Spatial Model of Settlement Expansion and its Suitability to the Landscapes in Singkawang City, West Kalimantan Province

L. Lisanyoto¹, Supriatna¹, and W. Sumadio¹
¹Department of Geography, Faculty of Mathematics and Natural Science, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia

Abstract. Expansion of settlement is part of a change that happens in a land cover that occurs in a city, changes in the land cover itself occur due to a development process that happens dynamically. Singkawang City has experienced land cover changes, in 2014-2015 Singkawang City have decreased the farming area by 5.33% and a population growth of 2.67%, and from the projection of data, Singkawang’s Population will increase by 22.14% from 2015 to 2035. The purpose of this study aims to analyze the spatial pattern of settlement expansion that occurred in Singkawang city, and by using Cellular Automata Markov Chains (CAMC) it could identify the condition of settlement in Singkawang City in 2032 by model projection. This method assumes that each existing cell will represent a unique land cover and will affect each other's surrounding cells after the model have been made, the model will be overlaid with the Singkawang City landscape suitability model using Spatial Multi-Criteria Evaluation (SMCE) method. The results show that the calibrated data can be used to predict settlement expansion by 2032 and suitable landscape conditions will support the current existing expansion. Afterwards, settlement areas that are currently expanding will always be affected by geographical and development factors in the region. In the end, it is necessary to analyze between the model that has been developed with the Regional urban plan of Singkawang City to see the availability of space for the construction of settlements and buildings in a sustainable manner.

1. Introduction
The land use pattern reflects the level and orientation of community life in the region. This pattern of land use is essentially a result of a combination of historical factors, physical factors, socio-cultural factors, economics and location [1], Dwiprabowo et., al [2] refers to Koomen et al. (2007), states that land cover change is an integral part of a dynamic and complex process, which has a direct connection between the natural environment with humans and a direct impact on soil, water, atmosphere, and other global environmental issues. Land cover is one of the components of earth system that is closely related to human activity and its physical environment that forms the basic dimensions of resource and policy making [3]. This study discusses lands for settlement areas are a representation of land use settlement and its development. The City of Singkawang experienced a significant land cover changes, which was stated in Singkawang City Land Use Statistics [4] of 2015 issued by the Central Bureau of Statistics of Singkawang City, there was a change in the extent of some types of land cover within the span of a year, farming areas were decreased by 5.33% from 2014 to 2015. This led to an increase in non-farming and non-agricultural land area, which increased by 0.56% and 0.13%, respectively.

The research of Agustiono et al. [5] uses the Cellular Automata (CA) method to look for changes in the land use and obtain a pattern for predictions in the future. The simulation process performed on a CA-based model was discussed in a study conducted by Gonzalez et al. [6] which provides classical CA simulations with three stages, which are: calibration; validation and prediction. In its research, the
classical CA concept is a way to form a pattern. The purpose of this study is to identify the expansion of settlements as part of the urban growth phenomenon in Singkawang City, as in the Hai and Yamaguchi [7] studies. However, this study does not include the migration of its population as a basis of urban growth phenomenon, but only from the expansion of the settlements and built-up areas [8]. The method that is used in this study is CA, to look for the changes in settlement area and to predict its changes in the future. The research from Marko et al. [9] stated that using CA to predict land cover in the Ci Leungsii basin, the study used an independent scenario and this study also used the same scenario as used by Marko et al, in this study authors use a landscape suitable approach appropriate for settlement areas only. The authors also use the same concept of conformity as in the research conducted by Supriatna et al. [10] which uses the concept of the settlement suitability regions, using the physical landscape variables, but in this study, the social landscape variables are included as a part of the settlement suitability landscapes.

2. Methodology
This research was conducted to analyze the model of settlement expansion that resulted to the spatial and regional planning and the existing condition of the landscape, the development of the region is one of the causes why the land cover of the area is changing. The changing land cover which reduces the vegetated land area and increases the non-vegetated area. This change could be identified by the change of basic service facility in Singkawang City, the existence of this facility cannot be separated from the existing spatial and regional planning and the development of Singkawang City. In this study, there are five variables used which are: physical/geographical condition, infrastructure, land cover, policy, and landscape (figure 1).

![Figure 1. Research Diagram](image)

The process of creating the driving factors is by using fuzzy logic with fuzzy overlay technique, in which according to Zadeh (1994) [11] fuzzy logic is a logical system that aims to formalize from the estimation of reasoning represented in terms of degree of interest that has a Boolean value range (0-1).
According to Zachariah and Nizar, 2017 [12] fuzzy logic is an excellent tool for interpreting continuous data effectively and efficiently, this is a good way to model cellular automata based modeling because it uses parallel computing which consists of units (cells) that are interconnected and have continuous value. Therefore, in this study the author process the data of driving factors by using the concept of fuzzy logic. The main important thing in modeling is the accuracy, the accuracy of the model is tested using K-standard calculation (Kappa Coefficient). For calculating kappa, the value of confusion matrix will be used with ground truth image, then enter the 2017 land cover prediction on which will be validated, afterwards enter the land cover of 2017 which will be classified as ground truth image, then it will generate a file containing information about K-standard and overall accuracy of the model. The result of the simulation is expected to get kappa value> 70% (accurate). If it is not yet valid then model iteration and verification should be done at each modeling step [13].

Table 1. Driving Factors

| No | Parameters                  | Classes     | Score |
|----|-----------------------------|-------------|-------|
| 1  | Distance from coastline     | < 100 m     | 1     |
|    |                             | 100-2000 m  | 2     |
|    |                             | > 2000 m    | 3     |
| 2  | Distance from rivers        | 0-25 m      | 1     |
|    |                             | 25-50 m     | 2     |
|    |                             | 50-12000 m  | 3     |
| 3  | Slope                       | 0-3 %       | 3     |
|    |                             | 3-15 %      | 2     |
|    |                             | 15-40 %     | 1     |
|    |                             | >40%        | 1     |
| 4  | Elevation                   | 0-2 m       | 1     |
|    |                             | 2-7 m       | 1     |
|    |                             | 7-25 m      | 3     |
|    |                             | 25-100 m    | 2     |
|    |                             | 100-500 m   | 1     |
|    |                             | > 500 m     | 1     |

| No | Parameters     | Classes     | Score |
|----|----------------|-------------|-------|
| 5  | Distance from POI | < 100 m     | 4     |
|    |                 | 100-400 m   | 3     |
|    |                 | 400-1000 m  | 2     |
|    |                 | > 1000 m    | 1     |
| 6  | Distance from roads | 0-25 m     | 5     |
|    |                   | 25-50 m     | 4     |
|    |                   | 50-100 m    | 3     |
|    |                   | 100-1000 m  | 3     |
|    |                   | > 1000 m    | 1     |

Source: Modification from Arselan [14], Ozturk [15], Supriatna [10], Moghadam [16]

Figure 2. Result from Overlay of Fuzzy Driving Factors
3. Result and Discussions

3.1. Conversion of Land Cover to Settlements Areas

The conversion in Singkawang city is shown in Figure 3 that shows the land gain and losses chart over the last 15 years (2002-2017), and the result shows that the largest increase happens in settlement areas, which is 1,310 Ha. The most significant decrease occurred in a non-agricultural land cover which is 2,724 Ha, in addition to the increase of settlements and built-up area, the agricultural land cover also increased by 1,159 Ha, this is greater than the increase of open field that only amounted to 784 Ha. The largest contributor to the addition of land cover for settlements and built-up areas for the last 15 years is 780 Ha of non-agricultural land cover, followed by a decrease of 385 Ha from agricultural land cover, and an open land cover decreasing by 145 Ha (figure 4).

Figure 3. Fuzzy Driving Factors
3.2. Simulation of Singkawang City Expansion

3.2.1. Simulation one (for accuracy test)
Table 2 shows the transition probability matrix of the first simulation (2017), the numbers in these tables show the possibility of changes in land cover. If the value equals to 1, it means during the period the land cover will not change, if the value equals 0 then it means that no land cover is changed to cover the land, the higher the number the more likely it is that a land cover changes. Table 4 shows the accuracy test for the model, the accuracy test is done by using existing land cover data (in 2017) as main data for simulation 1 and the result shows in simulation one data accuracy from kappa coefficient is 97.87%. Figure 7 shows the result of simulation one (simulation for 2017).

Table 2. TPM Simulation One

|   | I    | II   | III  | IV   | V    |
|---|------|------|------|------|------|
| I | 0.9421 | 0.0197 | 0.0263 | 0.0119 | 0     |
| II| 0    | 0.9597 | 0     | 0.0403 | 0     |
| III| 0   | 0     | 0.9548 | 0.0452 | 0     |
| IV| 0    | 0     | 1     | 0     | 0     |
| V | 0    | 0     | 0     | 0     | 1     |

Landcover Details:
I: Non-Agricultural Areas
II: Open Field
III: Agricultural Areas
IV: Settlements Areas
V: Water Bodies

Table 3. TPM Simulation Two

|   | I    | II   | III  | IV   | V    |
|---|------|------|------|------|------|
| I | 0.8292 | 0.0555 | 0.0737 | 0.0416 | 0     |
| II| 0    | 0.8788 | 0     | 0.1212 | 0     |
| III| 0   | 0     | 0.8467 | 0.1353 | 0     |
| IV| 0    | 0     | 1     | 0     | 0     |
| V | 0    | 0     | 0     | 0     | 1     |

Landcover Details:
I: Non-Agricultural Areas
II: Open Field
III: Agricultural Areas
IV: Settlements Areas
V: Water Bodies

3.2.2. Simulation two (for prediction to 2032)
Table 3 shows the transition probability matrix (TPM) of the second simulation (2032), the numbers in these tables also show the possibility of changes in land cover. If the value equals to 1, it means during the period the land cover will not change, if the value equals 0 then it means that no land cover is changed...
to cover the land, the higher the number the more likely it is that a land cover changes. Figure 6 shows the expansion of settlement in Singkawang City From 2002-2032, and the result of simulation two shows in figure 8.

![Figure 6. Land Cover in Singkawang City from 2002-2032](image)

![Figure 7. Simulation Results 1](image)

![Figure 8. Simulation Results 2](image)

3.3. Settlement Expansion and its Suitability to the Landscapes

3.3.1. Suitability of Singkawang City Landscape for Settlements

To see the landscape condition in Singkawang city, this study uses two parameters, which are the shape of the terrain and Land Utilities (in Indonesia is Wilayah Tanah Usaha or WTU) figure 9, which will eventually result in landscape suitability for the expansion of settlement area of Singkawang city. Singkawang city has a diverse terrain, ranging from flat to steep mountains, the shape of the terrain itself
is composed of slope gradient parameters and elevation. The land utilities of Singkawang City is
dominated by the main WTU 1b, the concept of this business land area incorporates the parameters of the
slopes, and the altitude area that existed in Singkawang city, the result shows that in Singkawang city
still supported by the concept of land utilities. Spatially the result shows that Singkawang City is
dominated by 1 main class with function as settlement, rice field, and garden, and this is one of the
reasons for the expansion of settlements that will occur in the city of Singkawang.

**Table 4. Accuracy Test**

|       | I    | II   | III  | IV   | V    | Total |
|-------|------|------|------|------|------|-------|
| 2017  | 360.672 | 0   | 1.121 | 2.814 | 0  | 364.607 |
| 2017  | 75  | 37.613 | 0   | 239  | 0  | 37.927 |
|       | 0   | 61.077 | 990  | 0    | 0  | 62.067 |
|       | 0   | 0   | 0   | 0   | 633 |       |
|       | 364.607 | 37.927 | 62.067 | 35.726 | 633 | 500.960 |

(Overall Accuracy) $\frac{487.500}{500.960} = 97.31\%$
Kappa Coefficient (K-Standart) = 0.9787 (97.87 %)

Landcover Details:
I: Non-Agricultural Areas
II: Open Field
III: Agricultural Areas
IV: Settlements and Built-up Areas
V: Water Bodies
* The yellow shows amount of the same pixel in prediction and existing data.

The landscape suitability area for settlements in Singkawang city are divided into two classes,
which are: suitable and not suitable, to identify the landscape suitability for settlement expansion
two parameters are used which are the shape of terrain and the land utilities area, figure 10 describes
the suitability area for the expansion of settlements and built-up area in Singkawang City.

**Figure 9. Shape of Terrain and Land Utilities (WTU)**
3.3.2. Model Settlement Expansion According Landscape

Landscape in Singkawang consist of 39,398.94 Ha the areas that suitable for settlement expansion or 87.39% areas of Singkawang is suitable for settlement expansion, and from simulation two (prediction) is showed that 99.02% of settlement areas (4,967.91 Ha) in 2032 is located in the suitable areas in Landscape, and the result is shown in figure 11.
4. Conclusions

Based on the results of the modelling, settlements areas has increased in each period during the last 15 years (2002-2017). The non-agricultural land cover is the largest contributor to a land cover that is converted towards the use of settlement (in 15 years converted 780 Ha into a settlement). From the change of the pattern during the last 15 years, a modelling is done by giving the driving factor into it. The driving factors that is used is a static factor, which encourages the dynamics of the land cover, and the results show that the accuracy of the model obtains a high kappa coefficient value of 97, 87%, therefore this model has a nearly perfect model. The city landscape of Singkawang itself is dominated by a suitable area for settlements (87.34%) which is why the ease of development is based on the aspect of the landscape that exists. By 2032 the resulting expansion model has 99% accuracy on the suitability of the existing landscape (an area of 4,967, 91 Ha for settlements in the suitable landscape area).

Acknowledgments

The authors would like to thank the Department of Geography, Faculty of Mathematics and Natural Science, University of Indonesia which has facilitated the research activities through excellent research grants.

References

[1] Sandy, I. (1985). Republik Indonesia Geografi Regional. Depok: Jurusan Geografi, FMIPA, Universitas Indonesia.

[2] Hariyanto Dwiprabowo, Deden Djaenudin, Iis Alviya, and Donny Wicakson. (2014). Dinamika tutupan lahan: pengaruh faktor sosial ekonomi Daerah Istimewa Yogyakarta. Yogyakarta: PT Kanisius.

[3] George. P Petropoulos, Konstantinos G. Arvanitis, Nikolaos A. Sigrimis, Dimitrios D. Piromalis, Anastasios K. Boglou 2012 Land use cartography from hyperion hyperspectral imagery analysis; results from a mediterranean site, IEEE 24th International Conference on Tools with Artificial Intelligence 26-31.

[4] Badan Pusat Statistik Kota Singkawang 2015 Statistik penggunaan lahan kota singkawang 2015, Kota Singkawang.

[5] Ariyadi Agustiono, Sitorus, Santun R.P., Kartodihardjo, Hariadi 2014 Study of landuse change for referral of spatial pattern arrangement in the gedong wani production forest area, Lampung Province. Majalah ilmiah globe 16 59-67.

[6] Pablo Barreira Gonzalez, Francisco Aguilera-Benavente,Montserrat Gomez-Delgado 2015 Partial validation of cellular automata based model simulations of urban growth : An approach to assessing factor influence using spatial method. Environmental modelling & software 69 77-89.

[7] Pham Minh Hai, Yasushi Yamaguchi 2007 Characterizing the urban growth from 1975 to 2003 of hanoi city using remote sensing and a spatial metric. Forum Geografi 21 104-110.

[8] Cheng He Guan, Peter G. Rowe 2016 Should big cities grow? Scenario-based cellular automata urban growth modeling and policy applications. Journal of Urban Management 5 65-78.

[9] Kuswantoro Marko, Fariz Zulkarnain, Eko Kusratmoko 2016 Coupling of Markov chains and cellular automata spatial models to predict land cover changes (case study: upper Ci Leungsi catchment area) IOP Conference Series: Earth and Environmental Science 47.

[10] Supriatna, Jatna Supriatna, Raldi Hendro Koestoer, Noverita Dian Takarina 2016 Spatial dynamics model for sustainability landscape in Cimandiri Estuary, West Java, Indonesia Procedia - Social and Behavioral Sciences 227 19–30.

[11] Lotfi A Zadeh 1994 The role of fuzzy logic in modeling, identification and control Modeling, identification and control 15 191-203.

[12] Jerry Jose Zachariah, Abdul Nizar M 2017 A fuzzy classifier using continuous automata. Intl. Conference on Computing and Network Communications 269-273.

[13] Albertus Yogo Dwi Sancoko 2017 Model spasial perubahan penggunaan tanah studi kasus das komeriing, sumatera selatan. Tesis Magister Ilmu Geografi,
Program Magister Ilmu Geografi, Universitas Indonesia. Jakarta.

[14] Arselan, Ahmad 2009 Variasi penggunaan tanah pada berbagai jenis bentukan asal di Kabupaten Mandailing Natal. Skripsi Sarjana Sains, Program Studi Sarjana Geografi, Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Indonesia. Jakarta.

[15] Derya Ozturk 2017 Modelling spatial changes in coastal areas of Samsun (turkey) using a cellular automata-markov chain method Tehnički vjesnik 24 99-107.

[16] Hossein Shafizadeh Moghadam, Marco Helbich 2013 Spatiotemporal urbanization processes in the megacity of Mumbai, India: A Markov chains-cellular automata urban growth model Applied Geography 40 140-149.