Model prediction and scenario of urban land use and land cover changes for sustainable spatial planning in Lhokseumawe, Aceh, Indonesia

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Abstract. The purpose of this research is to find the best-fit scenario to support spatial planning, which can optimize the ecological function of urban areas. This study was conducted in Lhokseumawe city, a city which is the center of national activities. The city is also known as an industrial city and special economic zone. Prediction of future growth for this city needs to be done to anticipate the environmental damage that will occur. This prediction uses 2018 land use/cover (LUC) map, to get a prediction of the LUC pattern until 2032. The first stage is to create a raster map for the four variables reviewed in this research, namely a) distance to activity center (DAC), b) distance to road (DRD), c) distance to river (DRV), and d) reserve area (RAR) which are made in the form of a raster layer. The next stage is a scenario model simulation. There are two prediction scenarios assessed in this research to choose the best-fit scenario for 2032, business as usual (BAU) and reserve area interest (RAI). The results showed that the scenario should be chosen is the (RAI) scenario.

1. Introduction

Urbanization is a complex process which can lead to changes in economic, social, and cultural aspects [1]. In addition, significant changes can also occur in ecological and environmental aspects [2]. The urban area is a place where the population is concentrated, as part of the urbanization process. More than 50% of the world's population lives in urban areas, and it is estimated that it will reach 69.6% in 2050 [3]. The occurrence of urbanization is also marked by changes in the regional and urban landscape, namely land use/cover (LUC), which in the long term and uncontrolled can result in detrimental to the ecological function. Recent studies show that changes in LUC also have an effect on the emergence of an urban heat island, local climate change, and reduce the value of ecosystem services [4–6].

Lhokseumawe City, a center of national activities dominated by settlements, offices and industry, was chosen as the object of the study because of its high urbanization and unique typology of industrial cities [7]. Also, this city is a Special Economic Area (SEZ), which was established by the government...
of the Republic of Indonesia. This research was conducted to obtain the scenario best-fit for spatial planning [8], in an effort to control urban growth sustainable.

Determination of scenarios and future LUC models can assist in the management of urban expansion, change and the development of alternative plans before the transformation of land into protected areas [9][10]. Therefore, simulating future LUC growth scenarios can assist policymakers in evaluating alternative development schemes, and form the basis for urban planning policy recommendations for sustainable urban development.

Cellular Automata (CA) which is integrated with the Analytic Hierarchy Process (AHP) is used as a simulator in this study [8], in an effort to gain researchers insights regarding changes in LUC in Lhokseumawe. Until now, no simulation based on future growth scenarios for Lhokseumawe has been reported, and this research is one of the few studies that uses driving and inhibiting factors to analyze and compare based on the simulation result scenario [10–12]. In this paper, we present a scenario-based urban simulation of Lhokseumawe. The aim is to understand and predict the dynamics of urban growth in Lhokseumawe with the six LUC categories, and to assess the best-fit scenario, for sustainable spatial planning.

2. Materials and methods

2.1. Study location

Located in Lhokseumawe City, which is also a Special Economic Zone. The city which has an area of 181 km² is located at 4°-5° North Latitude and 96°-97° East Longitude. The mean surface elevation is 13 m above sea level. The boundaries of Lhokseumawe City, to the north are bordered by the Malacca Strait, to the south with Kuta Makmur District (North Aceh), to the East with the Syamtalira Bayu District (North Aceh), and to the West with Dewantara District (North Aceh) (Figure 1).

The economy of Lhokseumawe city leads to the residential, lodging, restaurant and industrial sectors [15]. This sector is increasing from year to year. The level of demand for lodging in this city is also fairly high, because it is a transit city between Medan and Banda Aceh. In addition, public and private
employees who work in Lhokseumawe City often look for lodging while on assignment, considering they come from outside Lhokseumawe City. Based on the results of the Geological research, in this city area there are excavation type C such as limestone, landfills and sand/gravel besides that, there are also natural resources in the form of natural gas. Gas processing result in the form of condensate is also utilized by the Aromatix Factory which was built in 1998 and other large companies such as fertilizer factories [7].

2.2. The data used
This study uses data for land use/cover 2018, which has been classified from the 2018 Lansat satellite imagery, obtained from [16] LUC is divided into six categories, namely 1. built-up area; 2. vegetation; 3. agriculture; 4. bare land; 5. Wetland, and 6. water body. Each LUC map has a kappa coefficient of 0.86 LUC maps for 2018 can be seen in Figure 2.

Figure 2. LUC 2018 [14]

2.3. Methods
The simulation model for predicting land use change in Lhokseumawe City from 2018 to 2032 was carried out using software LanduseSim 2.3.1 based on cellular automata (CA) [8,18,19]. Simulations using this software were also carried out by previous researchers with good results [20]. The Predictions incorporate land use or land use Lhokseumawe in 2018 as the initial land use, factors (proximity to roads, proximity to the river, and the proximity to the center of city services) and inhibiting factors (reverse area plan), the fuzzy sets value of the growth potential of land, a neighborhood filter 3x3, and progression transition map.

The first stage is to create a raster map for the four variables reviewed in this research, namely a) distance to activity center (DAC), b) distance to road (DRD), c) distance to river (DRV), and d) reserve area (RAR). RAR is an inhibiting factor, while other variables are driving factors. DAC, DRD, and DRV variables were created using the Euclidean distance tool in ArcGIS 10.1, using data on field conditions. Activity center data, apart from referring to spatial plans, is also adjusted to existing conditions. The RAR raster variable is created by converting the protected area vector data that has been defined in the spatial plan into raster form.

The next stage is a scenario model simulation. Both scenarios are predictions of growth that will occur in 2032, which is the end of the validity period of the Lhokseumawe City spatial plan. Two scenarios are compared in this study. These two scenarios, apart from being based on previous studies, are also the results of in-depth interviews with several experts related to spatial planning, as follows:
a. Business as usual (BAU) [18]; This scenario is based solely on the trend of changes that occur in the coming years, where the 2018 LUC is used as the basis for determining future predictions, using only the driving variables of DAC, DRD, and DRD.

b. Reserve area of interest (RAI); This scenario is based on efforts to provide strong protection in areas that are dominated by vegetation. In addition to the driving variable, an inhibiting variable is also applied, namely RAR.

The driving and inhibiting factor accessibility raster maps that have been converted into ASCII format in the previous stage still use the ESRI system in the simulation stage in the software LanduseSim, so that the data is converted again into raster format (.tif) with the LanduseSim system, but the difference is that there is no real value yet on this raster. Weights are processed using analysis Analytical Hierarchy Process (AHP) to obtain weight with expert considerations, namely proximity to roads (0.40), proximity to rivers (0.20), and proximity to city service centers (0.40).

Next is to form the Neighborhood Filter (NF), which is a neighbor calculation process that works on a grid system. Basically, the neighborhood system that is most commonly used is the neighborhood system with a 3x3 filter, because the system is able to accommodate the changing ability of each grid so that it has the most optimal value.

3. Results and discussion

3.1. Results

Figure 3. Raster layers of variables
Figure 4. LUC maps using the BAU scenario
Figure 5. LUC maps using the RAI scenario
There are four raster maps produced, which are the variables in this study, namely DAC, DRD, DRV, and RAR. RAR is an inhibiting factor, while other variables are driving factors. The results of making this raster can be seen in Fig. 3.1. (a) is a raster visualization of the distance to activity center variable calculated in meters. The different colors in the image indicate the distance of each pixel to the city center, in case the locations of the activity centers in the Lhokseumawe City area. This variable is a continuous variable.

Figure 3 (a) is a raster visualization of the distance variable to locations that are centers of economic activity, which are calculated in meters. The different colors in the image show the distance of each pixel to the closest centers of economic activity. Determination of the center points of economic activity is based on Qanun no. 4 of 2009. This variable is a variable continuous.

Figure 3 (b) is a raster visualization of the DRD variable, both arterial and collector roads, which are calculated in meters. The different colors in the figure show the distance of each pixel to the nearest road line. This variable is a variable continuous. Figure 3.1 (c) is a raster visualization of the variable distance to the river, which is calculated in meters. The rivers chosen are large rivers that divide the city of Lhokseumawe. The different colors in the figure show the distance of each pixel to the nearest river line. This variable is a variable continuous.

Whereas in Figure 3.1 (d), you can see a raster visualization of the tightly controlled area variable, namely RAR. This distance is also calculated in meters. The different colors in the image indicate the distance of each pixel to the shoreline and this variable is a variable continuous.

The simulation results using BAU and RAI scenarios in 2032, produce a LUC map as can be seen in Figure 4 and Figure 5. A comparison of the two scenarios can also be seen in Figure 6 and Figure 7, which describes the quantitative. The built-up area has the same increase, in both scenarios in the period 2018 to 2032. The percentage of increase that occurs is 19.55%.

In the vegetation category, there are different predictions of widespread change. In the BAU scenario, vegetation experiences a wide decline each year, which at the end of the predicted year, 2032, is only 46.25%. In the RAI scenario, a vegetation is used as a reserve area variable, so that there is no change or decrease in the area again, still 48.85% of the total area of the city. Likewise with the water body, which in the RAI scenario is included in the reserve area, so that it does not experience a change in area, where the area remains as in 2018, which is 3.023 ha.

The bare land category also experienced broad declines in both scenarios. In the 2018-2032 period, the broad decline in the BAU scenario reached 11.67%, while in the RAI scenario a drastic reduction in area reached 25.95%. The area of bare land in each scenario is 1.81% and 1.51% of the total area of Lhokseumawe City.

In the agriculture category, the simulation results also show the differences between the two assessed scenarios. In the BAU scenario, the agriculture area decreased by 1.27%, while in the RAI scenario, the area of this category decreased by 5.92%. The decrease in area also occurred in the wetland category, both in the BAU and RAI scenarios. The BAU scenario simulation shows that the wetland category decreased by 18.33% and 35.06% in the 2018–2032-time frame.

3.2. Discussion

Based on the two prediction scenarios that have been analyzed, it shows that the city has experienced a change in the LUC pattern in the 2018-2032 period. The growth of the built-up area continues. This happened because the population was still increasing, which also triggered an increase in buildings to accommodate additional community activities. The BAU scenario shows the future urban growth will run without any control [9,22], which is only triggered by driving factors, namely DAC, DRD, and DRV. The RAI scenario shows the growth of the future city, apart from the driving factor, also includes an element of control, where there is an area that is used as a reserve area.

Under the BAU scenario, many vegetation will disappear in the future and urban areas will occupy 29.19% of the area in 2032 [9,23]. Using the RAI scenario, by maintaining a reserve area, vegetation can be maintained up to 3,580 ha. In the BAU scenario, the built-up area develops using vegetation land, while in the RAI scenario, the built-up area uses bare land and wet land in its development. In the water
body category, each scenario gave similar results. In fact, the use of this BAU scenario can maintain a water body area of up to 72 ha. Under the BAU scenario, the LUC agriculture category can be saved as much as 803 ha compared to the simulation results in the RAI scenario. The same condition is also experienced by LUC in the wetland category. The BAU scenario can save the wetland category by up to 26.19% compared to the RAI scenario.

![Figure 6](image1.png)

**Figure 6.** Area of each LUC category in the BAU scenario

![Figure 7](image2.png)

**Figure 7.** The area of each LUC category in the BAU

In each scenario, there are land categories that decrease and increase in size. The built-up area category has significantly increased, while the vegetation category has decreased. This is caused, among other things, by the increase in population and activities. If it is based on the value of ecosystem services [24,25], the greatest value is on forests, which in this study are categorized as vegetation. Even though wetland can be saved in the BAU scenario, using the principle of ecosystem service value (ESV), the
The RAI scenario is considered the best-fit scenario, because forests in this study are categorized as vegetation are designated as the largest ESV [26].

The results of this scenario prediction will be able to guide and support urban planners to make sound policies to achieve sustainable development. The RAI scenario also directly protects limited land resources and promotes sustainable development, by increasing ESV [27]. This study provides a design and methodology in implementing predictive scenarios and presents an approach to analyzing future urban growth patterns with the aim of producing a sustainable spatial plan, and determining the best-fit scenario as a direction and regulation [28,29]. Further quantitative analysis, considering both ESV and other methods, as well as comparisons with other scenarios, needs to be continuously studied.

4. Conclusion
The use of CA with its transition rules allows for future urban growth scenarios to be generated, which in this study predicts to be carried out until 2032. Assessment of land use change in the coming year is carried out in two scenarios, namely BAU and RAI. The BAU scenario eliminates a lot of vegetation land categories, while under the RAI scenario, it removes a lot of wet land and bare land. Because the largest ESV is in the vegetation category, in order to achieve a sustainable spatial plan, the RAI scenarios are selected best-fit. The use of Geographic Information System (GIS) and Remote Sensing (RS) in this study is effective in producing predictive models for LUC growth scenarios, which assesses the LUC dynamics and associated LUC changes driving factors.

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