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Projected Land Use Change Based on Protected Scenarios in Malang City

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ABSTRACT

Regional spatial planning often requires studies of projected land-use changes. However, these land-use change projection studies often neglect the protection function aspect in their modeling scenarios. Modeling using protection function scenarios is expected to make a significant theoretical and practical contribution to regional spatial planning and geospatial analysis. The research aims to develop a model for projecting land use change based on protected scenarios to support sustainable development in Malang City. Projection of land-use change based on scenarios is carried out quantitatively and involves spatial modeling. Spatial modeling was carried out using Cellular Automata (CA), which is integrated with Markov Chain (MC) and Artificial Neural Network (ANN). Hybrid modeling of Cellular Automata (CA) – Markov Chain (MC) – Artificial Neural Network (ANN) is expected to offer more attractive advantages compared to single modeling techniques. The model was developed by paying attention to the driving factors and constraint variables as scenario variables in the form of maintained protected areas. This research produced a projected model of land use change in 2029 based on a protected scenario in Malang City. The projection results indicate potential land change for sizable settlements in Malang City, especially in the eastern and western parts around the center of activities and the Malang-Pandaan toll road. The potential development of these settlements needs to be anticipated and directed so that they do not cause various spatial conflicts in the future and do not trigger environmental degradation. With scenario-based projections, several protected areas such as city parks, green belts, city forests, and river banks can be relatively maintained in 2029 according to the spatial pattern plan in the Malang City spatial plan.

INTRODUCTION

Malang City is the second-largest city in East Java Province after Surabaya City. With nearly 1 million people, Malang City is developing into a metropolitan area characterized by high population density, which has continued to increase from 2009 to 2019 (Badan Pusat Statistik, 2023). The increase in population activity across various sectors, especially in the economic and education sectors in Malang City, has driven land demand, thereby encouraging land-use changes. Land-use changes can lead to inconsistencies with regional spatial plans (Pravitasari et al., 2020; Tejaningrum et al., 2019). Early detection of all future land-use changes is critical as a reference for land-use control to minimize inconsistencies (Kurnianti et al., 2016).

One of the main factors that causes environmental damage, such as land degradation, biodiversity loss, and climate change, is unsustainable land use. Therefore, sustainable land use planning must be implemented to maintain environmental conditions. Sustainable land-use planning is essential in today's development, given the increasing demand for land, population growth, and rapid infrastructure development (Dewi et al., 2014; Juwono et al., 2022).

In the context of land use, future changes are expected to be directed and controlled by the regional spatial plan. For this reason, it is necessary to develop a projection model for land use change with specific scenarios to ensure that land use change does not degrade environmental quality. The ecological approach to projecting land use change should be applied to maintain specific land uses for environmental conservation. Thus, development will be more directed towards sustainability. Models and simulations are often used in land use planning to help make more efficient and sustainable decisions. Using models and simulations can help evaluate land use, project its impacts, and assess future land use alternatives (Lasaiba, 2023).

Scenario-based land use change projection models are more likely to support decision-making in planning land use more appropriately by considering various possibilities, including potential risks. In addition, understanding the potential for change can help utilize resources efficiently and sustainably (Aghaloo & Sharifi, 2025). Spatial data processing must be carried out when developing scenario-based land-use projection models. Spatial data from various sources, such as satellite imagery, maps, GPS data, and other sources, can be processed and analyzed to produce the information needed for decision-making to support sustainable land-use planning (Muttaqin et al., 2022; Wahyuni & Wahid, 2018).

The city of Malang is undergoing an inevitable process of urbanization. As a result, the community's need for land continues to increase as various sectors develop. The progress of a region can be hindered by uncontrolled growth. These adverse impacts can cause environmental and social problems, including increased average temperatures, food scarcity, land degradation, threats to ecological services such as water and air quality, reduced conservation areas, and even the possibility of social conflicts over land ownership (Vollmer et al., 2016).

The region has undergone many changes in various aspects during its development. These changes can be related to population growth, economic development, land-use changes, and other factors. The development that occurs can lead to better conditions, but can also lead to situations that are not desired. In the context of development, the direction of regional development can lead to sustainable development, and, conversely, to unsustainable conditions. This happens because there is uncertainty in the development process, especially regarding future changes. Uncertainty arises from many factors that affect development; not all can be controlled.

Given the uncertainty in the development process, a more precise planning approach is needed. Planning must be able to make projections that anticipate uncertainty. One way to make more accurate projections is to make scenario-based projections. Using scenarios when making projections is very appropriate for reducing uncertainty in development outcomes, thereby aligning them more closely with expectations. Thus, potential risks can be minimized by using the applied scenarios.

The research aims to develop a scenario-based land-use change projection model for 2029 to support sustainable development in Malang City, using the Cellular Automata-Markov Chain (CA-MC) and Artificial Neural Network (ANN). The projection model, developed using a protected scenario that aims for several designations, such as green open spaces, river borders, and flood-prone areas, remains unchanged, thereby supporting the sustainability of development.

Many studies have investigated land-use change projections, including those by Gui et al. (2025), who used cellular automata, and Dumdumaya & Cabrera (2023), who used artificial neural networks. However, these studies still use a single approach. Hybrid modeling of Cellular Automata (CA), Markov Chain (MC), and Artificial Neural Network (ANN) is expected to offer greater advantages than single modeling techniques. Hybrid modeling is intended for complex spatiotemporal applications, such as land-use/land-cover (LULC) change prediction, urban growth simulation, or environmental modeling. Cellular Automata, Markov Chain, and Artificial Neural Network are expected to be complementary. Cellular Automata (CA) are very good at capturing spatial patterns and local environmental interactions. Markov Chain (MC) provides quantitative transition probabilities between states over time (temporal dynamics). Artificial Neural Networks (ANNs) can model complex, nonlinear relationships between driving factors and land-use change. Given their advantages, they can complement one another to produce a higher-quality model.

RESEARCH METHODS

The projection of land-use change based on protected scenarios is carried out using a quantitative approach and spatial modeling. Spatial modeling was carried out using Cellular Automata (CA), which is integrated with Markov Chain (MC) and Artificial Neural Network (ANN). The CA–MC–ANN hybrid modeling approach, as a methodological innovation, synergistically integrates spatial dynamics (CA), probabilistic temporal transitions (MC), and nonlinear driver analysis (ANN) to produce more accurate modeling. The integration of this model aims to simulate land-use change in Malang City in 2029.

Research Variables

Cellular Automata (CA) and Artificial Neural Networks (ANNs) are used to predict land-use change, with several variables serving as driving forces. Projection models are also carried out using specific scenarios to support sustainable development. The scenario developed is aimed at maintaining some land use in the future, especially regarding protective functions. Some of the maintained land uses are variable constraints in model development. The following variables serve as driving forces and constraints in the model development presented in Table 1. The determination of the driving factors of land-use change is based on various studies, including those by Santé et al. (2010), Li et al. (2024), and Dumdumaya & Cabrera (2023).

Table 1. Table of Research Variables

No.	Variable Driving Forces	Variable Constraint
1	Distance to arterial road	Green open space
2	Distance to collector street	River borders
3	Distance to the railway	Flood danger areas
4	Distance to the settlements that have been built	Road plan
5	Proximity to markets, shopping malls, & convenience stores	
6	Distance to college and high school/equivalent	
7	Distance to hospital facilities	
8	Distance to office buildings	
9	Distance to factory	
10	Distance to the river	
11	Distance to the city center (PKN)	
12	Elevation	
13	Slope	

(Source: Data Research, 2025)

Projected changes in use are modeled by determining land-use changes from 2014 to 2019 and from 2019 to 2024. Land-use changes were identified from remote sensing imagery, including SPOT-5 imagery for 2014 and Sentinel-2 imagery for 2019 and 2024. Image processing is performed using QGIS (Quantum GIS). The remote sensing image is corrected first using radiometric and atmospheric corrections/calibration to convert its digital values back to spectral reflectance. After the correction is complete, the classification process continues. The classification process uses the available classification algorithm, namely maximum likelihood, to obtain land cover classes, which are then manually reclassified based on visual inspection and local knowledge.

The initial processing was carried out using the Euclidean distance module in GIS software to analyze distance-based driving forces. This step aims to generate spatial data in a raster format, where each pixel stores the distance to a specific observed phenomenon. Then, the Euclidean distance was normalized to 0-1 using a fuzzy membership function based on the membership of each driving force. In addition, slope modules are applied to elevation data to obtain slope-related variables. Cramer's V is used to indicate the potential explanatory power of each driving force.

In software, the CA-MC and ANN processes are initially executed separately. The ANN process trains the model on each sub-model, each representing a change from one type of land use to another. However, not all changes are processed as sub-models. Only logical and feasible modifications, such as those that increase utilization rates, are selected for training. Instead, unreasonable changes, such as shifts from settlements to fisheries, which are usually caused by misclassification, are either eliminated or not included in the sub-model's training.

The neural network training process is carried out in each sub-model through several stages. First, all variables (driving forces) are processed as constants. The system trains the model using all available variables, then determines the variable influence order from most significant (most influential) to least important (least influential). This sub-model also tests various combinations of variables to identify which combinations have the least impact when held constant. This process is done gradually by holding other variables constant until only one remains. The final results show the model's accuracy and skill level (Gharaibeh et al., 2020). Meanwhile, constraint data indicate which locations are allowed to change and which are not in the modeling. The data constraint is altered to a Boolean data type, where 0 (zero) is not permitted to change, and 1 (one) is allowed to change.

Next, a stepwise backward analysis is carried out: the selected variables are removed one by one in each iteration, and the model is retested. This process aims to identify whether removing certain variables improves the model's accuracy or capabilities. In this way, eliminating variables for retesting is no longer necessary. The development of each sub-model will generate a potential transition map for each sub-model.

Separately, the Markov Chain process compares the two images to generate a cross-tabulation. The tabulation results are used to create a change probability matrix, which is then used to build a transition area matrix. This matrix serves as a reference to determine the area (in pixels) of the predicted or simulated land use in the target year.

The Cellular Automata model is used to analyze spatially processed data. This process involves filtering and iterating over each pixel, considering the eight surrounding pixels. The results of this process are normalized and then multiplied by the image value for each transition map generated by the ANN. This step produces a land-use transition map or a soft prediction with a value range of 0 to 1.

In the final stage, the results of the developed model are integrated with the transition area matrix. This matrix serves as a reference to determine the number of pixels in the target year, while the ANN-CA results determine the location of the change. The closer the value is to 1, the greater the chance of a change occurring. This process results in a simulation or prediction of land use for the target year. Predictions are carried out under a business-as-usual scenario, representing space allocation conditions with either no or minimal policy control. In this scenario, it is assumed that land use change occurs optimally without the intervention of relevant regulations or policies (Kurnianti et al., 2016).

The model must pass a feasibility test before predicting land use in 2029 (the final target year). This test includes an accuracy test on the model and validation of the simulation results in 2024. In the validation stage, the transition potential map for 2024 was compared with the actual change map from 2019 to 2024 to measure the model's accuracy.

The accuracy test was carried out using the Relative Operating Characteristics (ROC) module, which produced an Area Under Curve (AUC) value. The AUC value ranges from 0.5 to 1, where 0.5 indicates a completely random model, while 1 indicates a model with perfect prediction. Eastman (2021) stated that the minimum AUC required to predict land use over a given period is 0.800. The validation test was carried out through the validate module on the Land Change Modeler, which produced a map with four classifications: (1) hit (successful prediction), (2) miss (failed prediction), (3) false alarm (false prediction), and (4) correct rejection (no change). Diagrammatically, the work steps in developing projections of scenario-based land use change to support sustainable development in Malang City can be seen in the following diagram (Figure 1).

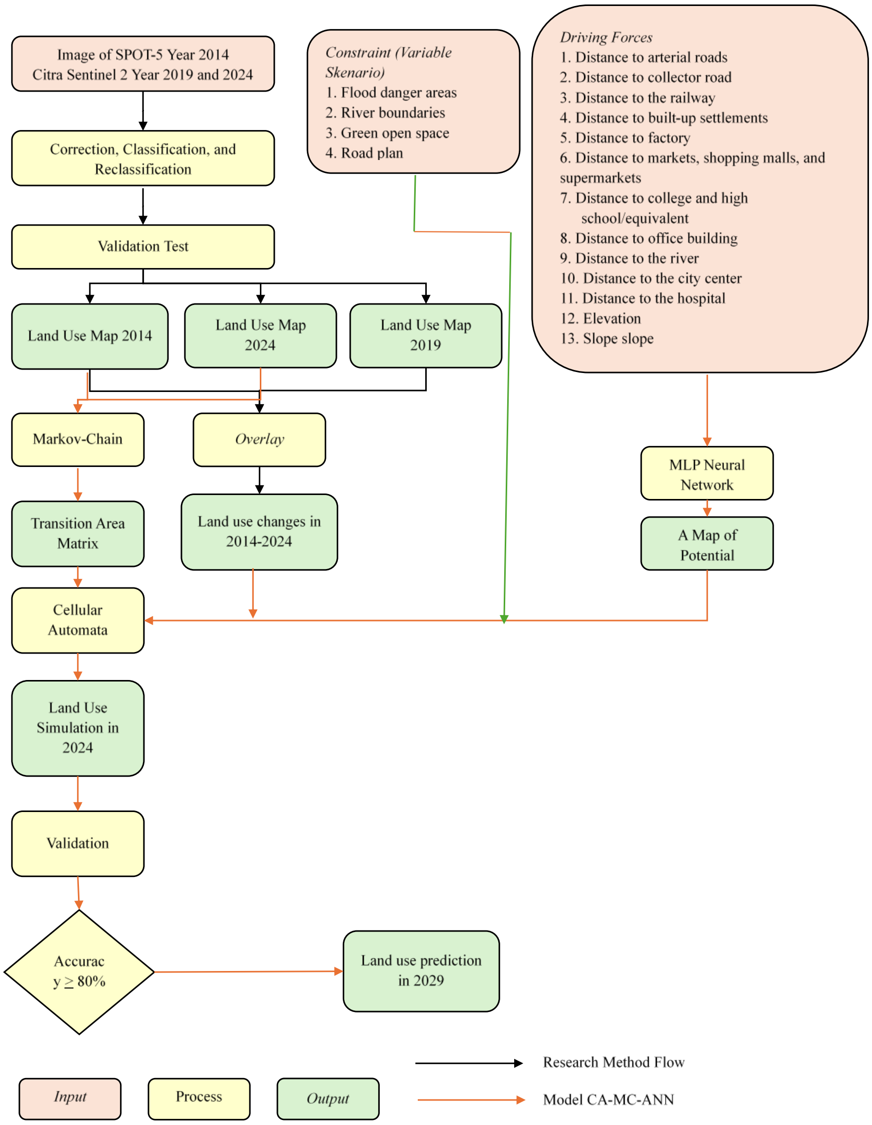


Figure 1. Work Steps Diagram in the Development of Protection Scenario-Based Land Use Change Projections to Support Sustainable Development in Malang City
(Source: Data Research, 2025)

RESULTS AND DISCUSSION

The results and discussions presented are divided into 3 (three) parts. The first part concerns land-use classification in Malang City. The second part discusses modeling land-use projections for 2024, and the third part presents the results of modeling projected land-use changes under the protected scenario for 2029.

a. Land Use Classification of Malang City

The land use classification in Malang City was carried out 3 three times, namely in 2014, 2019, and 2024. Remote sensing imagery is used to classify land use. The classification results were validated by a random sampling method using the AcATaMa (Accuracy Assessment of Thematic Maps) extension in QGIS. Evaluation is based on the Kappa index, which indicates the degree of agreement between the classification and the image reference. According to Landis & Koch (1977), a Kappa index above 0.80 indicates high confidence in classification. The results of the accuracy test are shown in Table 2, and the year achieved a Kappa value above 0.91, indicating excellent classification quality. This is also reinforced by Jensen's (1996) opinion that classification accuracy above 85% is suitable for advanced spatial analysis.

Table 2. Land Use Map Accuracy Test Results

No.	Year of Image	Accuracy (Kappa score)
1	2014	0.91795
2	2019	0.91911
3	2023	0.91585

(Source: Data Research, 2025)

The map and table of land-use classification results for 2014, 2019, and 2024 in Malang City are presented in Figure 2 and Table 3, respectively.

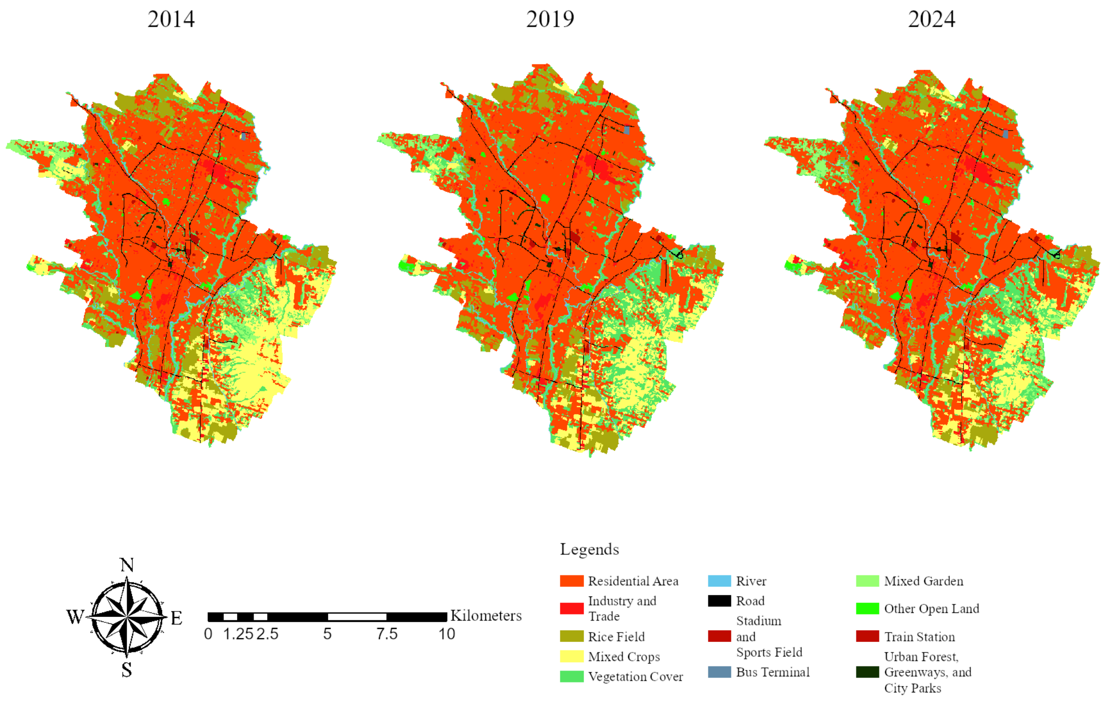


Figure 2. Land Use of Malang City in 2014, 2019, 2024 Based on Imagery of Sense
(Source: Data Research, 2025)

Table 3. Land Use Area of Malang City in 2014, 2019, 2024

Land Use	Broad					
	2014		2019		2024	
	Hectares	%	Hectares	%	Hectares	%
Settlements	5915.59	53.26%	6507.96	58.62%	6654.66	59.91%
Industry and Trade	376.02	3.39%	339.14	3.05%	453.19	4.08%
Paddy	1099.04	9.89%	886.37	7.98%	780.66	7.03%
Farm/Farm	1540.31	13.87%	1033.88	9.31%	906.00	8,16
Other Natural/Semi-natural Vegetation Coverage	1246.63	11.22%	1634.94	14.73%	1466.36	13.20%
River	195.08	1.76%	160.54	1.45%	162.21	1.46%
Road	200.34	1.80%	207.74	1.87%	208.92	1.88%
Stadiums and Sports Fields	44.84	0.40%	50.73	0.46%	48.57	0.44%
Terminal Bus	5.15	0.05%	6.48	0.06%	6.77	0.06%
Mixed Gardens	400.64	3.61%	171.14	1.54%	317.75	2.86%
Other Open Land	62.84	0.57%	74.21	0.67%	74.09	0.67%
Railway Station	5.65	0.05%	5.67	0.05%	5.58	0.05%
Urban Forests, Green Lanes and Urban Parks	15.57	0.14%	23.11	0.21%	22.96	0.21%
Total	11107.71	100%	11107.71	100%	11107.71	100%

(Source: Data Research, 2025)

The land use of Malang City for a decade (2014–2024) shows significant spatial dynamics. Settlements have increased from 5,915.59 ha (53.26%) in 2014 to 6,654.66 ha (59.91%) in 2024, with an increase of 739.07 ha. This trend indicates increasing urbanization pressures, driven by population growth and the influx of immigrants from outside the city. On the other hand, land use for fields or moorlands decreased sharply, from 1,540.31 ha to 906.00 ha, a decrease of 634.31 ha (−41.18%). This decline reflects a significant shift to non-irrigated agricultural land, especially in areas with sloping topography that are easier to develop. The area of rice fields also shows a decline, albeit on a smaller scale.

Meanwhile, industrial and trade estates showed fluctuations: they decreased to 339.14 ha in 2019 before increasing again to 453.19 ha in 2024. This increase can be attributed to the intensification of industrial estates in locations such as Jalan Tenaga (Blimbing District) and Ciptomulyo Village (Sukun District). In addition, fluctuations in industrial and trade estates can also occur due to visual misinterpretations of remote sensing images, resulting in a decrease in the number of these areas in 2019. During the observation period, urban forests, green paths, and urban parks increased from 15.57 ha to 22.96 ha, reflecting the government's support for green open space (RTH) programs. The construction of city parks, such as Merjosari Flower Park and Merjosari Singha Park, also shows this increase. In addition, the road network has been added along with infrastructure development, including the Pandaan-Malang toll road, which has been fully operational since 2020.

Spatially, changes in residential land tend to be concentrated in the eastern and western regions of Malang City. The area around the toll gate in Kedungkandang District is experiencing rapid settlement growth, likely driven by increasing regional connectivity. The urban sprawl pattern from the city center is also evident in the intensification of built-up land that follows a network of roads and river channels, creating settlements with a semi-rural pattern of spread. Other natural/semi-natural vegetation coverage increased from 1,246.63 ha in 2014 to 1,466.36 ha in 2024, mostly abandoned land overgrown with shrubs or low-level vegetation. This change shows that some agricultural land undergoes a post-abandonment naturalization process in addition to conversion to settlements.

b. Modeling of Land Use Projections in 2024

Projection of land use change is carried out using Idrisi Selva software with a combined method of Artificial Neural Network, Cellular Automata, and Markov Chain (ANN-CA-MC), which is available in the Land Change Modeler module. The model used 2014 and 2019 land use maps from the SPOT-5 and Sentinel-2 image classifications, with 13 land use categories and uniform spatial dimensions. Modeling begins with selecting logical and relevant transition sub-models, i.e., only land changes that tend to occur significantly in the field. Unrealistic transitions, such as converting settlements into rice fields, are excluded to maintain the model's learning accuracy.

The sub-model was developed using the Multi-Layer Perceptron Neural Network (MLPNN) module, with the same predictor variables for each sub-model. Training is carried out automatically with a dynamic learning rate, 10,000 iterations, a momentum factor of 0.5, a sigmoid constant of 1.0, and a hidden layer with 10 nodes. The prediction stage uses Cellular Automata to generate soft predictions based on the transition probability map of each sub-model. The end-of-2024 simulation was produced by combining the transition map using an area matrix as a reference for the number of pixels and a potential map as a reference for the change location. Predictive modeling of land use in 2024 is conducted by creating simulation maps and validation test maps. The simulation maps are grouped into hard prediction (left) and soft prediction (right). An overview of the simulation map and the validation test map for land-use prediction in 2024 is shown in Figures 3 and 4.

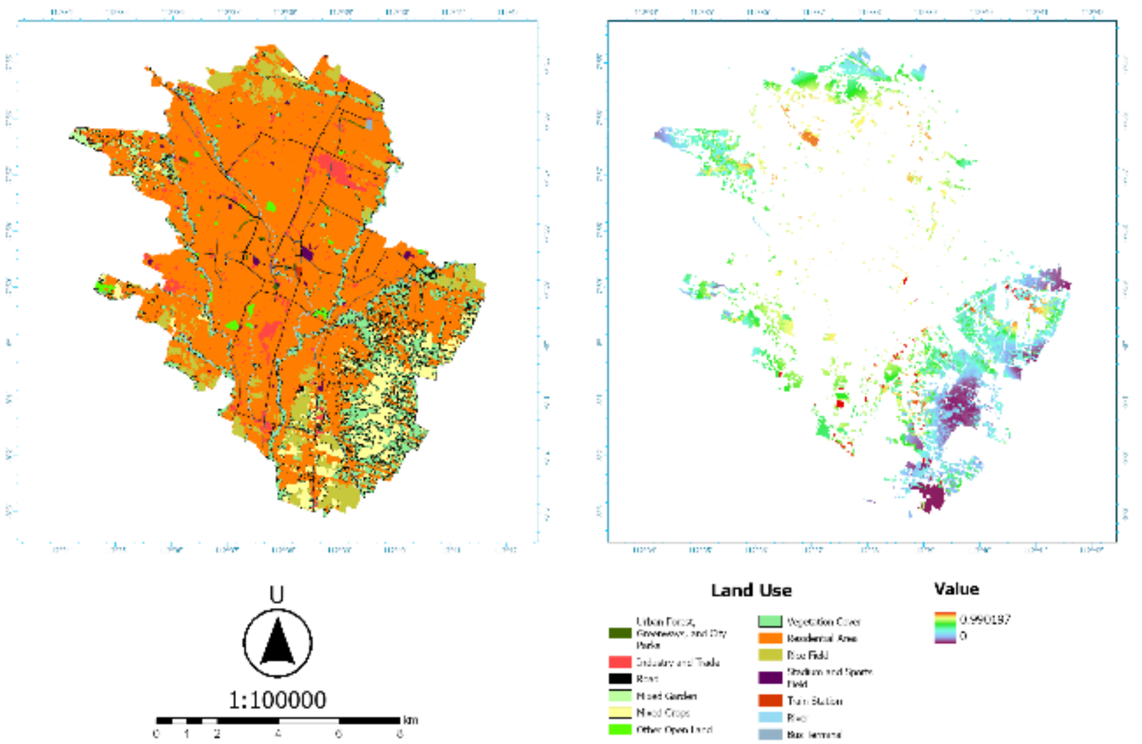


Figure 3. 2024 Simulation Results, Hard Prediction (Left), Soft Prediction (Right)
(Source: Data Research, 2025)

The validation results were obtained by comparing the classification map, used as reference material, with validation options integrated with LCM, displayed in 4 classifications based on signal detection theory. The validation results showed that the prediction accuracy for the absence of land-use changes reached 79.24%, while that for land-use changes reached 1.75%. Thus, the overall accuracy reached 80.99% (see Table 4). The overall accuracy results fall into the good-to-high range. According to Congalton & Green (2008), an accuracy value of more than 80% falls into the good category.

Table 4. Results of Land Use Prediction Validation Test in 2024

No.	Validation Results	Hectares (ha)	Percentage (%)
1	Correct Rejection	8803.78	79.24%
2	False Alarms	535.77	4.82%
3	Hits	194.60	1.75%
4	Misses	1575.51	14.18%
	Grand Total	11109.66	100.00%
	Overall Accuracy		80,99%

(Source: Data Research, 2025)

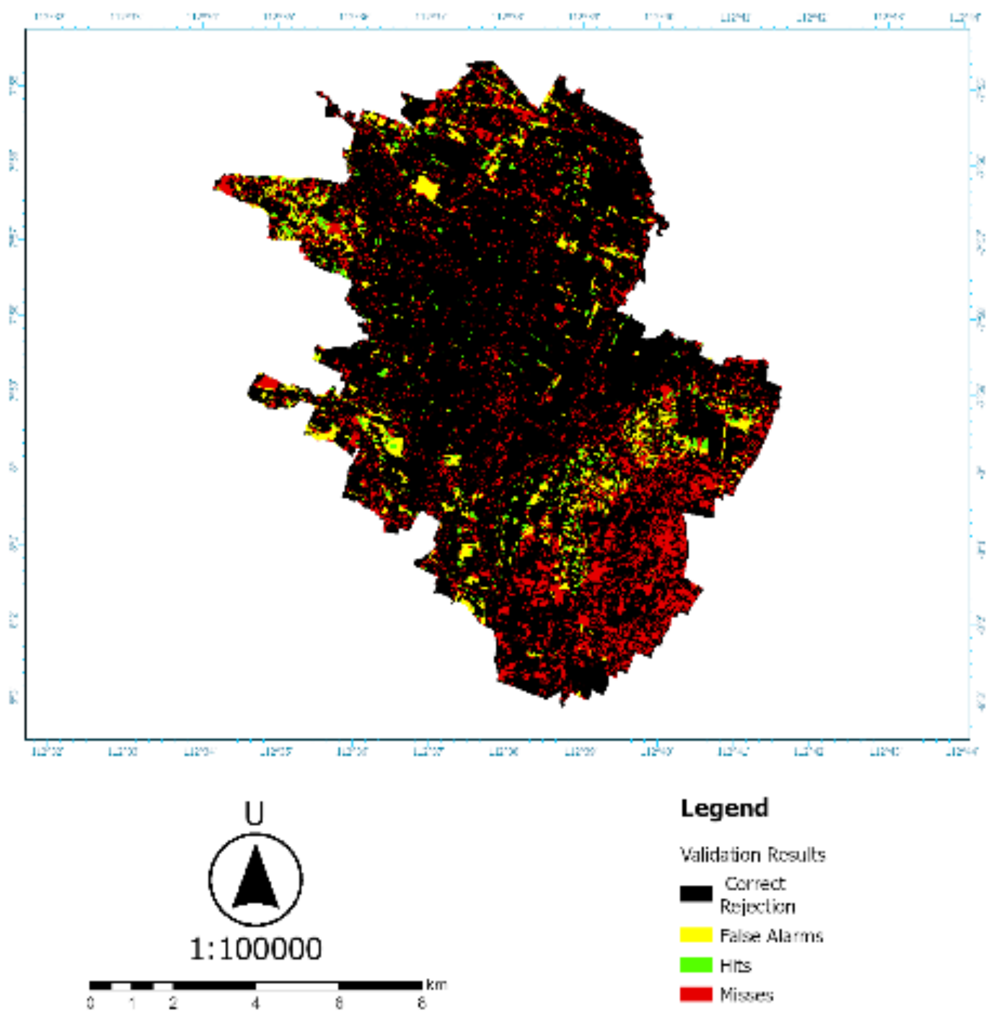


Figure 4. Results of Land Use Prediction Validation Test in 2024
(Source: Data Research, 2025)

When viewed spatially, the results of the Miss category mostly occur in the eastern and southeastern parts of Malang City. This miss occurs more often in single or small pixels than in large, clustered, or aggregated pixels. This result also occurs due to land-use characteristics in the southern and southeastern parts, which are primarily agricultural, increasing the likelihood of the change. In addition, the development of industrial estates in the Southeast and South also encourages the development of new areas around them. This is different in the central and northern parts, where land use tends to be concentrated in residential areas.

c. Projected Land Use Based on the Protected Scenarios in 2029

In developing the 2029 land use projection model, in addition to considering the driving factors, it is also carried out using constraint or scenario variables. The importance of using these scenario variables is highlighted by the direction of (Verburg et al., 2004). The scenario variables include various protective collapses in the Magelang City Regional Spatial Plan (RTRW). The protection designation includes urban forests, green paths, city parks, and river borders. In addition, it also involves the road network as a constraint variable. The purpose of using the constraint variable is to produce a projection of land-use changes that better maintains the protective function of the Malang City RTRW document, thereby ensuring the city's sustainability. A visual representation of the distribution of the constraint variables used is shown in Figure 5.

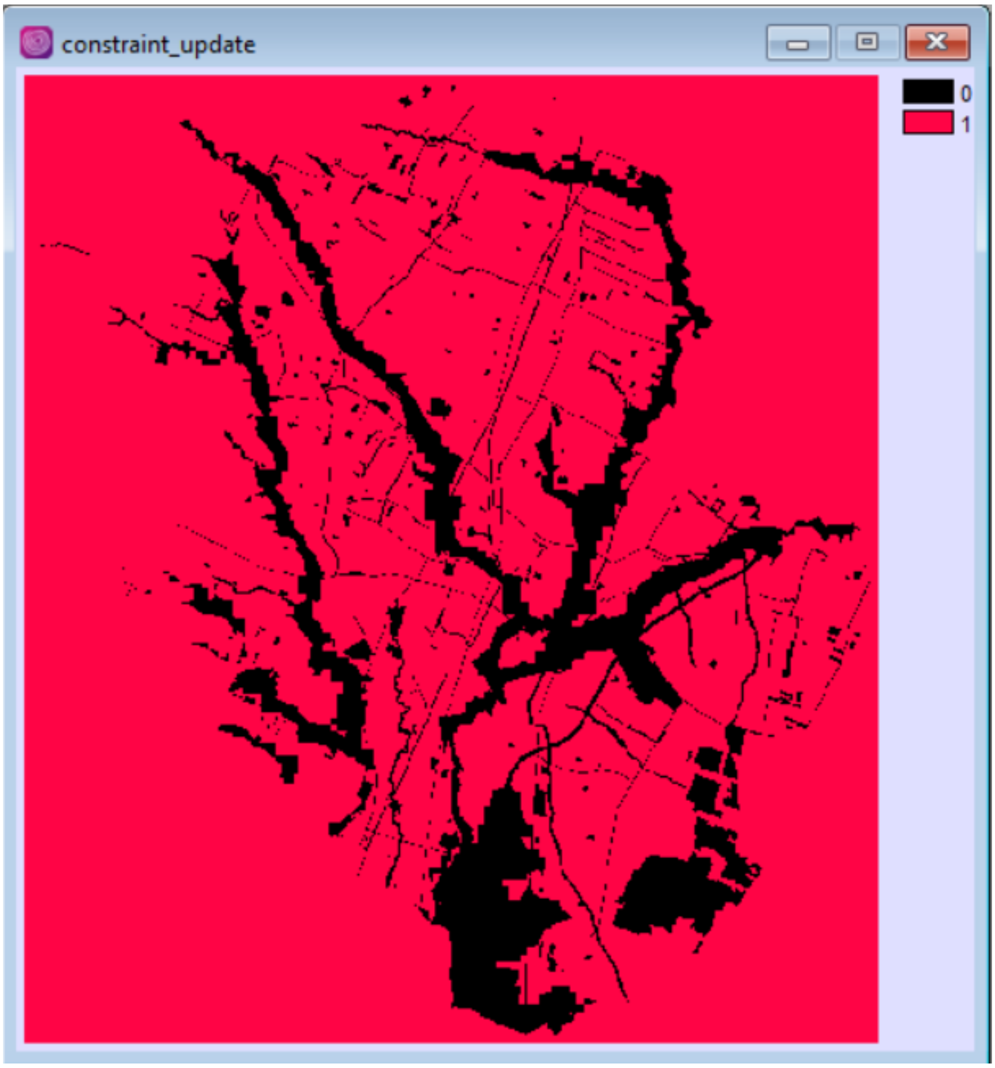


Figure 5. Visualization of Constraint Variable Distribution (Source: Data Research, 2025)

When projecting land-use changes for spatial planning and sustainable development, it is essential to integrate protective functions into the modeling. The "exclusion" layer that prevents changes to protected zones must be used to project future land-use changes (Eastman, 2021). In the modeling carried out in this study, according to Eastman (2021) above, the constraint variable was used as an "exclusion" layer in the form of a protective function plan in Malang City. The projection results in several areas, such as city parks, green paths, urban forests, and river borders, that will be relatively maintainable in 2029 by the Malang City RTRW spatial pattern plan.

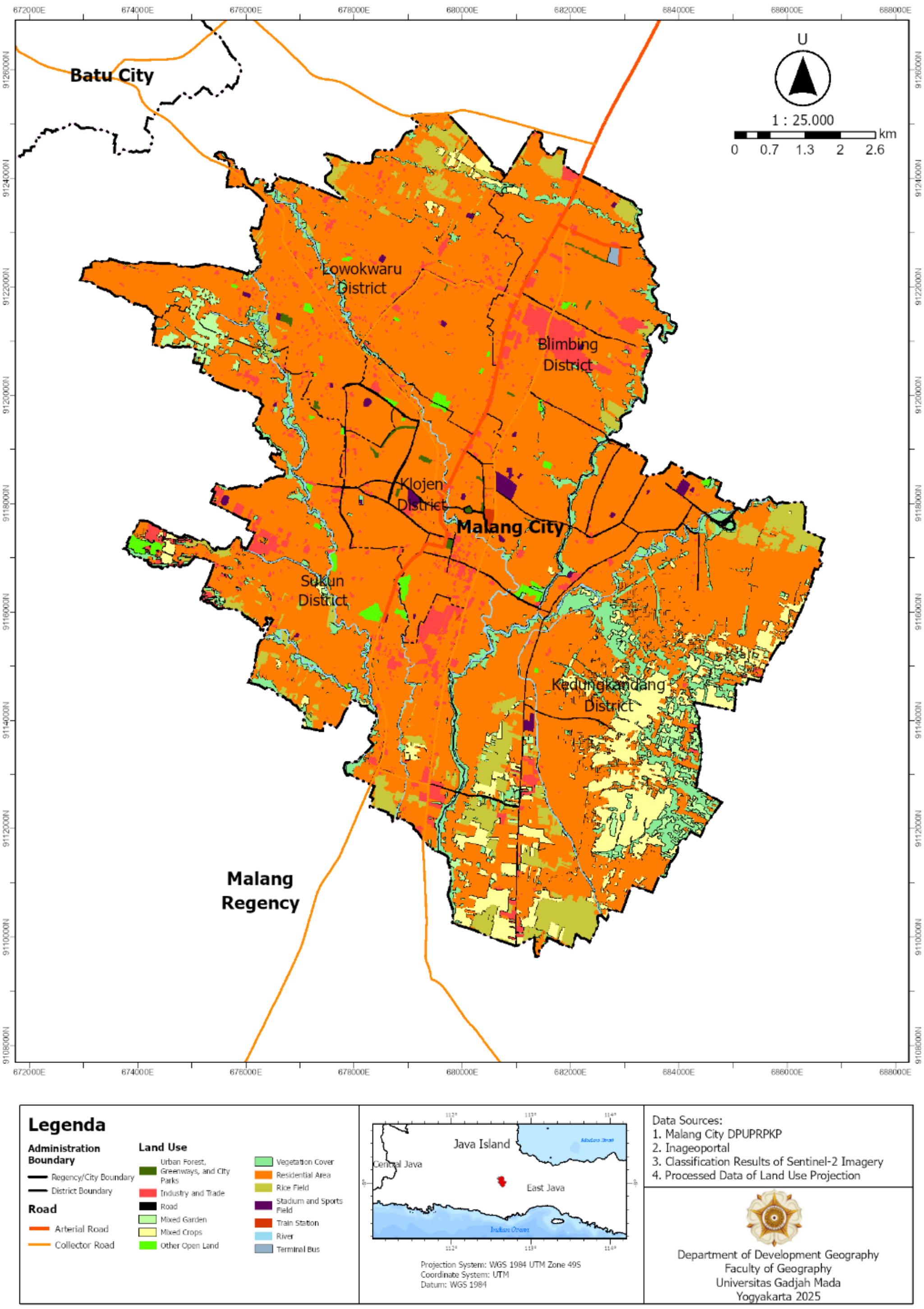
The modeling results also show that in 2029, settlements will remain the dominant land use class, covering 7,827.53 ha (70.47%), a significant increase from 2024 (6,654.66 ha). This increase reflects the continuing urbanization trend in Malang City, especially in Kedungkandang and Lowokwaru Districts (Picture 6). The rise in settlement area occurred along with the conversion of agricultural land and semi-natural vegetation, which showed a sharp decline in area.

Based on land-use change projection modeling in Malang City, areas requiring tighter zoning regulations due to potential changes in residential areas are in the Kedungkandang and Lowokwaru sub-districts. Tightening and regulating land-use changes in these two sub-districts is intended to prevent environmental protection from being impacted by land conversion. Green open spaces are essential for preservation through regulatory development and institutional management (Cobbinah et al., 2023).

The potential for built-up land development in Kedungkandang and Lowokwaru Districts is part of the spatial urbanization process, driven by spatial interactions. Interactions along the Surabaya-Malang toll road drive the potential for urbanization in Kedungkandang District. In the Lowokwaru District, the potential for urbanization is likely due to the tourism corridor in Batu City. The potential for urbanization corridor development due to spatial interactions also aligns with several previous studies, such as those by Wijaya et al. (2020) and Amelia et al. (2022). The potential for change along these road corridors aligns with Alonso's (1964) and Garreau's (1991) urban development theory, which states that land along main roads tends to change land use.

Spatially, land-use changes mainly occur in the city's eastern and western areas. Agricultural areas, such as rice fields and fields/moors, are the most vulnerable to conversion, mostly into residential areas. This aligns with the results of ANN's learning, which shows that proximity to trade areas, arterial roads, and educational facilities are the dominant factors driving change. The concentration of economic activities in Pasar Gadang, Pasar Besar, MOG, and Matos, as well as the Malang-Pandaan toll road, increases the strategic value of these areas as new settlement locations.

Meanwhile, industrial estates (501.14 ha) and urban forests, green paths, and urban parks (22.87 ha) remained relatively stable. This is due to the attachment of the land class to spatial planning policies and other regulatory factors. Land use classes such as railway stations (5.66 ha), bus terminals (6.79 ha), and stadiums (49.18 ha) show no change, as their functions are fixed. Meanwhile, the area of natural and semi-natural vegetation was recorded at 823.30 ha (7.41%), a reduction from the previous year. Massive conversions are more common in moorlands, rice fields, and mixed gardens.



Picture 6. Projected Land Use Based on the Malang City Protected Scenarios in 2029
(Source: Data Research, 2025)

These findings confirm that settlements will continue to expand in the coming years. The potential for settlement development in Malang City will occur in many areas around the center of activity and toll roads. According to a study by Astuty & Dimyati (2024), residential land in Indonesia will continue to experience rapid development, especially in urban areas. The Malang City area will undergo many urbanization processes, one of which is marked by changes in land use for settlement areas. Land changes in urban areas are characterized by the development of settlements (Zhou et al., 2021). Built land that continues to develop, if not regulated and directed, will cause various negative impacts. These impacts include environmental degradation, deterioration of food security, and ecosystem damage (Abass et al., 2018). The potential for residential development in Malang City needs to be anticipated and directed to avoid spatial conflicts and environmental degradation. Efforts to control settlement development must be carried out, especially in disaster-prone and protected function areas.

The uncertainty and irregularity of land-use change in Malang City can be anticipated by developing scenarios such as the model presented here. These efforts align with Lasaiba's (2023) call for developing projections of scenario-based land-use change. Scenario-based land-use projections provide essential information for more effective spatial planning (Bittner et al., 2025). By understanding the potential for land-use change, governments and stakeholders can formulate more effective strategies to manage resources, prevent the negative impacts of urbanization, and protect the environment. This model also serves as a tool to anticipate the adverse effects of potential land-use changes, such as the emergence of disasters and environmental degradation. By visualizing future scenarios, these models allow decision-makers to plan the necessary mitigation actions (Xiang & Clarke, 2003). By using scenario-based projection models, decision-makers can develop more informative policies that are responsive to changing social and economic conditions. This includes better land use regulation, infrastructure development, and natural resource conservation.

Predictive models need to consider non-spatial factors such as strategic project interventions, development plans, and changes in government policies. Therefore, a more integrative predictive approach is required to produce more realistic spatial projections, primarily to support sustainable spatial planning and control in Malang City.

CONCLUSION

Using the Cellular Automata-Markov Chain (CA-MC) and Artificial Neural Network (ANN), a projected model of land use change in 2029 based on a protected scenario in Malang City was developed. The model was developed by paying attention to the driving factors and constraint variables, treating them as scenario variables, for urban parks, green paths, urban forests, and river boundaries as areas to be maintained. The overall accuracy of the resulting projections reached 80.99%, placing it in the good-to-high accuracy category. The projection results indicate potential land change for sizable settlements in Malang City, especially in the eastern and western parts around the center of activities and the Malang-Pandaan toll road. The possible development of these settlements needs to be anticipated and directed so that, in the future, it does not cause various spatial conflicts or trigger environmental degradation. Scenario-based projections indicate several protected areas, such as city parks, green belts, city forests, and river banks, that can be relatively well maintained in 2029, according to the spatial pattern plan in the Malang City spatial plan. By developing land-use projections based on protected scenarios, decision-makers should plan the necessary mitigation actions to make Malang City's development more sustainable.

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