Prediction of future urban growth using CA-Markov for urban sustainability planning of Banda Aceh, Indonesia

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Abstract. Banda Aceh experienced rapid growth, both physically, socially, and economically, after the Tsunami that devastated it the end of December in 2004. Hence policy controls are needed to direct the pattern of urban growth to achieve sustainable development for the future. The purpose of this paper is to generate a growth model for Banda Aceh using the CA-Markov process. By knowing the changes in land use between 2005 and 2009 from the results of previous research, simulations for 2013, 2019 and 2029 using the application of Idrisi@Selva. CA-Markov models were prepared to determine the quantity of changes. The simulation results showed that, after the Tsunami, the City of Banda Aceh tended to grow towards the coast. For the control of the LUC, the Banda Aceh City government needs to prepare comprehensive and detailed maps and inventory of LUC for the city to provide basic data and information needed for monitoring and evaluation that can be done effectively and efficiently. An institution for monitoring and evaluation of the urban landscape and the LUC should be formed immediately. This institution could consist of representatives from government, academia, community leaders, the private sector and other experts. The findings from this study can be used to start the monitoring and evaluation of future urban growth. Especially for the coastal areas, the local government should immediately prepare special spatial coastal area plans to control growth in those areas and to ensure that the economic benefits from disaster mitigation and coastal protection are preserved. For the development of the city in the future, it is necessary to achieve a balance between economic development, and social welfare with environmental protection and disaster mitigation. iIt will become a big challenge to achieve sustainable development for the future.

1. Introduction

Many cities in the world have grown in the last ten years, especially those in developing countries. This growth has resulted in the transformation of land uses and land cover changes (LUC), to accommodate the increased activity in these urban communities [1]. The transformation of land uses is a result of increasing population and the accompanying socio-economic development [2, 3, 4]. Although the growth of the city has a positive impact on the local economy, it also has a negative impact on the natural environment and on coastal ecosystems [5].

Banda Aceh has grown rapidly after the December 26, 2004, Tsunami, both physical-morphologically and commercially. Based on physical-morphological changes, the city has gone to the next step-up with its built-up area, of houses, offices, trade and services and infrastructure, which have grown about one and a half times larger than they were five years before [6]. On the other hand, the growth in the economy is shown by the increase in Gross Regional Domestic Product (GDP), which also grew about one and a half times larger in the same 5 years [6]. Likewise, the population, which is part of the socio-economic aspect [1, 7, 8, 9], has grown by an average of 1.65%/year since 2009 [6]

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and will double by 2020. This indicates that the City of Banda Aceh will continue to accommodate the needs of its people.

Having regard to the city's rapid growth, policy and control are needed in order to support sustainable development. Natural resources need to be maintained during the process of urbanization. Sustainable development is the main goal of urban researchers and decision-makers [4, 10]. Making the right policies is one of the efforts needed to control and direct urban growth.

A prediction model of urban growth can contribute to the understanding of future land use changes and make the right policies [1] to support the growth of a sustainable city. LUC change is complex, therefore some way is needed to demonstrate the potential impact of LUC change in the future [11]. A few decades ago, techniques for the detection and projection of LUC change were developed, one of them is the Markov chain [12].

2. Method

2.1. Study Area

This study is focused on the City of Banda Aceh, the capital of Aceh Province in Indonesia. The research area is located between latitudes 05°16'15" and 05^{0}36'16" and longitudes 95°16'15" and 95^{0}22'35" (Figure 1). The average elevation of the urban area is 0.80 meters above sea level, with an area about 6,136 ha and had a population about 228.562 [6]. Banda Aceh has nine sub-districts, seventy villages, and twenty urban villages. The coastal areas are located in the sub-districts of Meuraxa, Jaya Baru, Kuta Alam, and Syiah Kuala.

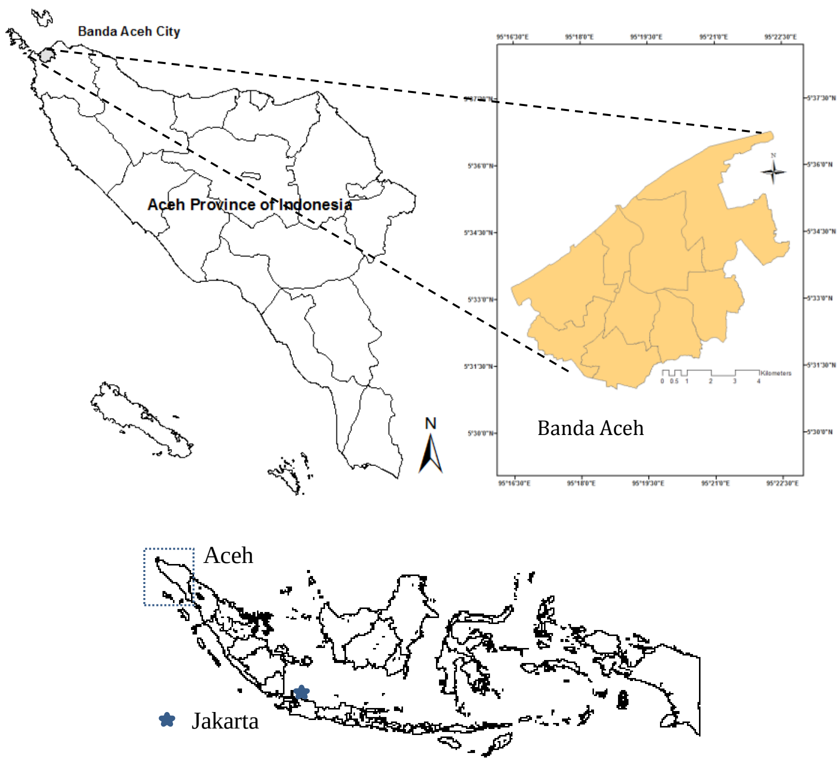

Figure 1. Location of study (see Achmad et al., 2015)

2.2. Method

Markov modules from IDRISI®Selva were used to calculate the probability of a Markov transition and to generate a transition probability matrix (in text file format). This matrix contained the numbers of pixels transitioning from one category to another category of land use, and a raster area indicated the transition areas (Markov transition areas). Markov transition probabilities were calculated from cross-tabulations using beginning LUC and end LUC. In this study, the beginning LUC is LUC 2005 and the end LUC is LUC 2009. Markov transition areas were obtained by multiplying each column representing the category of land cover in the Markov probability matrix with the number of cells of the same land cover classes in the next picture [13].

In a Markov process, the current condition of a system at time t2 can be modeled based on the previous condition, at time t1. The Markov process chain depends on the current condition [14]. The Markov Chain (MC) process produces a matrix of transition that is the transition matrix area (Table 1) and a set of conditional probability images from analysis of the two LUCs, in this study LUC 2005 and LUC 2009.

The MC models use a stochastic process, viz: a model that describes how one state changes to another state. It has a key descriptive tool, which is the transition probability matrix [15]. In a Markov process, the possibility of a change of circumstances to another condition only depends on the current condition and does not depend on how the condition is changed.

3. Results and Discussions

This study used data from previous studies, such as the LUC 2005 and the LUC 2009. LUC is classified using the ArcGIS®10.1 software. This classification is done using the maximum probability approach. The first step is to create training samples. Training for each class of cover was limited by visual interpretation [16]. About 50 samples were used for each category. Thus there were 200 total samples for each series (2005 and 2009). The next step was distilling the classifications. In this step, each sample was checked to ensure that the land categories were similar to the reference images. A majority of the filter is used as the final step in determining the best LUC.

After forming the LUC 2005 and the LUC 2009, the next step was the assessment of the accuracy. Accuracy assessment is a very important step in modeling the LUC and classification accuracy was measured in the right proportions (Estoque and Murayama, 2012a). The assessment was performed using the determination of sample points comparing them with the reference images. The stratified random sampling of points was determined by means of ERRMAT in IDRISI®Selva. The overall accuracy value was produced using IDRISI®Selva. Overall classification accuracy obtained from each LUC was 77.82% and 89.42% [7].

Qualifying results produced the maps for LUC 2005 and for LUC 2009 which can be seen in Figure 2 [7]. The results of the classification show that the undeveloped land almost doubled in area and the open space area was reduced significantly [7, 8]. The CA-Markov Simulation was done using the application of IDRISI®Selva. The results are shown in Table 2. Land use changes continue with complex dynamic processes related in time and space [18, 19]. The Markov chain model was made to determine the quantity of change while the CA model was used to allocate the possible changes that will take place, starting from the cells with the highest probability.

The simulation results showed that the conservation of the wet land was very good with a small, 10%, an increase in area. Some vacant lands to the north in Banda Aceh show that the coastal areas are areas with low density and are very suitable for development for conservation. Areas away from the city center, the center of economic activity, roads, and low-density residential areas showed little change [5, 20, 21, 22, 3, 1, 23, 9]. These areas are mainly in the eastern and southern parts of the city.

The simulation results also showed that the city was growing towards the coast. This was seen in the northwest areas of Banda Aceh. This could increase the risk of disasters when a tsunami occurs again. Only green spaces like mangroves should be provided in those areas [24, 25, 26, 27]. For that,

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discipline is important in policing all the regulations (Qanun No. 4, 2009) to ensure that the coastal areas stay as restricted areas with a very low density of population.

First, the coastal area should be used as green space so it can minimize the destructive force of Tsunami waves [24, 25]. Coastal areas, especially those that were totally destroyed in 2004, have been made low density, as mentioned in Qanun No. 4 (2009) for LUC for local area land use (RTRW) in Banda Aceh City from 2009 to 2029. These areas have become very low-density areas such as the northern, coastal parts of Meuraxa, Kutaraja and Syiah Kuala sub-districts, with planned population densities below 100 persons/ha.

Green space areas, such as mangroves can be combined with other plants as buffer zones and can be used as tourist areas (eg. a Tsunami evacuation park). The plants used can include *Cocosnucifera, Pandanus* odoratissimum, *Rhizophoraapiculata, Casuarinaequisetifolia, or Thespesiapopulnea,* and suitable bamboos for planting in coastal areas (Fig. 3). Scientific methods are needed to determine the type and structure of the vegetation that is most appropriate and most effective for protection from the Tsunami waves [24, 28]. The socio-economic conditions of local coastal communities can be increased with suitable vegetation, directly and indirectly, and community participation can be influential and important for effective development and sustainable management of coastal vegetation [24, 25]. In addition to the development of a Tsunami evacuation park, ponds for aquaculture and for recreational fishing can also be developed to improve the well-being of these coastal communities.

Table 1. Probability values and transition matrix for 2013, 2019, and 2029.

Probability	Land use category	BA	VE	WB	WL
Probability values for 2013 based on transition matrix of 2005-2009	BA	0.5244	0.3611	0.0298	0.0847
	VE	0.4086	0.3186	0.0411	0.2317
	WB	0.2127	0.2754	0.2847	0.2224
	WL	0.2222	0.3772	0.1086	0.2920
Probability values for 2019 based on transition matrix of 2005-2009	BA	0.4079	0.3675	0.0541	0.1705
	VE	0.4646	0.2795	0.0648	0.1911
	WB	0.3807	0.3283	0.0886	0.2024
	WL	0.4047	0.3437	0.0808	0.1707
Probability values for 2029 based on transition matrix of 2005-2009	BA	0.3799	0.3655	0.0658	0.1889
	VE	0.4739	0.2774	0.0650	0.1837
	WB	0.4389	0.3298	0.0548	0.1766
	WL	0.4508	0.3369	0.0647	0.1477

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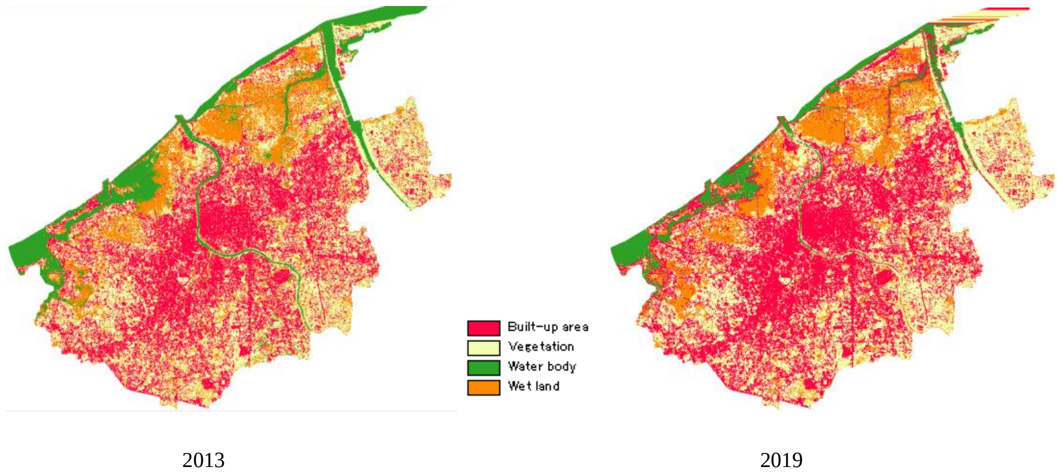

Figure 2 Simulation of LUC for 2013 and 2019

Green space areas, such as mangroves can be combined with other plants as buffer zones and can be used as tourist areas (eg. a Tsunami evacuation park). The plants used can include *Cocosnucifera, Pandanus odoratissimum, Rhizophoraapiculata, Casuarinaequisetifolia, or Thespesiapopulnea*, and suitable bamboos for planting in coastal areas (Fig. 3). Scientific methods are needed to determine the type and structure of the vegetation that is most appropriate and most effective for protection from the Tsunami waves [24, 28]. The socio-economic conditions of local coastal communities can be increased with suitable vegetation, directly and indirectly, and community participation can be influential and important for effective development and sustainable management of coastal vegetation [24, 25]. In addition to the development of a Tsunami evacuation park, ponds for aquaculture and for recreational fishing can also be developed to improve the well-being of these coastal communities.

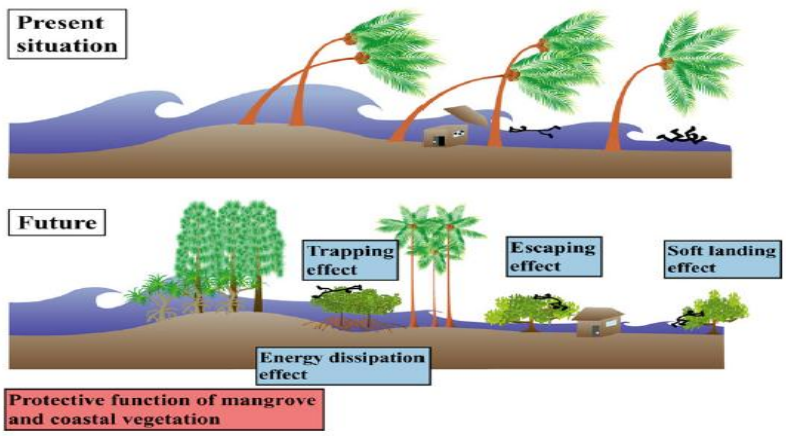

Figure 3 Vegetation functions in coastal areas (Tanaka *et al*., 2011)

The only buildings that should be allowed are offices, escape buildings, and houses of former community residents [29, 30]. This will lower the population density in these coastal areas, to make the evacuation process easier when another tsunami occurs so that casualties can be minimized. Correctly constructed access to higher ground or to an escape building should also be an important concern and these should not be too far away [31]. Communities also need to be trained to be more aware of the importance of evacuation [32]. Reconstruction must be done with a good evacuation system [31, 33].

Second, regulations for new growth should be prepared to anticipate the probability of very high growth in the city center. New growth in the city center will be relatively safe from the reach of a new Tsunami [31, 33]. Provision of wide roads and green open spaces and new centers of economic activity will encourage the growth of the city according to a plan for such new growth, particularly in the eastern and southern parts of the city. It will be necessary to remember the predictions of probability value below 0.5. The parts of the city that should be encouraged to grow to meet the needs of the future society include Lueng Bata, Jaya Baru, Banda Raya and Ulee Kareng sub-districts as well as the southern parts of Syiah Kuala sub-district.

Third, the planned location and layout of gardens and green open space in the city is also very important to support the sustainable city. The city government and land-use planners can plan a network of green open spaces connected by walking and bicycle paths with suitable land eg, along with the river banks.

If the city is planned to grow, it needs to 1) accommodate the needs of the growing population, 2) invite investment in trade and services, 3) become a tourist area that is integrated with the preservation of cultural heritage, and 4) become a city that is ecologically based on mitigating disaster in the future, where regulations must be in place to improve the quality of urban living. This will require strict regulation and careful planning for the protected and cultivated areas, the provision of open space along the coast and of green open spaces in the urban areas; controls to limit population in areas prone to Tsunami waves and to encourage the growth and development of offices, trade, and services. Finally, post-tsunami development is not only for survival from a Tsunami, it must also emphasize local knowledge and cultural traditions [29].

For the Government of Banda Aceh, this study can be a reference when revising the Spatial Plan (RTRW) for Banda Aceh from 2009 to 2029 to produce relevant city development policies, by placing greater emphasis on the conservation of the natural environment and on disaster mitigation in tandem with the development of the social economy. The city planners can make use of this research to plan for new growth areas and activities for supporting the growth of welfare of the people, by utilizing the variables driving significant growth.

From a scientific perspective, this research has contributed not only to understanding the past and the potential of the urban landscape in the future and the accompanying land use changes, but also the methods, techniques, and variables related to modeling the growth of the city and the factors driving growth. The prediction model for urban growth resulting from this study could be used as a reference for further research, especially the scenarios for urban growth to anticipate the conditions of the urban landscape as well as the results of predictions for 2029 and for land-use management, so as to get a scenario for the most effective and efficient ways to support sustainable development and also to plan for disaster mitigation.

For the control of the LUC, the Banda Aceh city government needs to do comprehensive and detailed mapping, of the present LUC to get the basic data and information needed for effective and efficient monitoring and evaluation in the future. An institution for monitoring and evaluation of the urban landscape and for LUC should be created soon, with membership from the government, academics, and community leaders. The findings from this study can be used as part of the basis for monitoring and evaluation.

For the preparation of the revised plan for Spatial and Regional Planning for Banda Aceh for 2009-2029, the Government of Banda Aceh City should consider a growth model such as that is found in this study, which integrates aspects of socio-economic and biophysical based tsunami reconstruction, to manage sustainable development in areas that are expected to develop and to protect areas that need to have restrictions put on their growth and be kept as green spaces. Especially for the coastal areas, the local government should immediately make a master plan to control growth to ensure the economic and social benefits of disaster mitigation and coastal protection.

For the development of the city in the future, it is necessary to have a balance between economic development and social welfare, and environmental protection and disaster mitigation as a vision for the future in the revised Spatial Plan of Banda Aceh. The City of Banda Aceh is a relatively small area so it will be a big challenge to manage sustainable development in the future, so the city government needs to work together with the Provincial Government and the Government of the surrounding Aceh Besar District to consider the conservation of landscape and the planning of urban development on a broader scale, which should include much of the Aceh Besar District.

4. Conclusions

For the control of LUC, the Banda Aceh City government needs to prepare a comprehensive and detailed map and inventory of the LUC of the city to provide the basic data and information needed to do effective and efficient monitoring and evaluation of LUC. Regular monitoring and evaluation of the urban landscape and the LUC can be done by a committee which can be composed of government representatives, academics, and community leaders. The findings in this study can be used as one of the inputs for the monitoring and evaluation.

In the preparation of the revised Spatial Planning and Regional Banda Aceh 2009-2029, the Government of Banda Aceh city should consider a growth model such as that which is found in this study, which integrates socio-economic and biophysical aspects for post Tsunami reconstruction, to manage sustainable development in areas that are expected to develop and to protect areas that need to have restricted growth and be kept as green spaces. Especially for the coastal areas, the local government should immediately make a master plan for these areas, to control the growth there for the benefit of disaster mitigation and coastal protection.

For the development of the city In the future, it is necessary to have a balance between, economic development with social welfare and environmental protection with disaster mitigation as the vision for the revised Spatial Plan of Banda Aceh. The City of Banda Aceh is relatively small so it will be a big challenge to manage sustainable development in the future, so the city government needs to work together with the Provincial Government and the Government of Aceh Besar District to plan the urban development and conservation of landscape on a broader scale, which can include many areas in Aceh Besar District. This is especially so since Banda Aceh is the capital city of Aceh Province and urban development based on Banda Aceh now extends seamlessly into areas of Aceh Besar that adjoin Banda Aceh, in particular, the sub-districts of Baitussalam, Kota Baru, Ingin Jaya and Pekan Bada and even as far out as the international airport at Blang Bintang.

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