Spatial modeling for prediction agricultural land-use change in Jampang Kulon, Sukabumi Regency

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Abstract. Indonesia is a developing country with high population growth. In terms of urbanization, a large amount of agricultural land has been transformed into an urban area that can directly lead to LULC (land use-land cover) changes. Understanding and accessing LULC changes mainly used simulation models like the Cellular Automata and Markov Chain. This model effectively combines the advantages of long-term predictions and can simulate land-use growth. This study aims to analyze and predict the future scenarios of LULC (2010-2031) in the Jampang Kulon Sub District using Cellular Automata and Markov Chain model by considering the physical and socio-economic drivers of LULC dynamics. The study revealed that agricultural land decreased by 17% from 2020 to 2031. Meanwhile, the neighborhood area will be increased by 41% from 2020 to 2031. The growth of neighborhood areas with a crowded pattern is in the northern and center parts of the Jampang Kulon Sub District. The CA-Markov model used in predicting LULC produced a kappa value of 0.87. This study can provide suggestions and a basis for urban development planning in Jampang Kulon Sub District Sukabumi Regency.

1. Introduction

Indonesia is a country with soil fertility levels above average. Therefore, many areas are potentially used as agricultural food land [1]. However, for developing countries like Indonesia, higher population growth is one of the drivers of land-use changes [2]. Based on population projections for 2015-2045, Indonesia’s population will reach 269.6 million by 2020 [3]. The rapid growth of urbanization has significantly changed land's function, especially on forest and agricultural land that has transformed into built-up or urban areas [4,5]. The land is a limited resource. The pressure for high demand and low land values causes land-use changes, especially from agricultural land to non-agricultural land [6].

Agricultural land conversion is an unavoidable phenomenon in several regions such as West Java, the province with the largest population like Sukabumi Regency. The location is quite strategic, not far from the Jakarta Metropolitan Area, so it has experienced rapid population development. It is recorded that the agricultural land area of the Sukabumi Regency decreased by 10,736 hectares from 2017 to 2018 even though Sukabumi Regency occupies the third position at the national level as one of Indonesia's rice barns.

One of the agricultural land conversions in the Sukabumi Regency has occurred progressively in the Jampang Kulon Sub District. Based on data from the Central Bureau of Statistics 2019, the land area for paddy rice fields in Jampang Kulon Sub District covering 4,627 hectares decreased significantly from the previous year of 5,487 hectares [7]. This subtraction also affects the production of lowland rice produced. In 2018 Jampang Kulon Sub District was only able to produce harvest 29,944 tons, reduced...
from 32,293 tons. The rapid conversion of productive agricultural land has resulted in increasingly limited land resources to be developed for farming activities. Therefore, the average tenure of agricultural land becomes narrow and unable to achieve an economic business scale [8]. The rapid large-scale transition process is a significant threat to food security and environmental sustainability [9].

It is necessary to have prediction-based spatial modeling of land-use change, to minimize land growth interventions on agricultural land [10]. In this case, modeling analysis techniques are used in cellular automata and Geographic Information System (GIS) to determine which agricultural land will be converted in the future or vice versa [11].

Simulation-based LULC can provide better insights into potential future developments [12]. This model effectively combines the advantages of the long-term predictions of the Markov model and the ability of the Cellular Automata (CA) model to simulate the spatial variation in a complex system, and this mixed model can productively simulate LULC changes [13,14].

Spatial modeling using Markov Chain and Cellular Automata methods has been used in several studies related to land-use changes in certain areas. According to previous research, they didn't use proximity to neighborhood area as a driving factor for the land-use changes [15]. While in this study, proximity to the neighborhood areas is one factor that assumes making agricultural land-use changes.

This study aims to analyze and predict the future scenarios of LULC (2010-2031) in the Jampang Kulon Sub District using Cellular Automata and Markov Chain model by considering the physical and socio-economic drivers of LULC dynamics. The results of the Markov Chain and Cellular Automata models can provide a reference for research on changes in agricultural land use and land management decision making [16].

2. Methodology

2.1. Land use change analysis

This research begins by making land use maps in 2010, 2015, and 2020. Digitization is carried out through visual interpretation using Landsat 7 ETM+ imagery in 2010, Landsat 8 OLI/TIRS in 2015 and 2020. Landsat images that have been geometrically corrected are used to extract the information needed to do this agricultural land prediction modeling. Digital interpretation using the multispectral supervised method maximum likelihood classification. The respective land use classifications are obtained, the land use map for 2010, 2015, and 2020.

2.2. Land use change prediction in 2031

The main stage in this research is to predict by modeling land-use changes that occur. The model simulation process is carried out in two stages. First, generate a land use projection for 2020 by simulating 2010 and 2015 land-use changes to validate the model's accuracy. Furthermore, land use in 2031 was obtained by comparing changes in land use in 2015 and 2020.

Several factors can determine the simulation of changing from agricultural land to non-agricultural land fields. The variables used in the simulation of agricultural land changes are roads, rivers, neighborhood areas, and POI. All parameter changes were carried out by distance analysis using the Euclidean distance, a horizontal distance between two vectors assuming that the topography is relatively flat, resulting in a linear distance [17].

2.3. Model validation

The model validation test aims to compare the 2020 land use prediction simulation with the actual land use. This comparison is intended to validate how accurate the simulation projection is. Accuracy is expressed in the form of a presentation where the higher the presentation, the better it is. The validation test is followed by calculating the Kappa Accuracy value [18] as follows:

\[
\text{Kappa Accuracy} = \frac{N \sum_{i=1}^{n} x_{ij} - \sum_{i=1}^{n} (x_{ij} + X_{ij})}{N^2 - \sum_{i=1}^{n} (x_{ij} + X_{ij})}
\] (1)
Where, \((r)\) = number of rows and columns in error matrix; \((N)\) = total number of observations (pixels); \((X_{ii})\) = observation in row \(i\) and column \(i\); \((X_i+)\) = marginal total of row \(i\); and, \((X+i)\) = marginal total of column \(i\).

3. Results and discussion

3.1. land-use change in Jampang Kulon sub-district

Land-use changes were seen in 2010, 2015, and 2020 results from processing Landsat 7 and Landsat 8 imagery. The digitizing data is used to analyze land-use changes in Jampang Kulon District over the last 19 years. Land use is classified into four classes: neighborhood area, agricultural land, built-up land, and vegetation. This analysis was carried out spatially, temporally, and descriptively.

Agricultural land is the most dominating land use in the Jampang Kulon Sub District in 2010, with an area of 5,597 Ha or 44.7% of the entire area in Jampang Kulon District. The smallest land area is in the neighborhood area, with only 940 hectares or 7.5% of the Jampang Kulon Sub District. Based on Figure 1a, it can be seen that agricultural land dominates in almost all villages in Jampang Kulon Sub District.

![Figure 1](image_url)

Figure 1. Study location of Jampang Kulon in (a) 2010 (b) 2015 (c) 2020.

In 2015, agricultural land still dominated land use in Jampang Kulon Sub District. The rice field area in Jampang Kulon Sub District is 6,557 Ha or 53.1% of the entire area in Jampang Kulon Sub District. The increase in agricultural land is relatively rapid because, in that year, the planting season coincided in almost all sub-districts in Sukabumi Regency. Besides, the ease with which farmers get organic fertilizers' distribution also encourages farmers to carry out agricultural activities [19, 20]. However, the increase in agricultural land was also accompanied by an increase in neighborhood area to 1,924 hectares or around 15.6%.

In 2020, agricultural land has decreased to 6,179 hectares or 50.4% of the Jampang Kulon Sub District. Along with the decline in agricultural land area, neighborhood area has increased to 3,500 hectares or 27.9% of the Jampang Kulon Sub District. Other land uses, such as non-built-up areas and vegetation, have also decreased by 659 hectares and 101 hectares in addition to the shrinking agricultural area.

Land-use changes in Jampang Kulon Sub District from 2010 to 2020 have shown significant results. Change occurs with an increased neighborhood area and decreased agricultural land, non-built up area, and vegetation. Agricultural land underwent the most significant change wherein 2015, 7,570 hectares decreased to 6,179 hectares in 2020. In addition to the neighborhood area, the non-built up area has also reduced widely by 3,383 hectares over the last ten years. These are not much different from the reduced vegetation conditions from 1,482 Ha in 2010 to 1,464 Ha in 2020.

Spatially in the southern part of the Jampang Kulon Sub District, the increase of neighborhood area occurred in Jampang Kulon, Padajaya, and Nagraksari Villages due to a local main road connects Jampang Kulon Sub District with Sukabumi Regency and other sub-districts. Apart from that, other driving factors are many public facilities that support people's lives, such as markets, schools, and banks. It increases the development of neighborhood areas in the region.
3.2. Land use prediction modeling of Jampang Kulon sub-district

The land use prediction model of the Jampang Kulon Sub District in 2031 is obtained using the Cellular Automata-Markov Chain model. The prediction is based on land use data in previous years 2010, 2015, and 2020. The determining factors in the changing area of agricultural land used in this study are divided into physical and socio-economic factors. The physical aspect is the distance from the river. Meanwhile, the socio-economic element, seen from the existence of infrastructure that supports development, includes the distance from the road, the distance from the neighborhood area, and the POI (Point of Interest).

Driving factors are used to estimate each pixel’s probability value of each existing land use not to change or to change. At IDRISI Selva requires driving factors in continuous format (Binary 0-1) for processing. Data on road networks, rivers, neighborhoods, and POI are processed using a multiple ring buffer process to produce the value of the distance from the roads, distance from the rivers, distance from neighborhood areas, and distance from POI. On each driving factor variable, the higher the score, the higher the probability of a land change.

Based on figure 3, it can be seen that the closer the land is to the road, the more potential the land becomes non-agricultural. It is considered that the closer to the street, the easier the accessibility will be so that it will trigger the development of neighborhood areas. For the distance from the river, it can be seen that the closer the land to the river, the smaller the potential for changing agricultural land to non-agricultural land. This potential is because rivers are the primary source of irrigation for agricultural land in the Jampang Kulon Sub District. The farther the agricultural land is from the water resources, the more expensive it will cost to irrigate agricultural land [21].

Furthermore, for the distance variable from the neighborhood area, the closer the distance from agricultural land to the neighborhood area is assumed to be, the higher the function change will be due
to the high price of land because of the need for a place to live. This estimation encourages people to sell agricultural land because of the high selling price of land or more profit. The POI distance consists of various public facilities such as markets, banks, schools, and restaurants. Suppose it is located close to agricultural land. It is considered to have a high potential to convert to non-agriculture because fulfilling life needs will be more comfortable to access and increase income like one of the POI, Cinagen Traditional Market, a shopping center for the local community various needs.

Each driving factor that has been given a score is carried out by the fuzzy membership process to convert the score into a constant unclear value (0-1). Furthermore, for each driving factor variable that has been carried out, the fuzzy membership process is then overlaid using a faint overlay. This process is carried out to combine each pixel's value from the four driving factors so that the processing can be carried out at IDRISI Selva. The highest overlay result is 0.93, indicating that the area's land can change, while the lowest value is 0.24, which suggests that the land in the area cannot change.

3.3. Land use model validation

In this study, land use in 2010, 2015, and 2020 was used to produce predictions in 2031. Before modeling for prediction, it is necessary to test the accuracy between the 2020 land use prediction and the 2020 actual digitization land use. Forecasts for 2020 land use were generated from 2010 and 2015, processed using the CA-Markov tool on the IDRISI Selva software. An accuracy test was carried out with Kappa Validation to determine the agreement value between the projection model and the interpretation results.

The standard value determines the level of accuracy of the model created. In this study, the typical value is 0.87, which shows that the agreement value between the prediction model and the actual land in 2020 is good (Kappa value 0.75). The accuracy-test results that produce excellent values can be carried out as a confirmed model design to be continued as a 2031 land prediction model.

3.4. Land use model for 2031

The prediction of land-use change in 2031 is shown in figure 4. It is found that the neighborhood area is expanding quite rapidly. The neighborhood area's growth occurs in the regions suitable for having a high driving factor value. This neighborhood area's growth can be seen from the expansion of the neighborhood area close to roads, poi, and the neighborhood area while away from the river. The neighborhood area is predicted to be widely spread in the northern part. This spread is assumed because the distance from the center of activities such as Sukabumi City and Pelabuhanratu City is the icon of Sukabumi is getting closer. Many agricultural areas have turned into a neighborhood area. The location of agricultural land from 5,597 in 2010 was reduced to 5,068 Ha in 2031. The site of decline is estimated to decrease by 9% from 2010 to 2031. Meanwhile, the area for the neighborhood area will increase by 61% from 2010 to 2031.

![Figure 4. Land use/land cover prediction of Jampang Kulon in 2031.](image)
4. Conclusions
Land-use change pattern in 2010–2020 based on Landsat images shows a significant reduction in agricultural land area to non-agricultural. Agricultural land has changed by 581 hectares or a decrease of about 10% from 2010 to 2020. Meanwhile, the neighborhood area has increased by 2,560 hectares or the equivalent of 73%.

The use of spatial data such as accessibility, existing neighborhood areas, activity centers, and rivers affects agricultural land changes and the accuracy of the CA-Markov model for predicting agricultural land in the Jampang Kulon Sub District in 2031. The accuracy results are 0.87 based on the Kappa Value. The projection model results show that agricultural land area will decrease by 17% from 2020 to 2031. Meanwhile, the neighborhood area will increase by 41% from 2020 to 2031. The growth of neighborhood areas with a crowded pattern is in the northern and central regions. Most agricultural areas have turned into a neighborhood area.

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