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Modeling of urban growth in tsunami-prone city using logistic regression: Analysis of Banda Aceh, Indonesia

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ABSTRACT

The urban development of Banda Aceh, Indonesia was very rapid after the tsunami in 2004, posing critical challenges in planning for its future sustainable development. Scientifically-derived information about its land change patterns and the driving factors of its rapid urbanization might provide vital information. However, the spatio–temporal patterns of its urban land use/cover (LUC) changes have not been examined. Hence, this study aims to: (1) detect and analyze the spatio–temporal changes in the urban LUC of Banda Aceh between 2005 and 2009; and (2) examine the driving factors that influence urban growth. The 2005 and 2009 LUC maps were derived from remote sensing satellite images using a supervised classification method (maximum likelihood). Both LUC maps contained four categories, namely built-up area, vegetation, water body, and wet land. The 2005 LUC map had an overall accuracy of 77.8%, while the 2009 LUC map had 89.4%. The two LUC maps were re-classed into two categories (i.e. built-up area and non built-up area) to facilitate logistic regression analysis. A total of seven variables or potential driving factors of urban growth were identified and examined, including two socio-economic factors (population density and distance to central business district) and five biophysical factors (distances to green open space, historical area, river, highway, and coastal area). The results showed that the LUC of Banda Aceh has changed drastically between 2005 and 2009, particularly its built-up area, which increased by 90.8% (1016.0 ha) at the expense of the other LUC categories. The socio-economic factors showed positive influence to the growth of the city, whereas the biophysical factors showed negative effect, except the distance to coastal areas. The importance of the findings for future landscape and urban planning for Banda Aceh is discussed.

Introduction

In terms of socio-economic environment, cities change rapidly. Throughout the last decade, many cities in the world have experienced growth, especially in developing countries. This growth is characterized by the transformation of land use/land cover (LUC) to accommodate the increased activity of the city (Yu & Qingyun, 2011). This transformation is caused by an increasing population and economic development (Bounoua et al., 2009).

Banda Aceh, a city affected by the tsunami in 2004, has also experienced growth, both in physical-morphological and economic conditions. Concerning physical-morphological change, the city has undergone a surge in built-up area for residential construction, office buildings, infrastructure, trade, and other urban services, which has increased one-and-a-half times in the past five years. The city has also been expanding economically. One important indicator is the Gross Domestic Product (GDP), which is currently five times greater than in 2000. Similarly, the population has been increasing at an average annual rate of 1.65% since 2009 and is expected to double by 2020. This diverse growth shows that the city of Banda Aceh will continue to grow to accommodate the needs and activities of society.

The tsunami that hit Banda Aceh on December 26, 2004, had a tremendous impact on the city and left badly damaged buildings, infrastructure, and LUC, particularly in the coastal areas. The activities undertaken during the rehabilitation and reconstruction

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period (2005–2008) focused on reconstructing buildings and damaged infrastructure, capacity building and community empowerment, economic activities, and other related social, economic, and cultural agendas. The rehabilitation and reconstruction activities in the regions affected by the tsunami should be a good starting point to structure a sustainable city. These activities optimize the construction of new growth centers that support environmental sustainability, historical preservation, and the mitigation of earthquakes and tsunamis. Urban growth must be controlled so that the city will achieve sustainable development goals.

Sustainable urban growth is a strategic issue in achieving a better quality of life by improving the quality of the urban environment. Through sustainable urban growth, future generations can meet their needs by implementing appropriate urban policies and strategies (Setioko, Pandelaki, & Murtini, 2012). Thus, sustainable development cannot be separated from land use and the potential of existing resources for human development goals and society. As a concept, sustainable development is a response to the challenges that face urban areas, such as globalization, decentralization, and rapid population growth (Rasoolimasnesh, Badarulzaman, Jaafar, 2011).

One way to promote sustainable urban growth is through appropriate policies. To formulate appropriate policies that support urban expansion, we need a growth model that considers the mechanisms of change in LUC (Yu & Qingyun, 2011). Geographic Information Systems (GIS) can facilitate and accelerate the process of urban growth analysis (Musaoglu, Tanik, & Kocabas, 2005). Although urban LUC is a complex system and a challenge for science and practice, GIS-based modeling can measure and visualize the potential trends and spatial patterns of future urban growth (Allen & Lu, 2003). In this research, GIS will show the LUC change in Banda Aceh from 2005 to 2009. This study will also build a model and predict the future potential change patterns in LUC. GIS is also used to assist national and local governments to store and manage large amounts of geographic information (Murayama & Thapa, 2011). Predictions of future urban growth scenarios are made to better understand the dynamics of urban development and to support landscape and urban planning (Hui-Hui, Hui-Ping, & Ying, 2012).

This study (1) detects and analyzes the spatio-temporal changes in the urban LUC of Banda Aceh between 2005 and 2009, (2) examines the driving factors that influence urban growth, and (3) predicts LUC in the year 2029. The year 2029 was chosen because of Banda Aceh's Spatial Plan Regulation 2009–2029. This study contributes to urban development planning for disaster-prone cities by providing information regarding the land changes in Banda Aceh. This information is vital to government officials and urban planners in their planning efforts, particularly in determining the development activities that support sustainable growth for the welfare of the community. Simulations of future urban growth and an associated environmental assessment can help policy makers in evaluating alternative development schemes and can form the basis of policy recommendations for the urban planning of sustainable urban development (Zhang, Ban, Liu, & Hu, 2011).

Materials and methods

Study area

This study focuses on the administrative region of Banda Aceh in the Province of Aceh, which has an area of 61.36 km^2. Geographically, this location is between latitude 05°16′15'–05°36′16″ and longitude 95°16′15″–95°22′35' (Fig. 1). The average altitude of the urban areas is 0.80 m above sea level. The population of Banda Aceh is 255,243 (2012), which is distributed over nine districts and 91 villages. The area is almost uniformly flat.

Banda Aceh, which is the capital of the Aceh Province, has been experiencing rapid infrastructure growth since a tsunami destroyed much of the urban area at the end of 2004. Many landmarks, both old and new buildings, decorate this historical city. The increasing infrastructure growth has not aligned with activities that effectively support the environment. Approximately half of the study area was damaged by the tsunami in 2004. The population just after the tsunami in 2004 was 177,881.

Land use/cover mapping and change detection analysis

The data that were used in this research are satellite imaging (Quickbird satellite images) as the primary data and socio-economic information as the secondary data. Quickbird satellite images were obtained from the Regional Planning Board of Banda Aceh. All images were geometrically registered to the Universal Transverse Mercator (UTM46N) coordinate system. The socio-economic data, such as population statistics, were obtained from the Central Bureau of Statistics of Aceh. LUC was interpreted from the satellite images of Quickbird for 2005 and 2009, which have a 0.6 m × 0.6 m resolution with 19,192 × 17,772 pixels. The satellite images have three bands, whereas the socio-economic data, such as population statistics, were used as secondary data. The population data were obtained from the 2009 population based on "Aceh in Figure 2010".

In this study, the land was divided in four categories concerning the urban area of Banda Aceh that were not used for agricultural purposes, namely, the built-up area, vegetation, water body, and wet land. The built-up area includes building structures, such as houses, pavement, bridges, and roads (Estoque and Murayama, 2012a; Karolien, Anton, Maarten, Eria, Paul, 2012). Vegetation includes trees, cropland, and undeveloped land. Water body includes seas and rivers, whereas wet land includes fish ponds and land that is saturated with water. For the logistic regression, both LUC 2005 and LUC 2009 was merged into two categories, namely, the built-up and non-built-up areas (Hu & Lo, 2007; Karolien et al., 2012; Liao & Wei, 2012). The built-up area was not merged. Vegetation and wet land were merged into a non-built-up area. There were "no data" (not defined) regarding the water body persisting in the future.The changing of the land category was conducted by the reclassification tool in ArcGIS® 10.1.

LUC was classified using ArcGIS® 10.1 software. This classification used supervised classification with a maximum likelihood approach. The first step was to create training samples. Training sites for each cover class were delimited through a visual interpretation (Karolien et al., 2012). Approximately 50 samples were derived for each category. There were 200 samples overall for each image (2005 and 2009). The next step was to refine the classifications. In this step, each sample was checked to insure that the land categories were similar to the reference image. A majority filter tool was used in the last step to determine each LUC to find a better LUC.

After forming LUC 2005 and LUC 2009, the next step was accuracy assessment. Accuracy assessment is very important in LUC modeling, and its overall accuracy classification is measured by the correct proportion (Estoque & Murayama, 2012b). To assess the accuracy of LUC 2005 and LUC 2009, the images of 2005 and 2009 were used as references because they were relatively clear and could be used in the assessment process. The assessment was conducted by determining the sample points that were compared with reference images. The stratified random sampling points were determined by the ERRMAT tool in IDRISI® Selva. The overall accuracy value was produced in IDRISI®Selva.