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Modeling Urban Land Transformation In Malang City: A Cellular Automata Model With Artificial Neural Networks And Logistic Regression

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Abstract
This study aims to model urban land transformation in Malang City using a Cellular Automata (CA) approach integrated with Artificial Neural Networks (ANN) and Logistic Regression (LR). The model was developed to predict land-use changes over the next 10 years (2024-2034) by utilizing spatial data from 2014 and 2024. The method involves spatial analysis using Quantum GIS (QGIS) software with the MOLUSCE plugin, which enables the simulation of land cover changes based on transition probability matrices. The results show that the CA-LR model provides higher accuracy compared to the CA-ANN model, with a Kappa value reaching 1 at the location level. The simulations indicate a significant decrease in non-built-up land, from 4,090.85 ha in 2024 to 3,731.40 ha in 2044, while built-up land increased from 7,030.70 ha to 7,390.15 ha over the same period. Factors such as population growth, accessibility, and land prices were identified as the main drivers of land-use change. The findings of this study can serve as a reference for stakeholders in planning sustainable urban development, particularly in managing settlement growth and maintaining a balance between built-up areas and green open spaces

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1. Introduction

The physical transformation of a city, which manifests as a tangible outcome of various ongoing changes, often becomes a crucial topic in urban planning and design. The dynamics of this development strongly reflect the evolving lifestyle patterns of urban communities. From a physical perspective, a city is predominantly an area where most of the land is not used for agriculture but rather for residential settlements and various types of buildings, making built-up areas more dominant than green open spaces. Spatial transformation can be identified through changes in land use patterns (Long et al., 2021; Niu et al., 2022), Physical and social characteristics of settlements (Nadeem et al., 2023), ease of access (Wekesa et al., 2011), as well as the population size and distribution (Wekesa et al., 2011), all physical and social aspects of a city are determined by the arrangement of the elements that shape it (Amen, 2022).

According to Mahendra & Pradoto (2016), the population density distribution pattern of Malang City, presented in 1990, was largely concentrated in the city center. In contrast, by 2010, there was a shift with an increase in density in the northern region, forming a high-density zone. However, the southern region still exhibited a low-density level (Mahendra & Pradoto, 2016). A study conducted bySusetyo et al. (2024) indicates that the percentage of building density in Malang City's administrative area increased by 8% over five years, from 2019 to 2023. Kedungkandang District recorded the highest growth in built-up land at 14%, while Klojen District had the lowest growth at 1%. The latest demographic data shows that

Malang City's population in 2024 reached 885,270 people. This figure indicates a positive population growth trend in the city, with a Compound Annual Growth Rate (CAGR) of 0.33% over the past five years (BPS, 2024).

Quantum GIS (QGIS) is an open-source Geographic Information System (GIS) software. This software can be operated on various operating systems. QGIS is designed to function as a GIS platform that allows GIS data visualization while also providing features and functions commonly used in spatial data management (Nagappan & Egambaram, 2023). The MOLUSCE (Modules for Land Use Change Simulation) plugin in QGIS offers various algorithms for predicting future land cover and generating probability transition matrices (Boakye et al., 2020). A popular algorithm frequently used for land cover prediction and simulation is Artificial Neural Networks (ANN) and Cellular Automata (CA) (Osman et al., 2023). The combination of these two algorithms has been proven effective in modeling future land cover changes (Alshari & Gawali, 2023; Lukas et al., 2023).

Artificial Neural Networks (ANN) is one of the methods used to predict land cover maps or land use change. These land cover maps are generated through a Cellular Automata (CA)-based approach, which is then validated using the kappa correction test (Arafah et al., 2024; Atef et al., 2023). The CA-ANN model offers advantages such as simplicity, flexibility, intuitiveness, and the ability to integrate variable data both spatially and temporally (Blissag & Kessar, 2024).

The Logistic Regression (LR) model is an effective tool for analyzing land use change, particularly in the context of urbanization, as represented by the logistic curve. Based on logistic regression, the CA model is consistent with the mechanisms of urban evolution. Logistic regression is also frequently used to describe the probability of land conversion and urban growth, as well as to identify key factors influencing city expansion (Cao et al., 2020).

Malang City is outlined in the Work Plan (Renja) of the Public Works, Spatial Planning, Housing, and Settlement Areas Office of Malang City for 2023. The plan sets forth objectives and targets aimed at achieving improved and equitable development of the city's infrastructure and facilities in an integrated manner. These targets include the index of public works, housing, and settlement infrastructure service quality, as well as the percentage reduction of slum areas. Malang City is predominantly characterized by extensive residential areas. This study aims to predict land use over the next 10 years using ANN-CA and LR models. Land use change prediction is conducted using the Artificial Neural Network-Cellular Automata (ANN-CA) model, implemented through Quantum GIS (QGIS version 2.18.15) software. The ANN-CA model utilizes an Artificial Neural Network (ANN) system consisting of multiple output neurons to simulate various land use change scenarios. Meanwhile, the CA-LR model applies logistic regression (LR) to predict spatial land conversion patterns. By utilizing these predictive models, land use conversion over the next decade (2024–2034) can be projected. The results can serve as a valuable reference for stakeholders in policy decision-making processes.

This study is crucial as Malang City continues to undergo rapid land use changes due to urbanization and sustained population growth. Land use change modeling using the CA-ANN and CA-LR approaches enables more accurate data-driven planning, which can support the formulation of more effective policies for managing urban growth. By gaining a deeper understanding of land transformation patterns, stakeholders can anticipate the negative impacts of urban expansion, such as the reduction of green open spaces, increased traffic congestion, and environmental degradation. Therefore, the findings of this study are expected to serve as a reference for sustainable urban development planning and support spatial policies that are more adaptive and responsive to the dynamic changes in Malang City.

2. Methods

Theoretical Framework

The CA modeling is conducted using QGIS 2.18.15 software with the MOLUSCE plugin. The land use maps used in this study are from 2014 and 2024. The modeling stages are as follows:

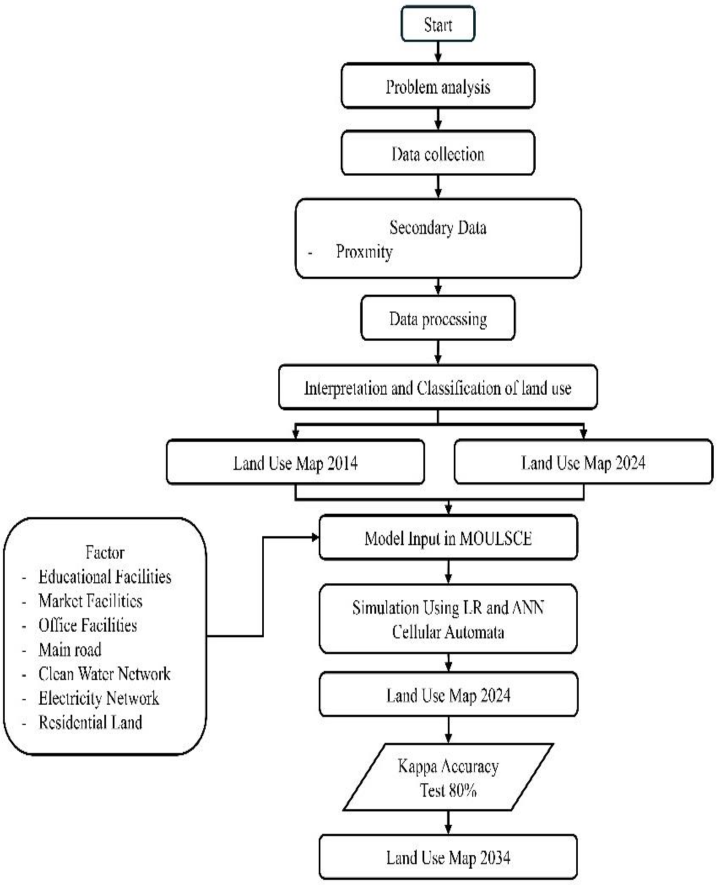

Figure 1 Steps for Creating the 2034 Land Use Prediction Map

Location of the reserach

This study was conducted in Malang City, which covers an area of 110.06 square kilometers, divided into five districts. The largest district is Kedungkandang, accounting for 36.24% of the total area, while the smallest district is Klojen, covering only 8.02% of the city's total area. Malang City is situated at an elevation ranging from 445 to 526 meters above sea level. December records the highest number of rainy days, with 26 days of rainfall.

Proximity

The proximity analysis method in Geographic Information Systems (GIS) is a technique used to measure the distance or relationship between geographic objects, such as points, lines, or polygons, within a given space. This technique is commonly applied to determine areas within a specific distance from a certain location, such as public facilities, or to understand spatial relationships between geographic elements (Pan et al., 2023). Some applications of proximity analysis include evaluating the location of healthcare facilities in relation to the population, defining buffer zones around rivers, and measuring transportation accessibility. Proximity analysis can be performed using tools such as buffers, nearest neighbor analysis, or cost-distance analysis, which support decision-making in spatial planning and resource management. According Nofirman et al. (2024), proximity analysis is an essential component of GIS, helping to identify spatial patterns and relationships within a geographic context.

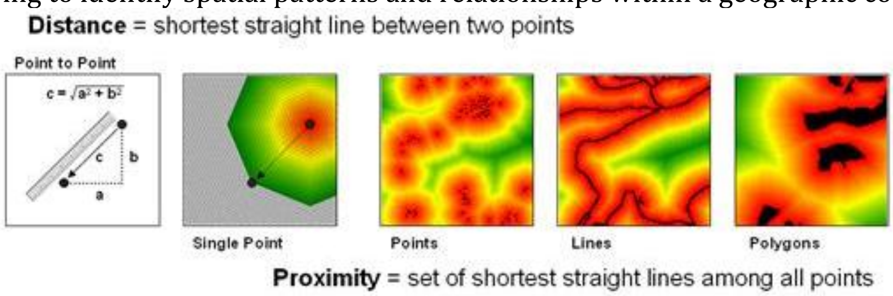

Figure 2 Example of Proximity (Source: GeoWorld, 2005)

Model Simulation Prediction

This study employs a quantitative approach with a focus on spatial analysis. The approach utilizes the MOLUSCE plugin available in QGIS software. The study develops a land-use change projection model by integrating the Cellular Automata (CA) method with Artificial Neural Networks (ANN) and Logistic Regression (LR) techniques. The analysis process is conducted using the MOLUSCE plugin on QGIS Desktop version 2.18.15, which has spatio-temporal analysis capabilities to: (1) Calculate land-use change dynamics, (2) Model land transition trends, and (3) Simulate regional development scenarios (Lukas et al., 2023).

ANN and LR as Analytical Tools In this modeling approach, Artificial Neural Networks (ANN) adopt working principles similar to biological neural networks, while the Logistic Regression (LR) model, based on logistic regression, is fundamentally consistent with the mechanisms of urban evolution, with the ability to recognize complex patterns in spatial data (Cao et al., 2020; Gasparovic & Jogun, 2018). This mechanism has been proven effective in classifying land cover changes through the processing of remote sensing data (Abebe et al., 2022). In its implementation, the MOLUSCE plugin utilizes ANN and LR algorithms to generate a land transition probability matrix, which represents the tendency of changes between land cover classes.

Data Collection

The data collection process was carried out exclusively using Geographic Information System (GIS) software, specifically QGIS. This tool was chosen because of its superior ability to manage and analyze spatial data. With QGIS, data can be obtained from various sources, such as digital maps, satellite imagery, and field survey data, which are then integrated into the GIS system for further analysis. Data collected through QGIS is used for in-depth analysis, including proximity analysis and network analysis, which provide deeper insights into geographic patterns and dynamics in the research area. In addition, QGIS allows real-time data updates, which is very important in research that demands high accuracy and precision of information.

3. Results asnd Discussion

Land Use from 2014 to 2024

The land use maps of Malang City for the years 2014 and 2024 illustrate the distribution of land categorized into two main types: developed land and undeveloped land. Developed land, represented in red, indicates areas that have undergone development, including residential, infrastructure, and other land utilization.

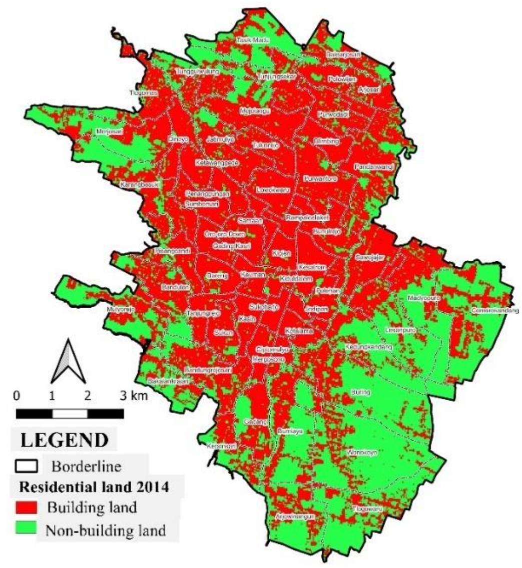

Figure 3 Residential Land in Malang City in 2014

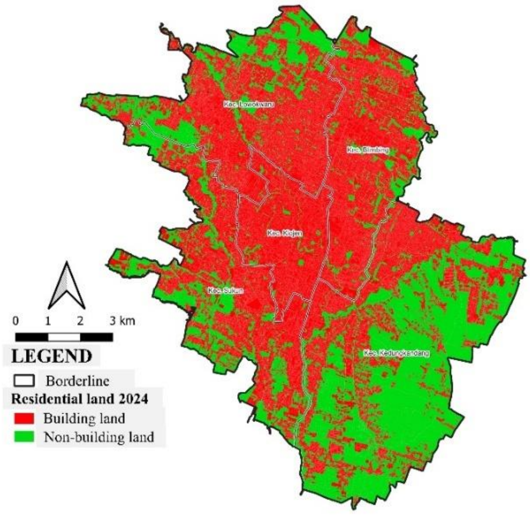

Figure 4 Residential Land in Malang City in 2024

Most of the Malang City area has been filled with developed land, reflecting a high level of urbanization and rapid settlement growth. The undeveloped land, depicted in green, indicates areas that remain open or undeveloped. These areas may consist of green open spaces, public areas, or land still in the planning stage for future development.

Proximity to Urban Infrastructure

Proximity to urban infrastructure is obtained through location proximity analysis. Each map displays the distribution of points colored according to their distance from specific facilities. Red indicates areas very close to infrastructure facilities, while blue signifies areas that are farther away. The results of the proximity analysis show that educational facilities, electricity networks, clean water networks, main roads, office facilities, as well as trade and service facilities are almost evenly distributed across the five districts in Malang City. Below are some of the location proximities included:

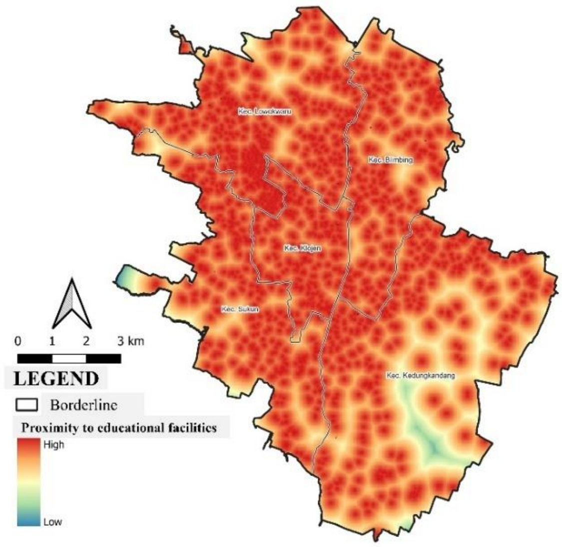

Figure 5 Proximity to Educational Facilities

Based on the map above, we can see that several areas in the city have a very high intensity of proximity to educational facilities, indicated by bright red. Most of these areas are located in the city center and districts with high population density, such as Blimbing District, Lowokwaru District, and Kedungkandang District. This indicates that educational facilities are easily accessible to residents in these areas, which may suggest a good level of educational accessibility for the city's population. On the other hand, there are some areas with low proximity to educational facilities, shown in blue and green. These areas are generally located on the outskirts of the city or in regions farther from the city center, such as Sukun District.

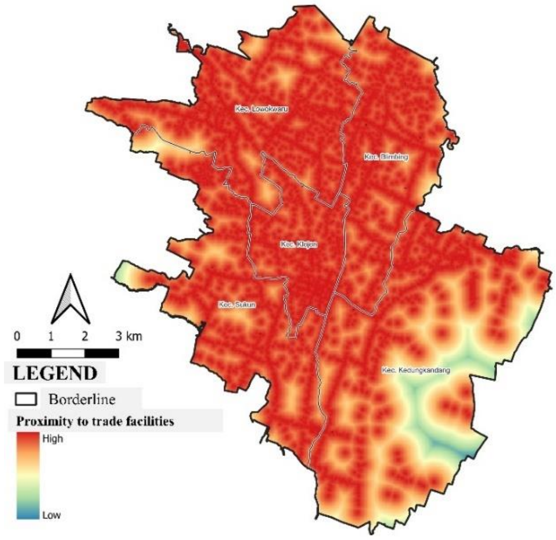

Figure 6 Proximity to Trade Facilities

Most trade facilities are concentrated in areas marked with bright red, indicating high proximity to commercial centers. Regions such as Blimbing District, Lowokwaru District, and Kedungkandang District have a high intensity of trade facilities. These areas serve as commercial hubs in Malang City, demonstrating that trade activities are highly accessible to residents in these regions.

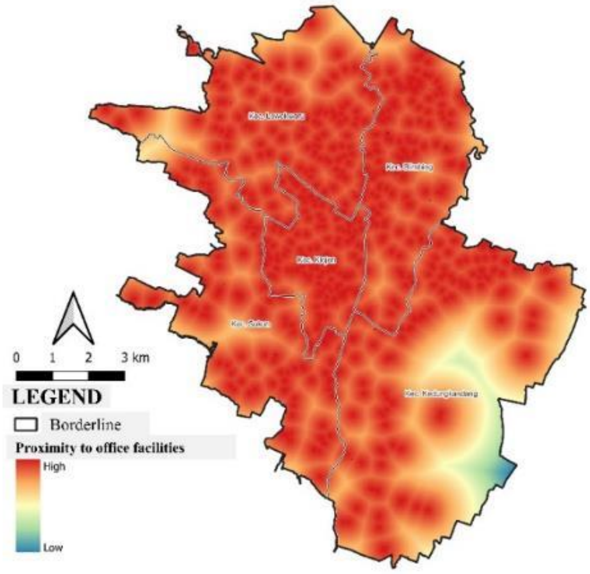

Figure 7 Proximity to Office Facilities

This map shows a very high concentration of office facilities in several central city districts, such as Blimbing District, Lowokwaru District, and Kedungkandang District, indicated by bright red. These areas demonstrate that business and office centers are concentrated in these regions, providing easy access for residents in the surrounding locations to reach offices and other business facilities.

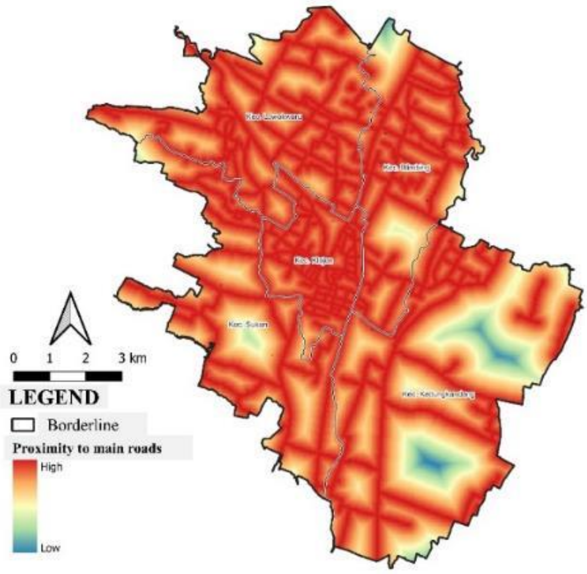

Figure 8 Proximity to Main Roads

This map shows a high concentration of main roads in the central city area, particularly in Blimbing District, Lowokwaru District, and the northern part of Kedungkandang District, indicated by bright red. This indicates that these areas have excellent access to main roads, facilitating mobility and connectivity between regions within the city, as well as with areas outside the city. Conversely, there are some areas with low proximity to main roads, marked in blue and green, especially in Sukun District and the southern part of Kedungkandang District.

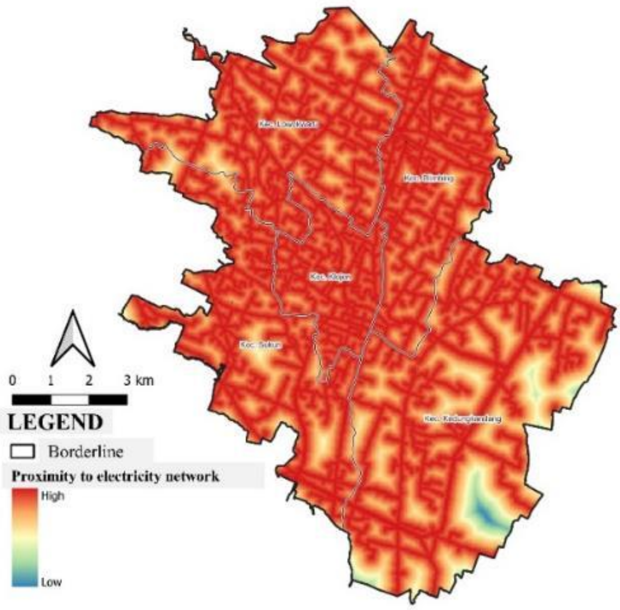

Figure 9 Proximity to Clean Water Networks

Most areas in Malang City have high proximity to clean water networks, as indicated by the bright red color in Blimbing District, Lowokwaru District, and the northern part of Kedungkandang District. These regions represent areas that are well-connected to clean water distribution networks, facilitating access to clean water for residents.

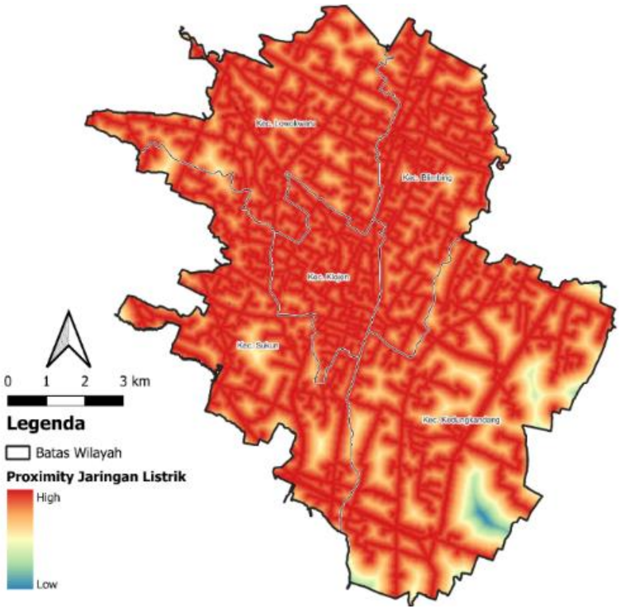

Figure 10 Proximity to Electricity Networks

Most areas in Malang City, particularly in Blimbing District, Lowokwaru District, and the northern part of Kedungkandang District, have very high proximity to electricity networks, as indicated by the bright red color. This demonstrates that the electricity infrastructure in these areas is well-integrated and easily accessible to residents.

Analysis of Land Use Change Simulation

Changes occurring in developing countries are caused by a lack of understanding of the importance of managing natural resources wisely, as well as excessive exploitation without considering long-term impacts, which stem from weaknesses in the existing legal system (Belihu et al., 2020). Malang City is also experiencing changes in land use, necessitating a predictive model to project land use changes over the next 20 years. This refers to Government Regulation Number 26 of 2008 concerning National Spatial Planning, which serves as a reference for national development planning and spatial regulation at the provincial and district/city levels.

CA-ANN

Table 1 CA-ANN Classification of Land Use and Non-Land Use Changes for the Period 2014 2044

Category	Area (Ha)		
	2024	2034	2044
Developed	7.030,70	7.032,64	7.039,14
Undeveloped	4.090,85	4.088,91	4.082,41

Source: CA-ANN Analysis Results

In Table 1, the area data indicates a reduction in non-developed land in Malang City from 2024 to 2044. This change is reflected in the data showing that the area of non-developed land in 2024 was 4,090.85 hectares, which then decreased to 4,082.41 hectares in 2044. This reduction of 8.44 hectares suggests the conversion of non-developed land into developed land, potentially driven by various factors such as urban expansion, infrastructure development, or changes in land use related to increasing demand for space for housing, commerce, and other economic activities. Considering the transition matrix data, which shows the probability of land use changes from specific categories, this can provide a clearer explanation of how land development patterns are progressing in Malang City. Based on the existing transition matrix, higher values in transitions between land categories indicate a faster rate of change, while lower values suggest stability in land use within a particular area.

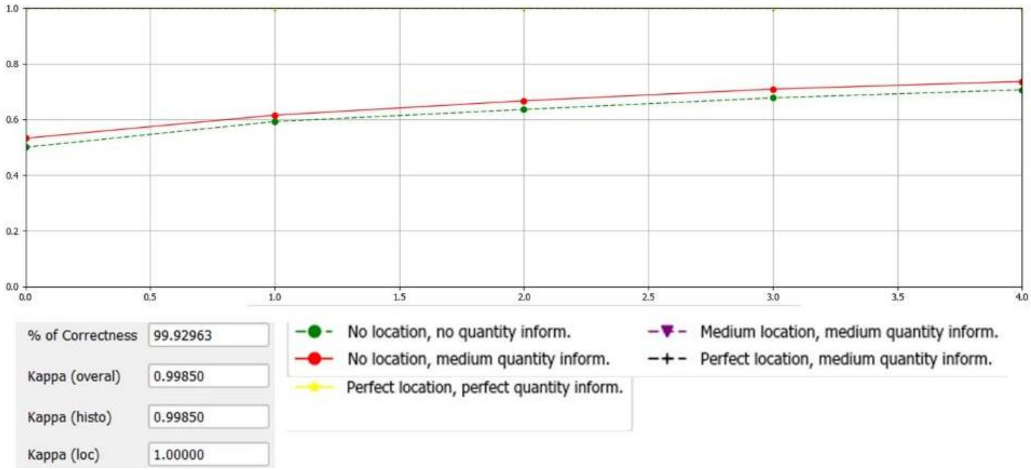

Figure 11 Accuracy of CA-ANN in Forecasting the 2034 Map

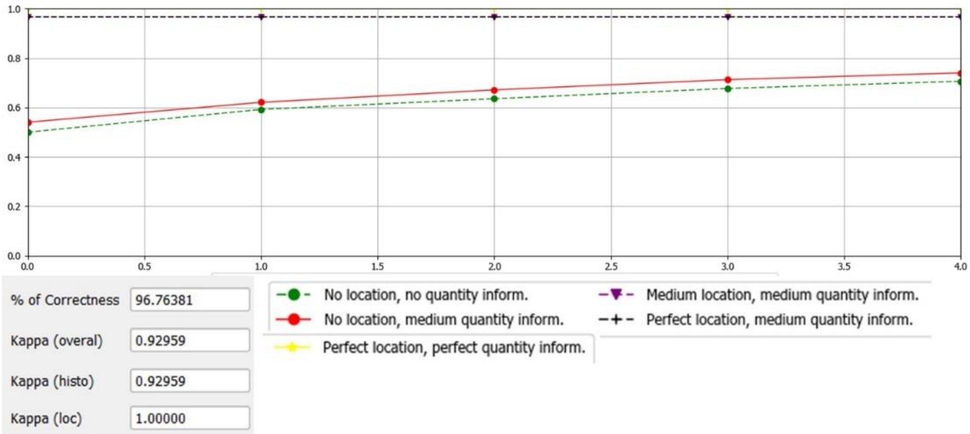

Figure 12 Accuracy of CA-ANN in Forecasting the 2044 Map

Land use modeling for the years 2034 and 2044 was conducted by applying the CA-ANN method using the Molusce plugin in QGIS version 2.18.15. Land use maps from 2014 and 2024 were used to project the land use maps for 2034 and 2044. Additionally, the total Kappa value of the land use projection model is approximately 0.87%, with an accuracy rate reaching 99%.

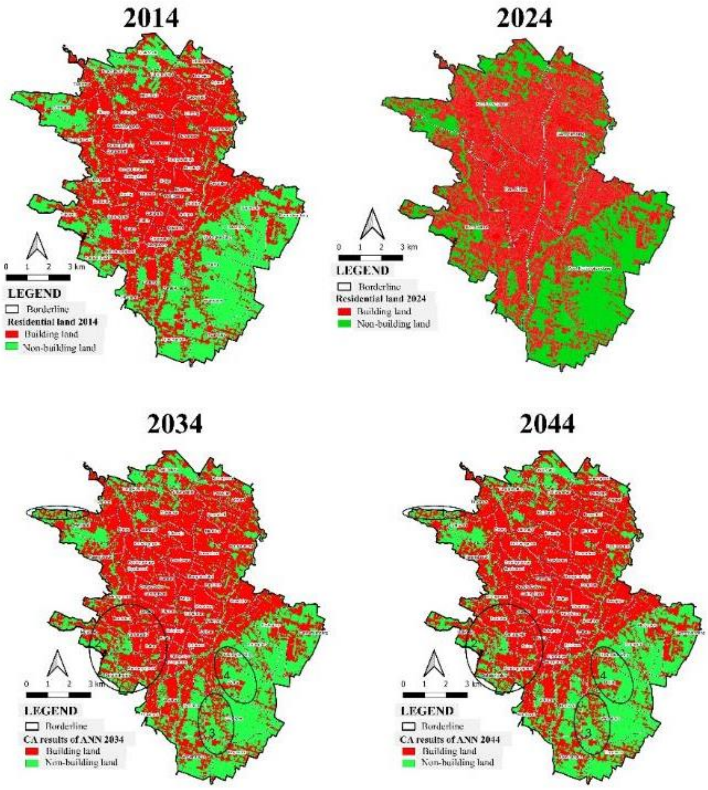

Figure 13 The CA-ANN results for the city of Malang map from 2014 to 2044

CA-LR

Table 2 The CA-LR classification of land use and non-land use changes for the period 2024-2044

Category	Area (Ha)		
	2024	**2034**	**2044**
built-up area	7.030,70	7.332,16	7.390,15
Non-built-up area	4.090,85	3.789,39	3.731,40

Source: CA-LR Analysis Results

In this CA-LR research, an analysis of land use class changes from 2024 to 2044 was conducted using the MOLUSCE software. The analysis results indicate significant changes in built-up land in the land use analysis. In the non-built-up land class, there is a decrease in area from 4,090.85 hectares in 2024 to 3,731.40 hectares in 2044, indicating a percentage decline from 36.78% to 33.55%. This decrease suggests a shift in land use previously categorized under this class. A significant portion of this change transitions to built-up land, which shows an increase in area from 7,030.70 m² in 2024 to 7,390.15 m² in 2044, reflecting a 5.11% rise over the 2024-2044 period. This increase illustrates a more dominant shift in land use. The transition matrix reveals a clear pattern of shifts between classes during the analysis period. Most areas classified as non-built-up land in 2014 remained in the same category in 2024 (92.34%). Meanwhile, a small portion (7.66%) of non-built-up land transitioned to built-up land, indicating a change in built-up land use. Conversely, there was no transition from built-up land to non-built-up land, as reflected by the 0% figure in the transition matrix.

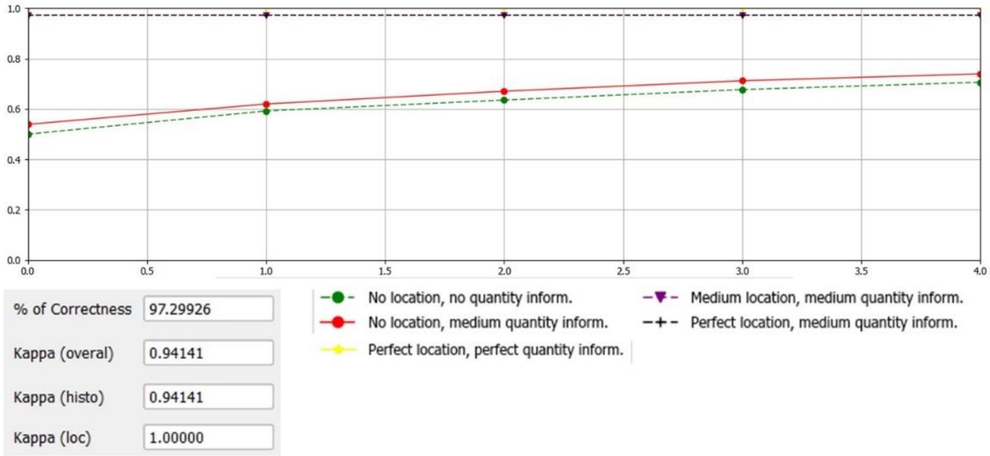

Figure 14 The accuracy of CA-LR in predicting the 2034 map

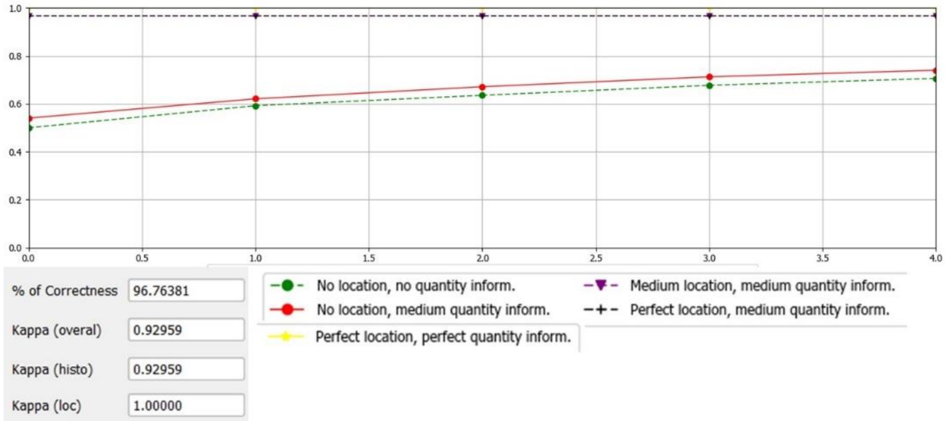

Figure 15 The accuracy of CA-LR in forecasting the 2044 map

The validation results show an accuracy rate of 96.76% and sufficiently high Kappa values (overall, histogram, and location), with the location Kappa value reaching 1, indicating a perfect match at the location level. The use of CA-LR approaches perfection in predicting the 2034 map, making it a reliable consideration for policy formulation.

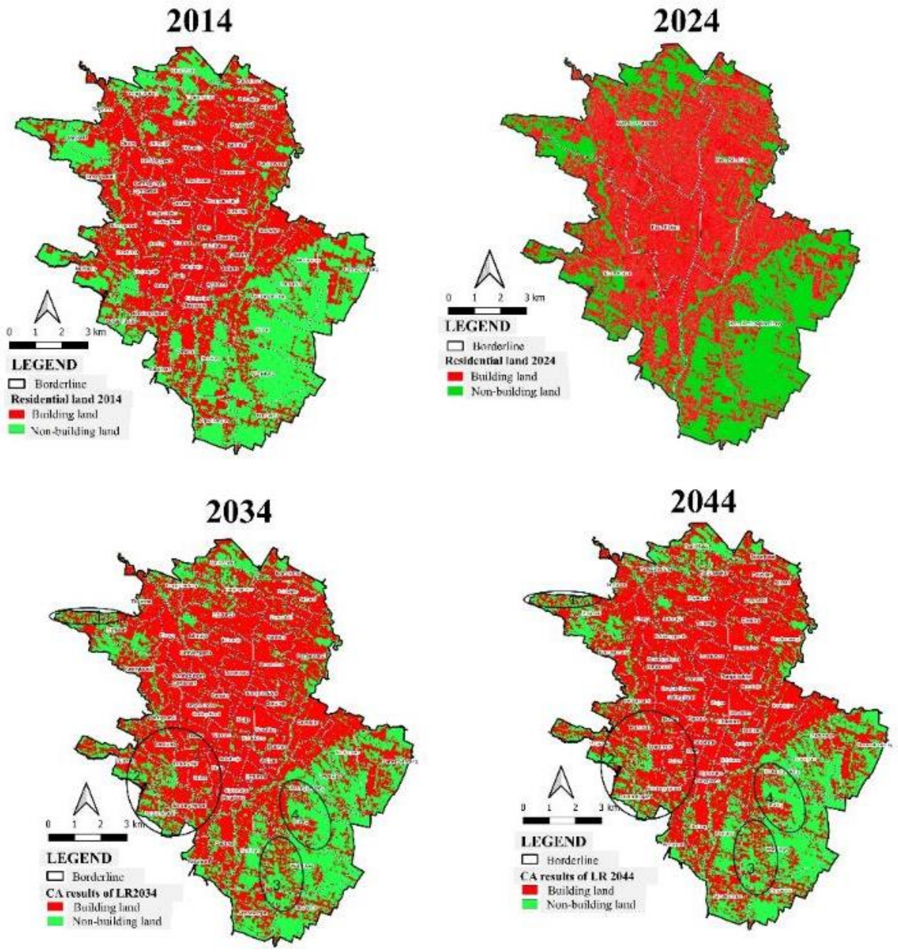

Figure 16 The CA-LR results for the city of Malang map from 2014 to 2044

The results of the 2044 map analysis using CA-ANN and CA-LR for the city of Malang indicate that several areas are predicted to undergo land use changes. In the 2044 map, Circle 1, located in the Merjosari sub-district, Lowokwaru District, shows an increase in built-up area. According to research by Bahrudin et al. (2023), Lowokwaru District experienced changes in non-built-up land from 2015 to 2020. Merjosari Sub-district has a significant number of middle-class housing units, with approximately 18 middle-class housing complexes. Research conducted by Nugroho et al. (2022) identified Lowokwaru District, including Merjosari, as a livable area, partly due to its geographical agglomeration near the city center. This supports the prediction of a reduction in non-built-up land in this area. Circle 2 is located in Sukun District. The area of non-built-up land in Sukun District has significantly decreased from 2009 to 2019 (Lewar et al., 2022). This confirms that Sukun is a suitable area for residential development. However, this contrasts with the findings ofNugroho et al. (2022), which indicate that Sukun District has a high level of agglomeration. This makes the area densely populated, potentially reducing the quality of life due to declining environmental quality or lack of green open spaces. Circles 3 and 4 are located in Kedungkandang District. This area has experienced the largest transition from non-built-up to built-up land in Malang City from 2014 to 2024. This change is influenced by population growth, land prices, and accessibility (Lion, 2022). In the 2044 map, the area shows slight development, likely due to the availability of accessibility that supports the growth of residential areas.

4. Conclusion

This study successfully modeled urban land transformation in Malang City using a Cellular Automata (CA) approach integrated with Artificial Neural Networks (ANN) and Logistic Regression (LR). The land use change prediction model for Malang City using the Cellular Automata-Logistic Regression (CA-LR) approach yielded more accurate and relevant results compared to the Cellular Automata-Artificial Neural Network (CA-ANN) model. The CA-LR analysis demonstrated a high level of accuracy, with a Kappa value reaching 1 at the location level, indicating a perfect match in predicting land use changes. Additionally, the CA-LR model was able to identify key factors influencing land conversion, such as population growth, accessibility, and land prices, providing a more comprehensive understanding of land change dynamics in Malang City.

The simulation results using CA-LR showed that non-built-up land in Malang City experienced a significant decline from 2024 to 2044, with the area decreasing from 4,090.85 hectares to 3,731.40 hectares. Conversely, built-up land increased from 7,030.70 hectares to 7,390.15 hectares during the same period. This indicates a trend of non-built-up land being converted into built-up land, particularly in areas with high accessibility and rapid population growth, such as Lowokwaru and Kedungkandang Districts.

Based on this research, the Malang City Government needs to conserve several green open spaces (RTH) to prevent their conversion into rapidly developing built-up areas. Green open spaces are essential urban elements that ensure oxygen production, provide recreational, activity, and relaxation spaces, and serve as sources of clean water and water absorption for the city. Furthermore, Malang City should also consider conserving Protected Agricultural Land (LSD) to maintain environmental sustainability and support sustainable urban development. LSD plays a crucial role in preserving agricultural land, particularly rice fields, to ensure national food security. Thus, efforts to conserve RTH and LSD will support environmentally conscious and sustainable development in Malang City.

Additionally, these prediction results can serve as an important reference for stakeholders in planning sustainable urban development, particularly in managing residential growth and maintaining a balance between built-up land and green open spaces. Moreover, this study identifies key factors influencing land changes, such as population growth, accessibility, and infrastructure availability, which need to be considered in future spatial planning. Therefore, the model developed in this study not only provides insights into land change dynamics in Malang City but can also be applied to other cities experiencing similar urbanization pressures.

Despite its strengths, this study has limitations, including data availability constraints and model sensitivity to parameter selection. The accuracy of land use predictions depends on the quality of input data, which may change over time. Additionally, the CA-LR model does not fully capture socio-economic and policy-driven factors influencing land transformation. Future research should integrate more dynamic variables, such as government policies, economic growth, and climate change impacts, to enhance prediction accuracy. Moreover, applying machine learning techniques alongside CA-LR could improve model robustness. Expanding the study to other urban areas can also validate the model's applicability in different contexts.

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