

Geospatial Simulation Based On Cellular Automata in Extrapolating Land-Use Changes

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Abstract—*The dynamics changes of land-use and their impact are a natural responses to human activities. These responses need to be understood in order to determine a proper management in the future. The aim of this research is to formulate the rules required for developing a Cellular Automata (CA) model so that the simulation of geospatial data are able to produce an extrapolation map of land-use changes from 2012 until 2037. This research employed CA-simulation and modeling. The input was in the form of spatial data of the multi-time use of existing land according to the condition in 2000 until 2012, and land physical factors in multi layer representation consisting of rainfall, slope, elevation, soil types, buffer zone regulation, and road accessibility. These spatial data were converted into ASCII format as Jeneberang sub-basin condition. The data were processed and analyzed by using Geographic Information System (GIS). The simulation was conducted in the condition of 2000 until 2012 with a time duration of every 3 years. Furthermore, the validation was conducted by using Kappa and Fuzzy Kappa algorithm. The results revealed that the formulated rules were able to develop a CA model to extrapolate the map of land-use change from 2012 until 2037. The validation of geospatial simulation revealed a very good accuracy level of more than 90%, it can be concluded as an excellent result.*

Keywords: Cellular automata, Geospatial, Geographic Information Systems, Fuzzy Kappa, multi layer.

I. INTRODUCTION

The phenomenon of land-use change and their impacts are nature responses to human behavior. These responses need to be understood in order to determine the proper action for future management. One of the consequences of land use is its impact on the sustainability of natural resources. This impacts should be minimized for sustainable use [1], [2].

According to [3], the use of GIS is very useful in relation to the dynamic of land use, especially with the availability of applicable models that are able to describe aspects of spatial dynamic. Further, Karsidi argued that the principle of *the Game of Life* [4] refers to a spatial cell-based model where changes depend on the surrounding cells or nearby parcels. The principle became the underlying basis for the model named *Cellular Automata (CA)*. [5] and [6] described a collection of cells that stained on a plot (grid) with a special form that evolved through a number of discrete time steps by a set of rules based on the state of its neighbour cells. A two-dimensional CA describes cells that change their color according to the color of the adjacent surrounding cells based on certain rules [7].

One simple rule to time change of the values of a state was formulated by [8] with the following factors: *An arbitrary function that determines the rules of CA and a set of rules that indicates the value of the i^{th} state for one-dimensional CA at time step t .* The values of a state will change after an iteration in the next period in accordance with the rules given.

CA application for land-use change and urban development have been implemented by various researchers [9]. conducted a simulation of urban growth based on empirical knowledge with the idea that such simulation will follow a simple spatial rule. [10] introduced a method to analyze neighborhood characteristics of land use. [11] applied the Neural Network and the CA to describe the settlement growth. [12] simulated a land-use change by developing a model of Markov-Cellular Automata. [13] predicted the urban growth using Landsat satellite imagery based on comparison of three models: the St. Markov, CA Markov, and Markov MLP. [14] introduced the SVC (*Support Vector Machine*) which was based on the GIS cellular automata for land-use change.

Dynamic of land-use change may always take place at any time and location; due to *driving forces* factors such as population growth, economic growth, as well as influenced by physical factors such as topography, soil type, and climate [15]. Therefore, this research was designed to construct rules that may affect changes in land-use using CA model to extrapolate land-use changes by taking into account the physical factors of land that are represented by multi layers such as rainfall, elevation, slope, soil type, road accessibility, and buffer zone regulations.

II. MATERIALS AND METHODS

A. Location and Database

The research was carried out in Jeneberang sub-basin, a part of the Jeneberang Watershed South Sulawesi Province Indonesia as shown in Figure 1. Type of this research is simulation and modeling research.

Materials and tools used include: multi-temporal Landsat TM image Jeneberang catchment area (2000 – 2012), the SRTM data, data and supporting maps: Rainfall [16], RBI maps, map of land system by RePPPProT. Software includes: ArcGIS 9.3 and Arcview version 3.3 with necessary extensions, *SpaCelle* for CA simulation [9],[17],[18],[19]. ILWIS Open Source [20] for image processing, and Map Comparison Kit (MCK) version 3.2.2 for map validation [21]; [22].

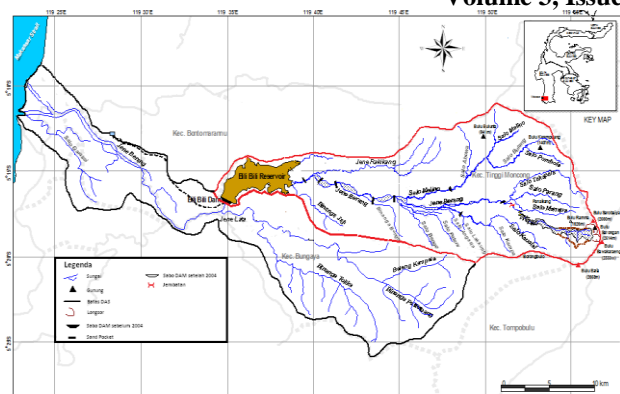


Fig. 1. Research location [16]

B. Methods

This research employed CA-simulation and modeling of spatial data in the range of year 2000 to 2012. The physical factors of rainfall, slope, elevation, soil types, buffer zones regulation and road accessibility are represented in multi-layers as spatial data. The first stage of this research was started with the generation of maps of land physical factors, namely rainfall isohyet that was analyzed using Geographic Information Systems [23] [24] based on rainfall data documented by several stations around the Jeneberang sub-basin, road accessibility and the criteria of protected areas were based on Decree of President No.32/1990 to produce the map of buffer zone regulation, slope and

elevation maps were generated by SRTM data, soil types were obtained using land system maps and field surveys, land-use interpretation from Landsat TM image from the year of 2000 to 2012 [25] [26].

The output was maps in from of grids with cell size of 30 m². The generated maps were then used as multi layers in the simulation [27] and converted to ASCII format. The simulation results were validated using the MCK program [21] [22] with Kappa algorithm [28], [29] and Fuzzy Kappa [21],[30],[31]. The results should be under categorized of good, very good or perfect to validated according to the level of accuracy of Kappa values proposed by [32].

III. RESULTS

A. The Rule of Simulation on Land-use Change

Figure 2a shows zonation of information of land-use changes that is used as a barrier layer; whereas Figure 2b to Figure 2h are multi layer of physical factors of land. This Layers are used as a reference for formulating the rules of change in the simulation program by considering the physical factors of land [7],[33],[34], regulatory factors of buffer zone, and road accessibility based on the conditions in the year of 2000 to 2012.

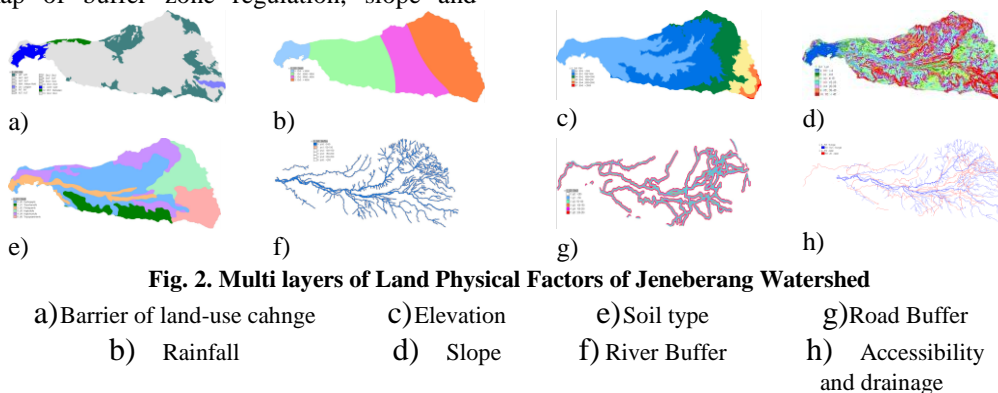


Fig. 2. Multi layers of Land Physical Factors of Jeneberang Watershed

- a) Barrier of land-use change
- b) Rainfall
- c) Elevation
- d) Slope
- e) Soil type
- f) River Buffer
- g) Road Buffer
- h) Accessibility and drainage

Using multi layers maps into the simulation program, the transition rules of land use change were formulated as: (1) First line: $S_b > K_c = PV(K_c; 8; 0.01; 1) * EV(Ch_0; 2) * ZV(Ch_1; 1) * ZV(S_bT; 1) * ZV(Lsr; 10)$, and (2) Second line: $S_b > K_c = PV(K_c; 6; 0.05; 1) * EV(S_bU; 1) * EV(Elv_1 + Elv_2; 5) * EV(jt_0 + jt_5; 3) * ZV(jt_1; 2) * ZV(S_bT; 1) * ZV(jt_6; 10) * ZV(Lsr; 20)$

The symbols of *, +, and > used in formulating the transition rules are interpreted based on [35] which is defined as follows: symbol * refers to AND, symbol + means OR, and

symbol > describes the change on type of the current spatial data to other spatial data, respectively [35].

B. Simulation of Land-use Change

Referring to Table 1, the period of 2000 to 2003 presents a difference of 6.03 ha for shrubs and -6.03 ha for mixed agriculture. Similarly, in the period of 2009 to 2012 shows insignificant differences for every type of land use.

Table 1. Difference between Simulation Result and Existing Land-use Change

Land-use	Year, area and percentage of land-use									
	2000		2003		2006		2009		2012	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00
Shrub	0.00	0.00	-6.0	-0.00	509.	1.00	-24.	-0.00	-24.	-0.00

		.00	3	.02	67	35	75	.07	75	.07
Horticulture garden	0.00	.00	0.00	0.	0.00	0.	0.00	0.	-80.	-0
Meadow	0.00	.00	0.00	0.	0.00	0.	0.00	0.	0.00	0.
Mix garden	0.00	.00	6.03	0.	-167	-0	-106	-0	-91.	-0
Rice field	0.00	.00	0.00	0.	50.9	0.	-67.	-0	-81.	-0
Residential	0.00	.00	0.00	0.	110.	0.	199.	0.	278.	0.
Bili-Bili dam	0.00	.00	0.00	0.	0.00	0.	0.00	0.	0.00	0.
Open land	0.00	.00	0.00	0.	-503	-1	0.00	0.	0.00	0.
					.55	.33				00

C. Validation Simulation of Land Use Change

Table 2 describes the employed program that contain aggregate count on the nine categories of land-use. However, the program may also generate statistical values for each category. Fuzzy Kappa, as listed in Table 2, with a value of 1,

is a type of land use that has not changed and, thus, the result of maps comparison came up with a perfect level. Whereas, the open land (Lt) was ended up with 0 in the comparison between reference map and simulation results for the year of 2006.

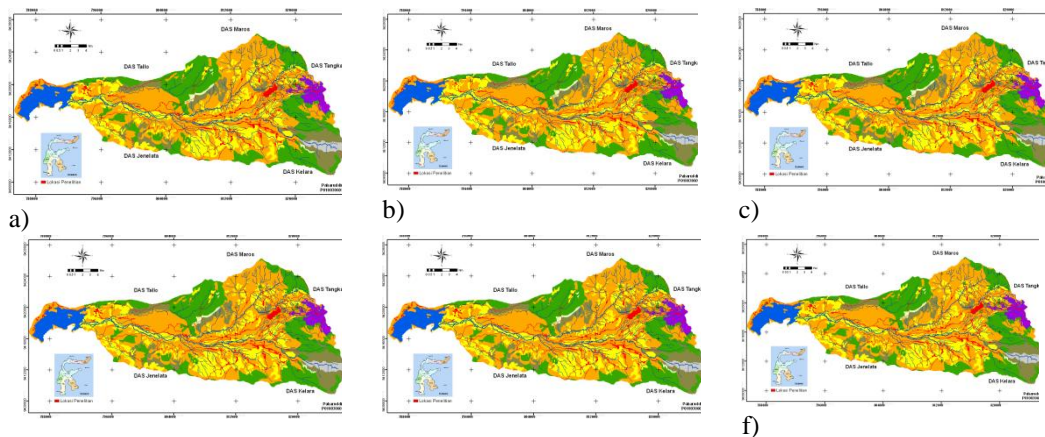
Table 2. Values of Kappa and Fuzzy Kappa, Simulation of Land-use Change based on the Category

Statistics & Land-use	Year - Fuzzy Kappa per Category of Land-use			
	2003	2006	2009	2012
Kappa	0.99902	0.97147	0.99026	0.98467
KLocation	0.99924	0.99533	0.99761	0.99476
KHisto	0.99978	0.97602	0.99263	0.98986
Fraction correct	0.99928	0.97888	0.99303	0.98888
Forest (Ht)	1	0.99999	1	1
Horticulture garden (Kb)	1	1	1	0.92853
Mix garden (Kc)	0.99646	0.98463	0.98645	0.97132
Open land (Lt)	1	0	1	1
Residential (Pm)	1	0.81145	0.90879	0.8781
Meadow (Pr)	1	1	1	1
Shrub (Sb)	0.99362	0.85774	0.98264	0.98264
Rice field (Sw)	1	0.99148	0.99449	0.99318
Dam (Wd)	1	1	1	1

D. Extrapolating the Land-use Change

In Table 3 and as spatially shown in Figure 3, it may note that each 5-year period, the type of land-use that decreased is

the mixed agriculture, whereas the residential and horticulture are increase; other types of land-use remain unchange.




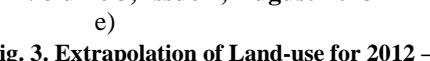
- d)  e) 
- a) Land-use changes in 2012 c) Land-use changes in 2022 e) Land-use changes in 2032
- b) Land-use changes in 2017 d) Land-use changes in 2027 f) Land-use changes in 2037

Fig. 3. Extrapolation of Land-use for 2012 – 2037

IV. DISCUSSION

This research result that formulated rules were able to developed the CA model for extrapolating the map of land-use change in year 2012-2027. The validation of geospatial simulation shows an accuracy more than 90%.

Based on the rule of simulation on land-use change, the first line refers to the current spatial data in the form of shrubs (Sb) that can be transformed into a mixed agriculture (Kc), when the proportion of existing Kc is at the distance of 8 km circle around a cell with a radius of 0.01 - 1 km, AND as far as 2 km from Ch0, AND there are no changes occurred in radius of 1 km around Ch1, AND there are no changes in radius of 1 km around the SbT, AND also no changes in radius of 10 km around the Lsr [17],[35].

The second line describes the spatial data which is currently in the form of shrubs (Sb) can be transformed into a mixed agriculture (Kc) when the proportion of existing Kc is at the distance of 6 km circle around a cell with a radius of 0.05 - 1 km, AND as far as 1 km from SBU, AND as far as 5 km from Elv1 OR Elv2, AND as far as 3 km from jt0 OR jt5 AND no changes in radius of 2 km around jt1, AND there are no changes in radius of 1 km around the SBT, AND there are no changes in radius of 10 km around jt6, AND also no changes in radius of 20 km around the Lsr [17],[35].

Results showed in part of simulation of land-use change, implies that the simulation results were not far from the real condition of the existing land-use. Contradictive result was obtained for the period of 2003 to 2006, in which, during this period, a big difference was observed between the simulation and the existing land-use; this may be due to the incidence of landslide in 2004 which strongly affected the application of the rules of land-use change in the simulation program. Normally, a syntax may be inserted into the simulation program when formulating the rules of land-use change; however, due to the fact that the landslide is a natural occurrence and it is impossible to predict the occurrence of similar incident, the factor can not be inserted.

Validation results indicates that there are no open land available in the comparison between reference map of 2006 and the simulation map of 2006 which based on the reference map of 2000.

Other land-use type which based on accuracy level of Kappa values classified by [32], was categorized at the very good level with value above 80%. These results are not much different from those obtained in the case of different [9],[17],[18],[35]. Therefore, the simulation process was followed by a 5-year period, assuming a medium-term development is conducted every 5 years starting from 2012 to 2037.

As for the extrapolation of land-use change, the increase phenomena of the residential areas is associated with the growth of structures and infrastructures, including better road accessibility. In addition, population growth also plays a significant contribution in accelerating the residential development [36]. This is confirmed by [36] which states that the rate of population growth in Gowa per year over the last ten years, i.e. from the year of 2000 to 2010 reach 2.10% [36].

Development of horticulture was found at the upstream areas of Jeneberang river, Bulutana village, Tinggimoncong subdistrict, a village near to Malino city and located on a plateau with an altitude of 2000-2500 meters above sea level. This is in line with the statement of the Head of Agriculture Department of Gowa Regency [37], that in the recent year production of vegetables from Gowa highlands reached 109,970 tons which harvested from nearly 5,000 hectares of planting area. A total of 18 kinds of horticultural commodities are grown in the highlands. Eight of these commodities are categorized as high commercial commodities, i.e. potato, fruit tomato, carrot, cabbage, green onions, green beans, tomatoes, and red pepper.

Development of vegetable production in 2010 for each commodity was also varies. Increasing commodities include onion (from 72 tons to 78 tons), beans (from 2,948 tons to 3,055 tons), tomatoes (from 1,669.6 tons to 8,616.8 tons). Other commodities such as potatoes, cabbage, mustard greens, carrots, peppers, eggplant, beans, cucumbers, kale, spinach, also increased production. While declining commodities include onion leaf (from 4,437 tons to 3,552 tons), squash (14,941 tons to 1,860.7 tons) [38].

V. CONCLUSION

The formulated rules have been proven to be successfully simulate the land-use change with results that approaching the initial conditions; this is supported by validation test that gives Kappa and Fuzzy Kappa values above 90% indicating a very good accuracy. Thus, it can be concluded that the model of CA is applicable to extrapolate land use changes from the year of 2012 to 2037.

To get a higher level of confidence towards the results of the formulation of land-use change simulation by CA model, the model needs to be tested for other sub-basins; in addition, the simulation process may also include social and economic factors and, thus, the making of change rules, with the presence of both factors, will provide more optimal results. Development of further research will be integrated in the application of land-use change associated with erosion and sedimentation class, with the result providing ease in watershed management

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Table 3. Area and Percentage of Simulation of Land-use Change in 2012 - 2037

Co de	Area and Percentage of Simulation of Land-use Change											
	2012		2017		2022		2027		2032		2037	
	Ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Ht	8.01	2	8.01	2	8.01	2	8.01	2	8.01	2	8.011	2
	1,5	1,2	1,5	1,2	1,5	1,2	1,5	1,2	1,5	1,2	,5	1,2

Sb	3.28	8	3.27	8	3.24	8	3.24	8	3.24	8	3.240	8
Kb	2,6	,7	0,0	,7	0,3	,6	0,3	,6	0,3	,6	,3	,6
Pr	638,	1	708,	1	797,	2	831,	2	841,	2	849,4	2
Kc	1	,7	8	,9	3	,1	5	,2	8	,2		,2
Sw	183,	0	183,	0	183,	0	183,	0	183,	0	183,7	0
Pm	7	,5	7	,5	7	,5	7	,5	7	,5		,5
Wd	16.3	4	16.2	4	16.1	4	16.1	4	16.0	4	16.08	4
Lt	18,0	3,2	08,4	2,9	35,3	2,7	01,1	2,6	90,8	2,6	3,2	2,6
Ju	6.81	1	6.87	1	6.79	1	6.79	1	6.79	1	6.793	1
mlah	1,2	8,0	8,3	8,2	3,4	8,0	3,4	8,0	3,4	8,0	,4	8,0
	589,	1	573,	1	672,	1	672,	1	672,	1	672,6	1
	0	,6	4	,5	6	,8	6	,8	6	,8		,8
	1.45	3	1.45	3	1.45	3	1.45	3	1.45	3	1.452	3
	2,2	,8	2,2	,8	2,2	,8	2,2	,8	2,2	,8	,2	,8
	503,	1	503,	1	503,	1	503,	1	503,	1	503,6	1
	6	,3	6	,3	6	,3	6	,3	6	,3		,3
	37.7	1	37.7	1	37.7	1	37.7	1	37.7	1	37.78	1
	89,8	00	89,8	00	89,8	00	89,8	00	89,8	00	9,8	00

Note:
Ht : Forest
Sb: Shrub

Kb : Horticulture garden
Pr : Meadow

Kc: Mix garden
Sw :Rice field

Pm : Residential
Wd: Bili-Bili dam
Lt: Open land