GIS-Based Modelling of Land Use Dynamics Using Cellular Automata and Markov Chain

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Abstract

Today, land use change has become one of the major issues in a developed region. Therefore, it is always important to monitor land use change within a certain period of time and predict patterns of future land use change on a spatial basis. The main objective of this research is to assess land use change in Maros regency up to a 20 year period. The analysis of land use change utilizes an integration method of Cellular Automata and Markov Chain (Cellular Automata-Markov) in Remote Sensing (RS) and Geographic Information System (GIS). The procedures used include: (i)) a preliminary data processing (geometric correction, radiometric correction, preparation of the composite image, object recognition) of Landsat images acquired in 2004, 2009, and 2012; (ii) classification of multispectral imagery; (iii) probability analysis to generate *Transitional Probability Matrix*, *Transitional Area Matrix*, and *Markov* factors; (iv) validation of raster Markov RGF 2012 image layer with 2012 land use using a Kappa index; (v) using the same analysis in step (iii) but considering the driving factors of land use change and constrains; (vi) Analysis using Cellular Automata-Markov to generate land use change in the next 20 years. The results show that in year 2029, an increase in built up area, but on the other hand, a decline in agricultural land use especially paddy fields, agricultural land, water bodies, and other uses. In terms of land use decision making perspective, such information may be used to direct land use change to a more beneficial and sustainable situation.
Keywords: land use change; Cellular Automata-Markov; remote sensing; GIS

1. Introduction

To date, monitoring intensive land conversion and dynamic has been conducted using remote sensing technology, with various techniques. Several methods of land-use dynamic analysis and prediction are *dynamic segmentation*, *fuzzy set*, *cellular automata* and *Markov chain* (Baja, 2012). Some studies that have used Cellular Automata (CA) method for many different kinds of land use analyses, both in urban and rural areas include Ahmed and Ahmed (2012); Behera *et al*. (2012); Riccioli *et al*. (2013). Cellular Automata has been also applied to land use assessment in the context of statistical analyses only. However, its integration with Markov approach within GIS and remote sensing makes it more powerful in the utilization of land use dynamics in a spatial perspective (Arsanjani *et al.*, 2011; Arsanjani *et al.*, 2013; Moghadam and Helbich, 2013; Subedi *et al.*, 2013; Xin *et al.*, 2012), because it can assess such parameters as probability related to *Transitional Probability Matrix*, *Transitional Area Matrix*, and *Markov factors*.

In the application of Cellular Automata Markov (CAM), Maros regency is selected as study area. Maros regency is one of four area districts/municipalities in the Mamminasata Urban Area. Mamminasata Urban Area is an area of national strategic which its spatial arrangement is prioritized. This is based on Local Regulation (Regulation) South Sulawesi Province No. 9, year 2009 about Region Spatial Planning (RTRW) in Mamminasata area in 2009-2020 and Presidential Decree (Decree) No. 55 of 2011 about Mamminasata Area Plan. Designation of Mamminasata Urban Region as a national strategic area has caused the area becomes very dynamic and experiences rapid urban development. This occurs due to rapid population growth, the demand on land increases sharply, and lifestyle changes that lead to land use change, primarily agricultural land into other uses (Baja *et al*., 2011).

Moreover, land conversion causes a decrease in the extent of agricultural land that is fundamentally needed to meet the population’s food needs that increased sharply. Another cause that emerges is natural phenomena that had never happened in Maros Regency, such as flash floods, droughts, and landslides. Therefore, conversion should be controlled in this area, by developing monitoring system so that land conversion may provide optimal benefits and remain sustainable. In such a response, an analysis is needed to monitor land use change within a certain time and predict patterns of future land use change. This information is useful as consideration for the policy makers in determining land-use management strategies in Maros regency (Baja and Sallatu, 2006).

The main objective of this research is to predict future land use changes in Maros regency using analytical integration Cellular Automata and Markov Chain (Cellular Automata-Markov).

2. Methodology

2.1 Study area

The study area (Maros Region) is located about 30 km north of Makassar City, the capital of South Sulawesi Province (**Figure 1**). It lies between latitudes 4°711' and 5°2' S, and stretches between longitudes 119°453' to 119°977' W. The area selected for this study includes some parts of Maros District covering a total area of 144,085 ha. There area 14 sub-districts included in the study region: Mandai, Moncongloe, Maros Baru, Marusu, Turikale, Lau, Bontoa, Bantimurung, Simbang, Tanralili, Tompobulu, Camba, Cenrana, Mallawa. According to local statistical data, total population living in this area is 303,211.

The study area consists of varying topography: flat, undulating, rolling, hilly, and mountainous. The flat – undulating areas (the slope gradient less than 15%) cover a total area of approximately 50,369 ha or 34.9% of Maros Region. Such areas are usually used for paddy field, dryland agriculture, and also as mixed crops. One of the unique characteristics of topography in this region is the existence of karst landform which becomes conservation zone, according to the spatial planning regulation.

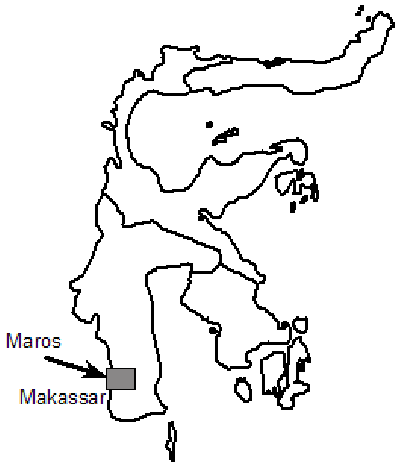


Figure 1. Sulawesi Island and the location of study area

2.2 Analysis procedure

The analysis used Cellular Automata Markov method (Ahmed and Ahmed, 2012; Behera *et al*., 2012; Riccioli *et al.*, 2013; Xin *et al.*, 2012) than works inside Remote Sensing. The analytical procedure used in this study can be seen in **Figure 2.** Three dates of imagery were employed in this study, include 2004, 2009, and 2012. Three of such imagery were first classified using supervised classification method before Markov parameters were generated. Land use changes within these three dates were assessed and then overlaid between them to generate statistical data, as described below.

2.2.1 Preliminary Analysis of Data Processing and Classification of multispectral

Landsat images acquired in 2004, 2009, and 2012 were processed using raster based image processing program. Preliminary analysis of the data processing starts with the geometric correction, radiometric correction, the preparation of the composite image, and supervised multispectral classification (Lillesand and Kiefer, 1979; Prahasta, 2008).

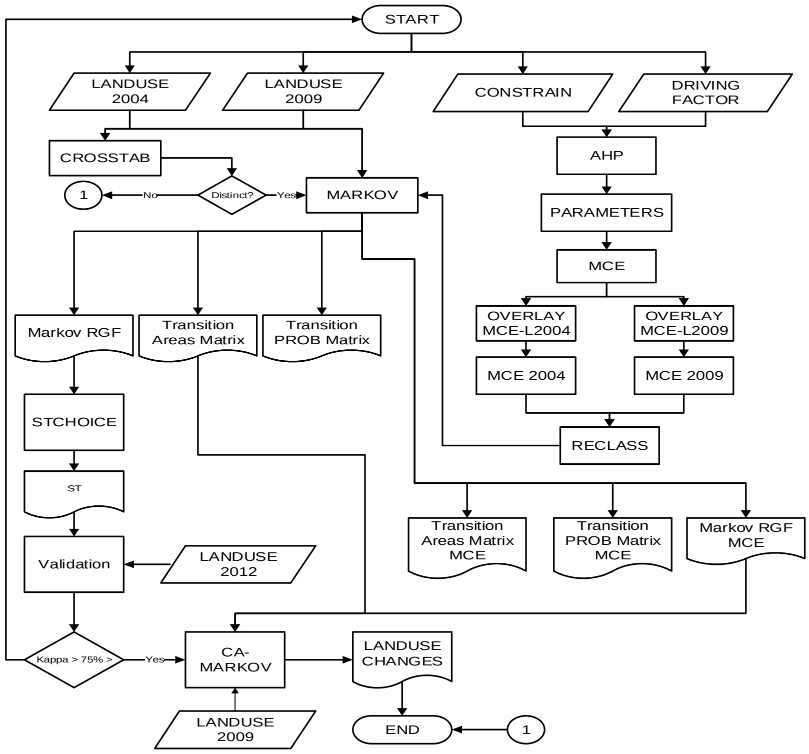


Figure 2. Flowchart of research method

2.2.2 Probability analysis of Markov Chain

Based on the land use maps in each of 2004, 2009, and 2012, land-use change analysis in Maros regency was conducted and it determined the probability of land-use change from 2004 to 2009 by using Markov Chain techniques. Markov analysis produces Markov RGF, Transitional and Transitional Probability Matrix and Transitional Area Matrix. Transitional Probability / Area Matrix (t_1-t_0), namely matrix change of land use that obtained by overlaying maps of land -use at two points year with Markov Chains module.

$$P\{X(tn) \leq Xn \mid X(t), t \leq tn\text{-}1\} = P\{X(tn) \leq Xn \mid X(tn\text{-}1)\} \quad \ldots\ldots\ldots\ldots\ldots \quad [1]$$

Markov RGF data were used to predict condition of land use in 2012.

2.2.3 Model Validation Kappa

Prediction result of land use changes in 2012 used a Markov probability analysis, and then validated from land use map of image analysis result in 2012 using the Kappa model validation. From the simulation results, this model could show how much deviation between Markov probability prediction results in 2012 with land use maps of image analysis result in 2012. In the classification, the common rule was taken: if the value of the model validation results was less than 75%, it should be re-run to obtain validation of models of higher value (Lillesand and Kiefer, 1994); but if the value of the results of the model validation is more than 75%, then the land-use change models will be used to predict changes in land use by 2029. Kappa coefficient was determined by the following formula (Koomen, 1996):

$$K = \frac{P(A) - P(E)}{1 - P(E)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [2]$$

where P(A) is the observed correct proportion and P(E) is the expected correct proportion.

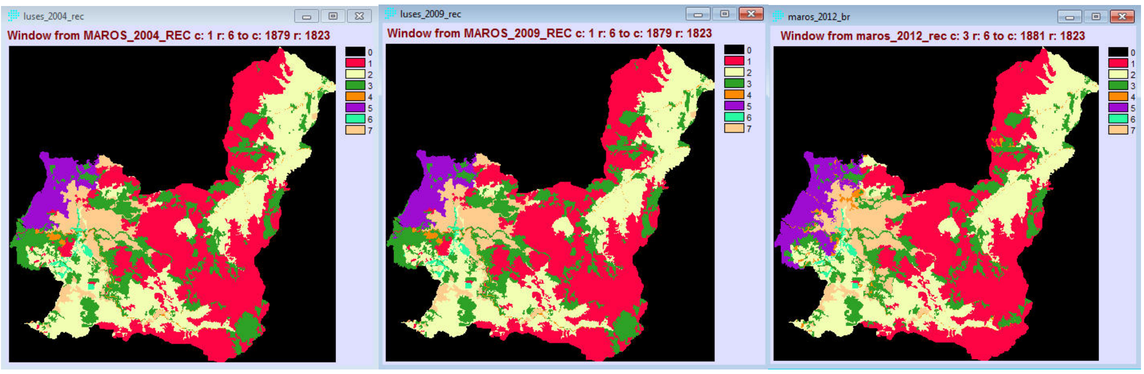
2.2.4 Simulation Model by Using Cellular Automata-Markov

Simulation model of land-use change by 2029 was conducted using Cellular Automata-Markov. Markov analysis was conducted in land use in 2004 and 2009 taking into account the *driving factor* of urban development pattern forming in the Maros Airport, residential areas and transport networks, as well as the constraint (limiting factor) namely the slope, protected forests, and bodies of water. Analysis results were integrated with cellular automata to obtain land use change prediction in 2029.

3. Results and Discussions

3.1 Land use year 2004, 2009, and 2012

Land use types of Maros regency produced from image analysis for 2004, 2009, and 2012 are shown in **Figure 3**. Land use type is generally dominated by dryland agriculture, although its area is continuously decreased.



a b c

Figure 3. Land Use in Maros Regency a) year 2004, b) year 2009, c) year 2012

3.2 Markov Probability Land Use Change 2004-2009

Markov Probability Change Land Use 2004-2009 use to predict changes in land use in 2012 and validated by the Kappa validation. Markov Probability Change of Land Use 2004-2009 presented as the following:

	Cl. 1	Cl. 2	Cl. 3	Cl. 4	Cl. 5	Cl. 6	Cl. 7
Class 1 :	0.8500	0.1500	0.0000	0.0000	0.0000	0.0000	0.0000
Class 2 :	0.0000	0.8497	0.0000	0.0075	0.1052	0.0376	0.0000
Class 3 :	0.0250	0.0250	0.8500	0.0250	0.0250	0.0250	0.0250
Class 4 :	0.0000	0.0000	0.0000	0.8499	0.1501	0.0000	0.0000
Class 5 :	0.0250	0.0250	0.0250	0.0250	0.8500	0.0250	0.0250
Class 6 :	0.0250	0.0250	0.0250	0.0250	0.0250	0.8500	0.0250
Class 7 :	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250	0.8500

Result of Kappa validation of land use change using Markov analysis in image analysis result in 2012 gives a positive value, *i.e.*, 83.6%. This means that the probability of Markov analysis results shows a sufficient validity to predict future land use changes.

3.3. Model of Land Use Change in 2029

Models of land use change in 2029, using Markov cellular automata analysis can be seen in **Figure 4**. Note that the legend assigns the following: 0=Back Ground; 1=Forest; 2=Dryland Agriculture; 3=Scrubs and Grassland; 4=Water Body; 5=Fish Ponds; 6=Residential; 7=Paddy Fields. The results show that in year 2029, an increase in built up areas, but on the other hand, a decline in agricultural land use especially paddy fields, agricultural land, water bodies, and other uses. The growth of residential area over a span of 20 years was 957.29 Ha, *i.e.* 1024.44 ha in 2009 and 1981.73 ha in 2029. This vast increase was generally derived from dryland agriculture (**Figure 5**).

In terms of land use decision making perspective, such information may be used to direct land use change to a more beneficial and sustainable situation.

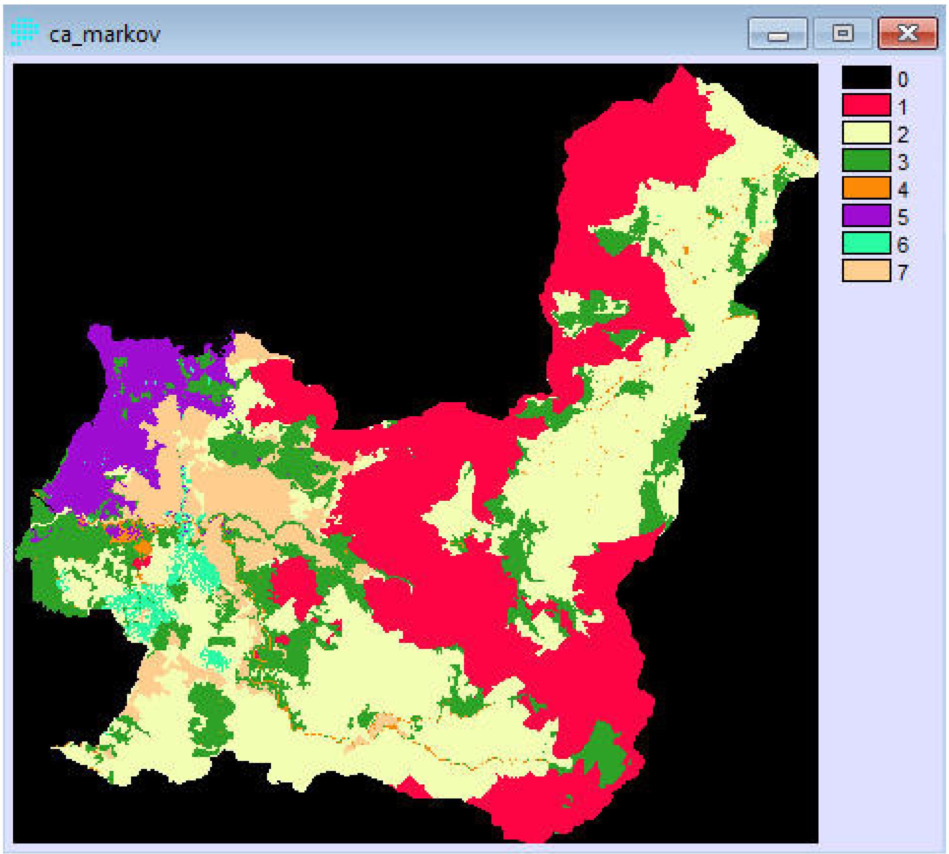


Figure 4. Model of 2029 land use: a result of cellular automata-Markov (CAM) (0=background; 1=Forest; 2=DrylandAgriculture; 3=Scrubs and Grassland; 4=Water Body; 5=Fish Ponds; 6=Residential; 7=Paddy Fields)

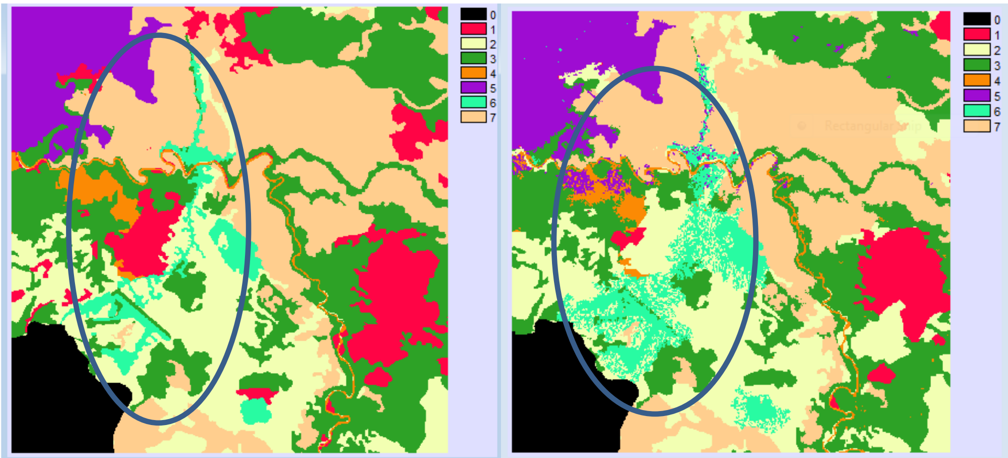


Figure 5. A window of land use change of residential within the period 2009-2029 (20 years) (0=Back Ground; 1=Forest; 2=DrylandAgriculture; 3=Scrubs and Grassland; 4=Water Body; 5=Fish Ponds; 6=Residential; 7=Paddy Fields).

4. Conclusion

The results of this study indicate that land use changes analysis has produced accuracy values of more than 80% (years 2004, 2009, and 2012). For the three dates under consideration, the largest declining areas of land use types (loss) occur at forest and dry land agriculture, while the largest increasing land use types (gain) are residential area (representing built up area). It also shows that based on the Markov projection for the year 2029, there will a significant increase in built up area, but on the other hand, a considerable decline in agricultural land use especially paddy fields, dry land agriculture, fish ponds, and other uses. In terms of land use decision making perspective, such information may be used to direct land use change to a more beneficial and sustainable condition. This research focusses only on the major change on a general scale, and therefore a more detailed analysis is needed to generate information on land use change in the urban areas in a more specific theme.

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