Prediction of land use and land cover (LULC) changes using CA-Markov model in Mamuju Subdistrict

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Abstract. Changes in land use and land cover (LULC) are one of the changes that are directly affected by human activities which are largely driven by socio-economic factors. Knowing, analyzing and modeling LULC change transformation plays an important role in planning, management and decision making activities. The purpose of this study is to develop LULC projection models using CA-Markov analysis to predict LULC in 2034 in Mamuju Subdistrict as the city centre of Mamuju Regency which has a rapid change in LULC. Inputs used in this research are data on river networks, roads, public facilities, LULC 2009, LULC 2014 and LULC 2019. The results showed that for 25 years (2009-2034) forest dominated land cover in Mamuju Subdistrict and settlement into LULC classes which has increased. In 2034, settlements have an area of 5.88% of the total study area or grow by 4.93% over the period of 2009-2034. The CA-Markov model used in predicting LULC changes was validated and produced a kappa coefficient of 0.969 (96.9%) which showed that the model had successfully predicted LULC changes in the study area.

1. Introduction

Changes in land use and land cover (LULC) are one of the most important changes that occur because they are directly affected by human activities [1]. Human activities which are largely driven by socio-economic factors create changes in land that is not built and still built even though it is limited by physical conditions [2]. Physical conditions such as topography and social factors such as population growth are the driving factors for LULC changes [3]. Knowing, analyzing and modeling LULC change transformations is important for many planning and management activities [4, 5]. Observing LULC changes in the past and present and estimating future changes play an important role in the development of decision making [6].

LULC change studies based on current and historical data comparisons available through remote sensing techniques and integrating with geographic information system (GIS) are able to provide some accurate information that allows knowing the area and pattern of changes in LULC [7]. GIS is very useful for knowing LULC changes, especially with the availability of models capable of describing aspects of spatial dynamics [3]. There are several methods used to predict LULC changes such as
mathematical equations, system dynamics, statistics, expert systems, evolution, cellular and hybrid models, but hybrid models are the most commonly used methods for the detection and simulation of LULC changes [8]. CA-Markov models are a hybrid of Cellular Automata (CA) and Markov models, this model has been considered a suitable approach for modeling LULC changes because it is able to take into account the spatial and temporal components of LULC dynamics [8, 9].

The CA-Markov model that can model LULC changes temporally and spatially has been widely applied by many researchers, including [10] which simulates population dynamics of three plant species spatially at the University of Giessen Germany from 1993 to 1996. In addition, [11] modeled temporal changes and spatial distribution of use by natural and socio-economic factors in Saga, Japan during the period 2015-2042. [12] Using the CA-Markov model to simulate changes in the land use structure in the Nangou watershed in 2025 and analyze the relationship between land use efficiency, level of land use dynamics, relative change in land use type, land use transfer matrix data and relevant indicators, and analyze policy implementation.

Mamuju Regency as the centre of economic growth in West Sulawesi, continues to experience rapid development from time to time. Development in the Mamuju area tends to be concentrated in the downtown area, namely in Mamuju Subdistrict, so LULC changes also take place quickly in the city centre along with the increase in existing activities [13]. This study aims to develop LULC projection models using CA-Markov analysis to predict LULC in 2034 based on LULC in 2009, 2014 and 2019 as well as the physical condition of Mamuju Subdistrict as the city centre of Mamuju Regency. Furthermore, future predictions of LULC changes can be useful for policy makers in making the right decisions for future land use challenges and can also be used as early warning systems.

2. Methodology and data

2.1. Research location
Mamuju Subdistrict is located at -2° 40’ 34” South Latitude and 118° 53’ 26” East Longitude (figure 1). Administratively, this district is divided into 8 villages, of which 4 out of 8 villages namely Binanga, Karema, Rimuku and Mamunyu are the city centre of Mamuju Regency, West Sulawesi [14]. As a city centre, this area has a significant rate of LULC change due to several factors including accessibility and government policy [13].

Figure 1. Image of research location
2.2. Data
The data used to achieve the research objectives include river network, road network, public facilities that includes educational facilities, health facilities, places of worship, terminals, commercial centre and offices obtained from the RBI map of the Geospatial Information Agency, LULC data of 2009 from Landsat 7, 2014 LULC data and 2019 from Landsat 8 and slope data obtained from the DEMNAS Geospatial Information Agency.

2.3. Method
The CA-Markov model is a combination of Cellular Automata and transition probability matrices generated by cross tabulation of two different images so that it can provide a strong approach in spatio-temporal dynamic modeling [8, 15]. The Markov chain model only provides temporal dynamics but does not consider driver data in predictions of spatial change [16]. In contrast to the Markov chain model, the CA model shows spatial and dynamic processes, where future changes depend on the spatial state of neighbour cells [16, 17]. Therefore, integration of CA-Markov is considered capable of simulating and predicting changes in LULC [6].

The Markov module contained in IDRISI Selva 17.0 is used to calculate the probability of a Markov transition which will then produce a transition probability matrix. The resulting matrix contains the number of pixels that move from one category to another category of land use and the raster area shows the transition area (Markov transition area) [18].

Inputs in the analysis of the Markov model are the results of analysis of land use in time series, projections for changes in LULC in 2034 from the trend of land change in the previous year. Before the model can be used to project LULC in 2034, it must be validated first. In this study, validation analysis using LULC maps in 2009 as the initial year (t1) and LULC in 2014 as the final year (t2) to project LULC changes in 2019. The value of model validity is obtained by comparing LULC in 2019 interpretation of satellite images and LULC in 2019 the results of the prediction, using the Map Comparison Kit (MCK) software to find Kappa values. From the analysis of using the MCK, the projection of 2019 with image interpretation in 2019 if a Kappa value of >=0.85 or 85% means that the projected model built can be used to project LULC changes in the future [6].

3. Results and discussions
3.1. Classification of images and LULC dynamics changes
This study uses LULC 2009, 2014 and 2019. Each LULC data is classified by supervised classification method with the help of ArcGIS 10.5 software. The first step in conducting the supervised classification is to make a training sample that represents certain spectral characteristics, which are then used to train the classification algorithm of the remaining images [18, 19]. In this study, LULC was divided into 7 classes. The classification results produce 2009, 2014 and 2019 LULC maps ‘figure 2’.

The classification results show that forests dominated land cover in Mamuju Subdistrict for one decade, from 2009 to 2019 (table 1). There is a trend of a significant increase in residential classes, while a downward trend occurs in pond, forest, mangrove and agriculture classes. LULC for settlement classes increased by 2.88% over the decade (2009-2019) or increased by 0.288% every year, while for pond, forest, mangrove and agriculture classes each decreased by 0.11%, 0.25%, 0.12% and 2.5%.

3.2. Markov Chain analysis
Markov Chain analysis describes changes in LULC from one period to another which are then used as a basis for projecting changes that occur in the future. The results of the change are obtained by developing a probability transition matrix from LULC changes from time one to time two which forms the basis for projecting future scenarios [8].
In this study, LULC 2019 was predicted based on the state of LULC in 2009 as the previous land cover image (t1) and the 2014 LULC as the land cover image then (t2). Prediction results using the Markov model produce transition area matrix (table 2), transition probability matrix and LULC prediction results in 2019. Transition probability matrix explains the chance of changes from each LULC class category to another LULC class while transition area matrix describes the total area expected to change in the next time period [8].

The transition area matrix (table 2) shows that over one decade, 30.6225 ha of forest area has the opportunity to be converted into agriculture class, while for other LULC classes except shrub and water body class, potentially converted into settlement class by 2019. The model ability to predict LULC 2019 was validated by comparing the LULC in 2019 as a result of interpretation of satellite imagery. The validation results show the kappa coefficient value is 0.969 or >= 0.85 which indicates that the predicted results built can be used to predict LULC changes in the future [6].
Table 2. Transition area (in ha) for prediction of LULC in 2019 by using LULC images of 2009 and 2014.

| LULC Classes        | Settlement | Pond       | Forest   | Shrub     | Mangrove   | Agriculture | Water Body |
|---------------------|------------|------------|----------|-----------|------------|-------------|------------|
| Settlement          | 652.86     | 0          | 0        | 0         | 0          | 0           | 0          |
| Pond                | 43.38      | 374.1075   | 0        | 0         | 1.2825     | 0           | 0          |
| Forest              | 6.8175     | 0          | 14113.79 | 5.747     | 0          | 30.6225     | 0          |
| Shrub               | 0          | 0          | 0        | 434.9025  | 0          | 0           | 0          |
| Mangrove            | 3.42       | 17.8425    | 0        | 0         | 200.1825   | 0           | 0          |
| Agriculture         | 370.6425   | 11.7225    | 0        | 0         | 3.6225     | 4339.643    | 0          |
| Water Body          | 0          | 0          | 0        | 0         | 0          | 52.875      |            |

3.3. **CA-Markov analysis**

Prediction of LULC changes using CA-Markov requires three types of data input, basic image of LULC, Markov transition area file and transition suitability image collection. LULC 2009 is the result of image interpretation, as a basic image. The Markov transition area file (transition area matrix) is generated when running the Markov module while the LULC transition suitability image collection is obtained by combining a map set (factor and constraint) using the multi criteria evaluation module (MCE) [8].

3.3.1. **Multi criteria evaluation (MCE)**

MCE is a method for assessing criteria based on expert understanding of interactions and the influence of factors on LULC change. The development of criteria depends on the influence of the LULC modifier. The more important a factor, hence the higher the weight allocated for factors in the development of criteria [8, 20]. In this research, there are 3 LULC classes (settlement, agriculture and pond) that change from one class to another from time to time based on factors and constraints, while the other 4 LULC classes are considered to change naturally.

Factors and constraints that affect changes in LULC class 3:

1. **Suitability of settlements**
   - Factors: settlement distance <800m, distance from road <250m and distance from public facilities <3000m. Constraints: Slope >15% [20] and water body.

2. **Agricultural suitability**
   - Factors: farm distance <3000m, distance from water body <1000, Distance from shrub <1000m and distance from forest <1000m. Constraints: Slope >35% [21], water body, road and previous settlement.

3. **Pond suitability**
   - Factors: pond distance <1000m, distance from mangrove <500m and distance from shrub <200m. Constraints: Slope >3% [22], water body, roads, forests and previous settlement.

3.3.2. **Analytical hierarchy process (AHP)**

Every factors map that has been made, each is given a weight based on the influence of changes in the LULC class. The greater the weight of the factor, the greater the effect on changes in certain LULC classes. The weight for each factor is obtained through an analytical hierarchy process (AHP) in the WEIGHT module on IDRISI Selva [20, 23]. The factor weighting results are shown in ‘figure 3’.
3.3.3. LULC changes prediction in 2034

The CA-Markov module in IDRISI selva 17.0 software is used to predict LULC in 2034. The data used in running the CA-Markov model is the LULC map in 2019 as a base map, the transition area matrix from 2009 to 2019 obtained when making LULC change predictions using Markov Chain analysis (Markov Module) and a collection of LULC transition conformity images obtained when running the MCE module, giving weights to the driving factors ‘figure 3’ and providing constraints for suitability of LULC changes.

The LULC prediction results in 2034 indicate a significant increase in settlement class ‘figure 4’ which increased by 2.05% from 2019 (table 3). In addition, between 2019-2014 the class of pond, shrub, mangrove and agriculture decreased by 0.12%, 0.09%, 0.1% and 1.79% respectively (table 3).

**Figure 3.** Weight for LULC change factors (a) factors for settlement class (b) factors for agriculture class (c) factors for pond class.

**Figure 4.** LULC Prediction in 2034.
Table 3. Comparison of the area of each LULC class in 2019 and LULC prediction results in 2034.

| LULC Classes | Year 2019 |  | Year 2034 |  |
|--------------|-----------|---|-----------|---|
|               | Area      | % | Area      | % |
| Settlement    | 791.364   | 3.83 | 1215.54   | 5.88 |
| Pond          | 409.932   | 1.98 | 384.57    | 1.86 |
| Forest        | 14143.6   | 68.4 | 14155.9   | 68.5 |
| Shrub         | 454.551   | 2.2  | 434.903   | 2.1 |
| Mangrove      | 214.747   | 1.04 | 194.76    | 0.94 |
| Agriculture   | 4595.81   | 22.2 | 4224.97   | 20.4 |
| Water Body    | 53.6189   | 0.26 | 52.8975   | 0.26 |
| Total         | 20663.6   | 100 | 20663.6   | 100 |

The settlement distance was a driving factor that played many roles in LULC change in Mamuju Subdistrict which was marked by a reduction in agriculture land and pond and an increase in new settlement. Agriculture class and pond converted become new settlement because the slope that is suitable for pond and agriculture is also relatively suitable for settlement, namely slope <15%. In addition, the factors of road networks and public facilities that are located around pond and agriculture also play a role in generating new settlement. Meanwhile, the forest class did not experience a decline because the slope for the forest was not suitable for pond, agriculture and settlement.

This study shows that during 2009 to 2034, settlement class continued to experience an increasing trend. For 25 years (2009-2034) settlement in the Mamuju Subdistrict are predicted to increase by 4.93% from the total study area or grow by 0.2% for each year accompanied by a decline in agriculture and pond class.

4. Conclusion
The result of LULC Mamuju Subdistrict modeling using the CA-Markov model show that settlement is LULC class which have continued to increase for 25 years (2009-2034). Settlement has an area of 5.88% of the total area of Mamuju district in 2034 or grew by 4.93% in the span of 25 years. The development of settlement class occurs at the expense of agriculture land and pond which means that the Mamuju Subdistrict will continue to experience degradation of agriculture land and aquaculture annually. The model used in predicting LULC changes has been validated and produced a Kappa coefficient of 0.969 (96.9%). This shows that the CA-Markov model has successfully predicted LULC changes in the study area.

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