	Water	Tree	Range Land	Crops	Built Area	
Water	**12**					**12**
Tree		**335**	5	7	1	**348**
Range Land	1		**0**			**1**
Crops	2			**252**	29	**283**
Built Area		1	2	3	**241**	**247**
Total	**15**	**336**	**7**	**262**	**271**	**891**

The Kappa Accuracy result from the above calculation is 91%. This falls into the "Strong Agreement" category (Lukas et al., 2023).

Land Cover Prediction for 2045

The 2045 land cover prediction was generated by applying Cellular Automata-Markov using the MOLUSCE plugin in QGIS iteratively, using the validated 2025 simulation results and land cover map for 2017 and 2021 as input data. The transition probability matrix and neighborhood rules obtained from historical data were applied repeatedly to simulate land cover change up to 2045. In this process, the iteration was performed six times, since the interval between 2017 and 2021 is four years, and therefore six additional iterations were required to reach the target year of 2045. The following map shows the predicted land cover in 2017, 2021, 2025, and 2045.

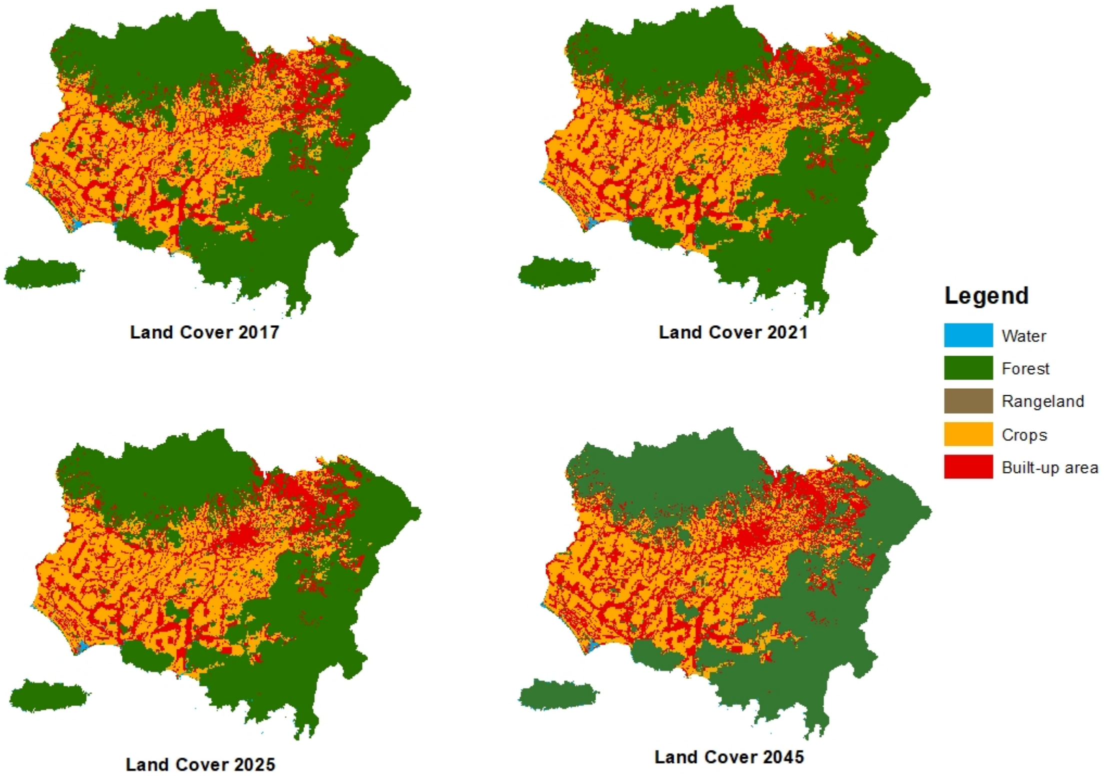
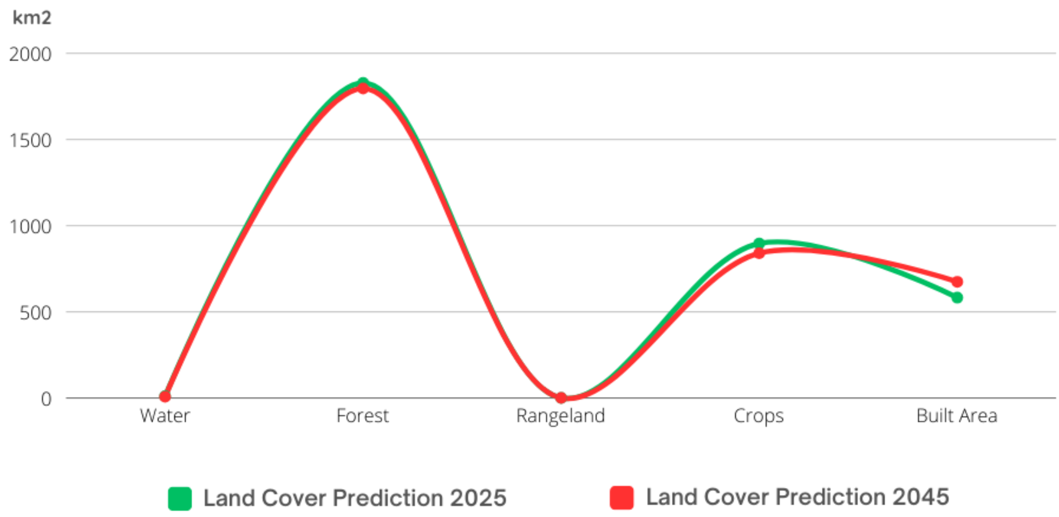


Figure 7. Land Cover Jember District in 2017, 2021, 2025, and 2045

The following figure shows the predicted results of land cover changes from 2025 to 2045.



These long-term land cover change predictions indicate that Jember Regency will experience a 9,212-hectare increase in built-up area over the next 20 years. This is in line with previous research, which stated that the trend of land cover change in East Java Province, including Jember Regency, showed an increase in built-up area by 370% of the total area during the period 1972–2021 (Mandala et al., 2023). In addition, more specifically, the land cover in the Bedadung watershed, which is the largest watershed in Jember Regency, has experienced a reduction in forest area and a significant increase in built-up area (Kartikasari et al., 2022). The reduction of forest area will lead to increased rainfall runoff and water discharge, which in turn causes flooding in the downstream areas (Basuki et al., 2023).

Land Cover Projection of Jember Irrigation Area

The irrigation areas in Jember Regency are divided into three administrative areas. According to the Land Cover Projection results for 2025 and 2045, the irrigation area in Jember Regency is estimated to experience built-up land growth in the next 20 years, namely 46.1% for the regency authority, 34.6% for the provincial authority, and 110% for the central government authority from the total agricultural area in Jember Regency. The projected changes in land cover have significant environmental and social implications, such as reduced agricultural productivity which will decrease natural capital's total value (Gabisa et al., 2025). The decline in agricultural land area has forced part of the community that depends on this sector to shift to non-agricultural jobs, and compensation funds have also been allocated more heavily for purposes outside the agricultural sector (Tran Tuan, 2021).

Information on land cover predictions can be used to prepare regional spatial planning. This spatial planning must be adhered to, with legal consequences in case of violations, per Regulation Number 18 of 2016 by the Minister of Agrarian Affairs and Spatial Planning/Head of the National Land Agency of Indonesia (Mahmud Hanafi, 2025). Therefore, it is necessary to establish a minimum limit on the area of national agricultural land that must not be violated even in the face of urbanization pressures. Another alternative is implementing a balanced increase and decrease policy for agricultural land by restoring agricultural land in rural areas to replace peri-urban agricultural land that has been taken for urbanization (Ye, 2015). If urbanization develops very rapidly, the policy has the potential to reduce the area of forest land due to conversion into agricultural land. Therefore, it is necessary to establish urban development boundaries to limit city expansion so that urban growth does not take over productive agricultural land (Cheng et al., 2025), or vertical housing development could be a solution to reduce land cover conversion and prevent horizontal expansion that sacrifices agricultural land and forest areas (Darshan Dash, 2024).

Conclusions

Over the next 20 years, land cover in Jember Regency is projected to experience significant changes, including an increase of 9,212 hectares in built-up land, a decrease of 5,634 hectares in crop area, and a loss of 3,265 hectares of dense vegetation or forest. Specifically, the irrigation areas under the central government's authority in Jember will experience the highest proportional growth in built-up area, reaching 110%. This figure indicates that the built-up land within the irrigated regions may more than double compared to the current extent, demonstrating rapid urbanization and land conversion pressures.

Land conversion pressures can be addressed through a well-thought-out regional spatial planning that considers land cover change predictions as a basis for determining protected crop areas or urban development boundaries to limit the expansion of built-up land. In addition to physical landscape changes, the conversion of agricultural areas to built-up areas triggers the loss of livelihoods for local farmers and decreases the food security of the region. Therefore, policies with firm consequences must also be implemented so that all community members can adhere to the spatial planning that has been made.

It is important to understand the limitations in modeling and predictions in this research, such as uncertainties in future socio-economic trends, policy interventions, and potential land use changes beyond the modeled scenarios. Therefore, the results of this study should inform decision-makers to carefully plan and regulate land use, focusing on preserving agricultural land, protecting remaining vegetation, and balancing development with long-term environmental sustainability.

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