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SPATIAL MODELLING OF LANDSCAPE AND LAND COVER PATTERN AT SEMARANG CITY

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Abstract: Semarang City is one of the largest city in Indonesia. Tidal flooding at the coast and landslide at the hills, are the issues the city currently dealing with as a side effect of land conversion. The study on spatial pattern and its change of landscape/land cover is important for a better understanding in environmental management at this city. Landsat images from 1996, 2003 and 2016 and landscape indices were used to analyze landscape/land cover pattern and its change. Binary Logistic Regression and GIS were used to build a mathematical and spatial modelling of landscape/land cover change using driving factors. Land cover change mostly happened to shrubs that turned into mixed crops at 1996-2003; while at 2003-2016, it happened to agriculture that turned into settlements. Landscape indices shows that the highest land utilization and land fragmentation with high mixing and diversity mostly occurred at elevation 25-100 MASL at 1996-2003; and at 2003-2016, it occurred at elevation 100-500 MASL. Spatial modeling of landscape/land cover at Semarang City can explain 61,98% from its actual condition. Elevation has the strongest significance relation to the landscape/land cover change.
Keywords: Landscape Indices, Land Cover, Spatial Modelling, Binary Logistic Regression

A. Introduction

Landscape is the result of numerous processes that operate and interact across different spatial and temporal scales (Synes et al. 2016). Landscape provides a various kind of services that are beneficial to human life (Kristensen 2016). According to the European landscape convention (2000), there are two major classes when talking about landscape: (1) natural landscape; and (2) anthropic landscape. Anthropic landscape being planly represented by the urban landscape (Gavrilidis et al. 2016). Urban landscape is continous interaction between human and nature and its ecological process (Wu et al. 2013). The process of human activity on landscape can be seen through landscape patterns (Luck an Wu 2002). Understanding the landscape patterns must be complemented by an understanding of the processes that shaped these landscape patterns (Liu et al. 2010).

Landscape patterns can be described by size, shape, arrangement and distribution of individual landscape element (Markuszewska 2013) and Landscape Indices can measure it. Landscape indices are part of the landscape studies to describe the spatial arrangement of land use (Geoghegan et al. 1997). It has been proven that Landscape Indices can measure the influence of human activities on the landscape (O'Neill et al. 1988). Landscape indices can be used to quantify the spatial pattern (composition and configuration) of land cover features (Long et al. 2010).

Semarang City is one of the fifth-largest metropolitan cities in Indonesia. Population Cencus 2010 shows that Semarang City had the largest population in Central Java. Population of the city keeps increasing from time to time (BPS Kota Semarang 2016). The study conduct by Ismanto et al. (2009) shows that from 2001 to 2007, Semarang City experienced massive changes in land use because of the population growth. Another study conducted by Maiyudi (2012) shows that the north coastal region of Semarang City experienced rapid growth of facilities and infrastructures compared to the other regions of the city.

Land use/land cover changes in Semarang City had lead to environmental problems. Based on survey conducted by Directorate of Environmental Geology and Mining Areas at 1996-2001, land subsidence was detected at coastal areas of Semarang City (Abidin 2016). Ismanto et al. (2009) concluded that the rate of land subsidence at coastal areas of Semarang City varied from <1 cm/year to 14,2 cm/year. Land subsidence occurred in the Semarang City led to other problems such as flooding and sea water intrusion. The result of a study conducted by Suhelmi (2012) shows that land subsidence play the important role in an expanded area of tidal flooding at the coastal areas of Semarang City.

The impact of land use changes also occurred at the hilly area of south Semarang City. Land use change from conservation to settlement led to landslide (Ridlo 2016). Based on data from the Regional Disaster Management Agency (BPBD) of Semarang City, in a period of 6 months (from January to June) 2016, Semarang City experienced 20 landslide (Purba et al. 2014). Bigger impact will occur including the decreasing of the landscape function if those environmental issues at Semarang City are not addressed properly.

One of the method that can be propose to address those issues is studying Semarang City based on its landscape. Landscape has become one of the key themes for environmental and territorial sustainability, concerning environmental, cultural and social matters (Gavrilidis et al. 2016). Along with this, mandatory of Semarang City Regional Spatial Planning 2011-2031 directing that the spatial use of Semarang City had to be done by taking account the ecological function.

This study examines the spatiotemporal changes in landscape and land cover pattern at Semarang City. Landscape/land cover pattern and change at Semarang City cannot be separated from its local characteristic such as physical, socioeconomic and environment. Anlysis of landscsape/land cover pattern and change with its local characteristic requires an evaluation scenario in order to create the effective policy recommendations. Therefore, the analysis will be strengthened by statistical analysis using logistic regression. A spatial-mathematical model of landscape/land cover change using driving factors will be build for this study as an evaluation scenario at Semarang City. The study on the landscape/land cover pattern and its changes is essential for the monitoring and assessment of the city. It provides better understanding in what formed the city as a whole system including its physical, social, cultural and environment. Thus studying landscape help to reach sustainable land management.

Semarang City is known by its elevation diversity. As a unit analysis, Semarang City divided into 4 (four) different region: (1) elevation of 0-25 MASL which is susceptible to land subsidence; (2) elevation of 0-25 MASL which is not susceptible to land subsidence; (3) elevation of 25-100 MASL; an (4) elevation of 100-500 MASL.

The first step of this study, authors learned land cover pattern and its change from 1996-2003 and 2003-2016 at Semarang City. In order to get the land cover pattern, the authors has to extract land cover information from satellite imagery and then classified the image to land cover classes. Land cover informations of 1996, 2003 and 2016 were extracted from Landsat 5 TM for 1996, Landsat 7 ETM+ for 2003 and Landsat 8 for 2016 using ENVI 5.1. National Standard Land Use Classification System For Small and Middle Scale (SNI Number 7645-1:2014) was used to classified land cover at Semarang City. Field data were collected to assist land cover classification.

The second step of the study was to learn landscape pattern and its change. For this step, the authors measured landscape using Landscape Indices. Four Landscape Indices such as PLAND (Percent of Landscape), PD (Patch Density), LPI (Largest Patch Index) and SHDI (Shannon's Diversity Index) were used to measured land cover of 1996, 2003 and 2016 at class and landscape level using FRAGSTAT 4.2. Landscape, as defined by Forman (1995), composed on three elements: (1) patch; (2) corridor; and (3) matrix. Patch is relatively homogenous area, which is different from its surroundings; meanwhile corridor is linear element, a network of linear elements, which usually connect patches; and matrix is the background of landscape (Markuszewska 2013).

Percent of Landscape (PLAND) equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage). PLAND approaches 0 when patches in a land use/land cover become increasingly scarce in the landscape, and 100 if the entire landscape consists of only one patch of the same type. PLAND at class level:

$$PLAND = P_i \frac{\sum_{j=1}^{n} a_{ij}}{A}(100) \qquad (1)$$

P_i = proportion of the landscape occupied by patch type (class) i

a_{ij} = area (m^2) of patch ij

A = total landscape area (m^2)

Patch Density (PD) equals the number of patches in the landscape, divided by total landscape area (m^2), multiplied by 10.000 and 100 (to convert to 100 hectares). PD at class level:

$$PD = \frac{n_i}{A}(10{,}000)(100) \qquad (2)$$

n_i = number of patches in the landscape of patch type (class) i

A = total landscape area (m^2)

Meanwhile PD at landscape level:

$$PD = \frac{N}{A}(10{,}000)(100) \qquad (3)$$

N = total number of patches in the landscape

A = total landscape area (m^2)

Largest Patch Index (LPI) equals the area (m^2) of the largest patch in the landscape divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage). LPI quantifies the percentage of total landscape area comprised by the largest patch. LPI at class level:

$$LPI = \frac{\max_{j=1}^{a}(a_{ij})}{A}(100) \qquad (4)$$

a_{ij} = area (m^2) of patch ij

A = total landscape area (m^2)

Meanwhile LPI at landscape level:

$$LPI = \frac{\max(a_{ij})}{A}(100) \qquad (5)$$

a_{ij} = area (m^2) of patch ij

A = total landscape area (m^2)

Shannon's Diversity index (SHDI) equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by the proportion. SHDI equals to 0 when the landscape contains only 1 patch (no diversity). It increases as the number of different patch types increases and/or the proportional distribution of area among patch types becomes more equitable. SHDI at landscape level:

$$SHDI = -\sum_{i=1}^{m}\left(p_i \ln p_i\right) \qquad (6)$$

P_i = proportion of the landscape occupied by patch type (class) i

The third step was learning the relationship between landscape/land cover changes and its driving factors. Driving factors used for this study were elevation, slope, land subsidence, population density, land ownership, land price, street density, drainage density, and distance from city center. For this step, authors processed the driving factors spatial data using ArcGIS 10.2. Several driving factors used for this study has to be proceeded and classified. Elevation and slope were extracted from DEM SRTM 2014 and classified using 3D Analyst tool based on Wilayah Tanah Usaha (WTU) by Sandy (1995). There are six classification for elevation and slope based on WTU:

(1) Limited I (elevation 0-7 MASL and slope 0-3%); (2) Primary Ia (elevation 7-25 MASL and slope 3-8%); (3) Primary Ib (elevation 25-100 MASL and slope 8-15%); (4) Primary Ic (elevation 100-500 MASL and slope 15-25%); (5) Primary Id (elevation 500-1.000 MASL and slope 25-40%); and (6) Limited II (elevation >1.000 MASL and slope >40%). Population density were classified to 3 classes: (1) Low; (2) Medium; and (3) High. Street and drainage density were obtained using kernel density estimator. Distance from city center using Euclidian distance method. The result of street density, drainage density and distance from city center were spatial data in a raster format with a cell size of 30 metres.

The fourth step was building mathematical model of landscape/land cover change by its driving factors using Logistic Regression. In statistic, logistic regression is used to predict the probability of an event (Agresti 2002). The logit model has been widely applied, including in study of land use/land cover change. The model is able to analyse the factors that contribute to changing land use and can estimate land use ratios so that it can be used to predict changes in land use (Carolita et al. 2003).

In this study, we use Binary Logistic Regression. Binary logistic regression is used to find the relationship between response variable (*y*) which is binary or dichotomous with the predictor variable (*x*) which is polycotomous (Hosmer and Lemeshow, 2000). The outcome of the response variable y consists of two categories, namely "success" and "failure" which is denoted by *y*=1 (success) and *y*=0 (failed). The mathematical model used is as below:

$$p(x) = \frac{e^{\left(\beta_0 + \sum_{k=1}^{p} \beta_k x_k\right)}}{1 + e^{\left(\beta_0 + \sum_{k=1}^{p} \beta_k x_k\right)}} \qquad (7)$$

In this study, landscape/land cover changes were response variables (*y*), meanwhile physical, socioeconomic and environmental factors are explanatory or predictor variables (*x*). For the response variable (*y*), landscape/land cover which changes were denoted by *y*=1, meanwhile landscape/land cover which did not changes denoted by *y*=0. The explanatory variables/predictors (*x*) were physical factors which presented by elevation (x_1) and slope (x_2); socioeconomic factors presented by population density (x_3), land status (x_4) and land value (x_5); and environmental factors presented by distance from the city/district center (x_6), street density (x_7) and drainage density (x_8).

The fifth step was building spatial model of landscape/land cover change. For this step, authors integrated the mathematical model with GIS by applying the concept of map algebra to produce spatial landscape/land cover predictions. The predictor variables were substituted in the equation of mathematical model. This substitution will produce a map of the landscape/land cover change's probability.

B. Land Cover Change

In 1996, natural land cover such as shrub had the largest area of the city (15,55%). The others are settlement/mix buildings (12,50%), wetland seasonal crops (12,01%) and mixed gardens and plants (9,83%). In 2003 settlement/mix buildings dominated the city (20,39% of the total area of the city). The others are mixed gardens and plants (18,14%), wetland seasonal crop (13,48%) and shrubs (11,05%). In 2016, settlement/mixed buildings became the most dominating land cover (34,15%). The others are wetland seasonal crops (14,93%), dryland seasonal plants (10,47%) and mixed gardens and plants (7,69%).

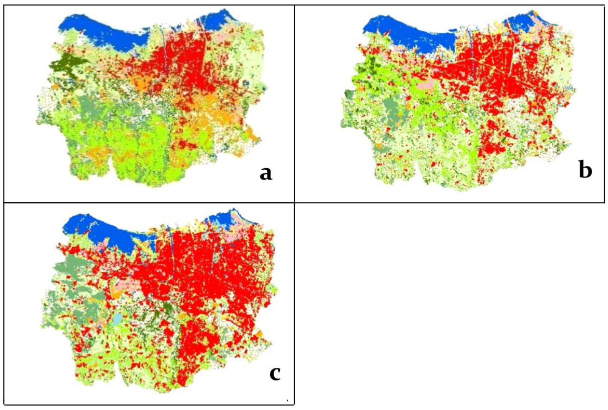

Figure 1. (a) landcover in 1996; (b) landcover in 2003; (c) landcover in 2016. Source: Authors, 2017

Based on Figure 1 (a), in 1996, the northern coast of the city was dominated by ponds and wetland seasonal crops. Settlement/mixed buildings dominated the central part of the city and then spread along the main street until reach the southern part of the city. Dry seasonal crops are common in the southeast and western part of the city. Meanwhile the southern part of the city heading to Mount Ungaran is dominated by bushes and shrubs. Based on Figure 1 (b), in 2003, the northern coast area of the city was dominated not only by ponds and wetland seasonal crops, but also non-settlement buildings and settlement/ mixed buildings. Settlement/mixed buildings can be seen clustered in the central part of the city and spread along with the main roads, from the western to the eastern part of Semarang City, and from the northern to the southern part of the city. Natural land cover such as forests and shrubs are found in the western part of the city. Agricultural land cover is generally located in the southern and eastern parts of the City. From Figure 1 (c), in 2016, northern part of the city was dominated by setllement/mixed buildings and non-settlement buildings. Settlement/mixed buildings takes part in the central and western part of the city completely. Land cultivated area such as plantations, wetland seasonal crops, dry-land seasonal crops, and mixed gardens and plants are generally spread in the western to the southern part of the city. Natural land cover such as shrubs can be found in the southern part of the city.

During period of 1996-2003, the biggest change in land cover occurred in shrubs that turned into mixed gardens and plants. These changes were more directed to the south, towards the hills. While during the period of 2003-2016, the most significant changes occurred in mixed plantations and wetland seasonal crops into setllement/mixed buildings. In both periods, the coastal areas and the lowlands or downtown did not experience significant changes. The map of land cover change can be seen in Figure 2.

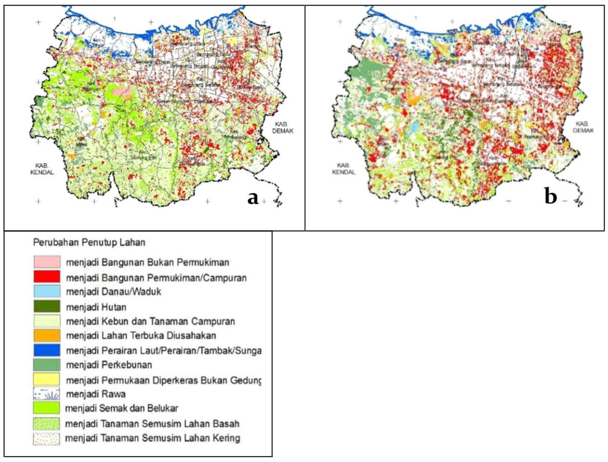

Figure 2. (a) landcover changes during period 1996-2003; (b) landcover changes during 2003-2016. Source: Authors, 2017

C. Landscape Indices

Landscape indices at landscape level shows that in 1996 and 2003, at 25-100 MASL, PD and SHDI the highest value, meanwhile LPI has the lowest value. This indicates that in 1996, there were many patches of small size with a high degree of mixing and diversity as well as a more balanced distribution at 25-100 MASL compared to the other three regions. While in 2016, this happened at 100-500 MASL. The distribution of Landscape Indices represented by the value of PD, LPI and SHDI in 1996, 2003 and 2016 can be seen in Figure 3.

Landscape indices as presented by PLAND at class level as shown at Figure 4, shows that in 1996, at coastal part where the land subsidence happened, the city was dominated by agricultural land cover; at 0-25 MASL, was dominated by urban land cover; and at 100-500 MASL, was dominated by natural land cover. In 2003, settlement/ mixed buildings were the most dominant land cover in the city, except at 100-500 MASL where mixed gardens and plants were the most dominance. In 2016, the entire part of the city was dominated by setllement/mixed building. From all the measuring landscape with Landscape Indices, we can condluce that there are intensive land activity by humans during period 1996-2003. It occurred especially at 25-100 MASL as reflected from the division of land into smaller and complex shapes, and higher level of mixing and diversity. While during period 2003-2016, this occurred at 100-500 MASL.

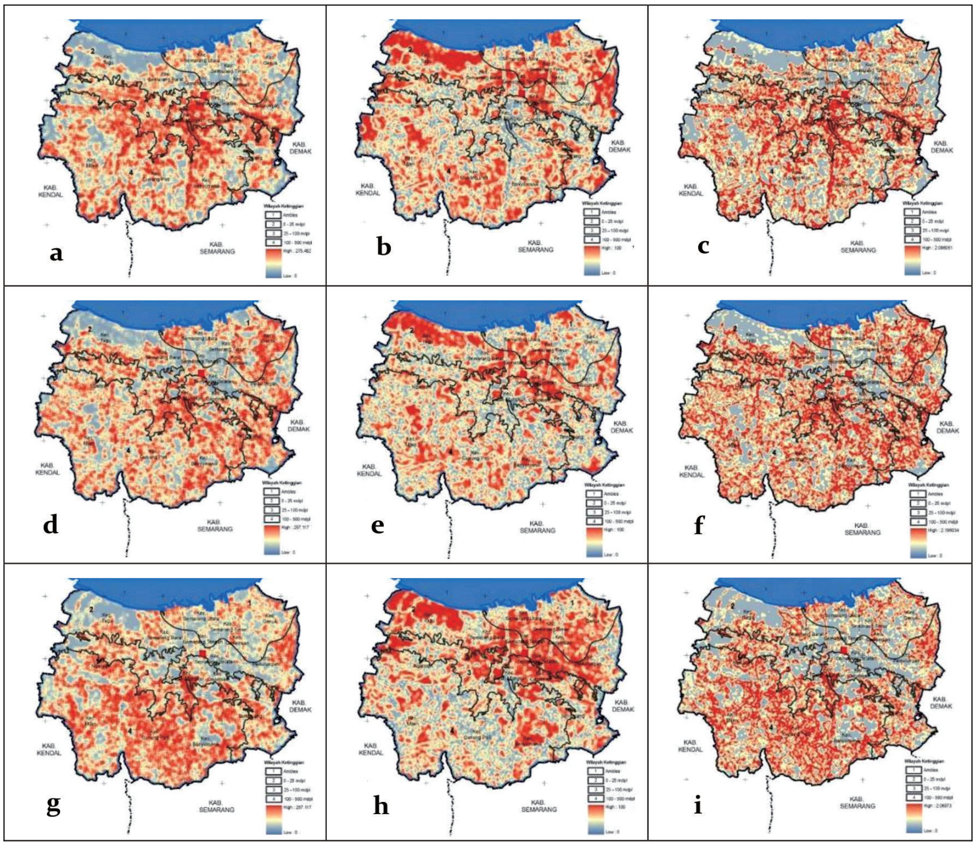

Figure 3. (a) PD in 1996; (b) LPI in 1996; (c) SHDI in 1996; (d) PD in 2003; (e) LPI in 2003; (f) SHDI in 2003; (g) PD in 2016; (h) LPI in 2016; (i) SHDI in 2016. Source: Authors, 2017

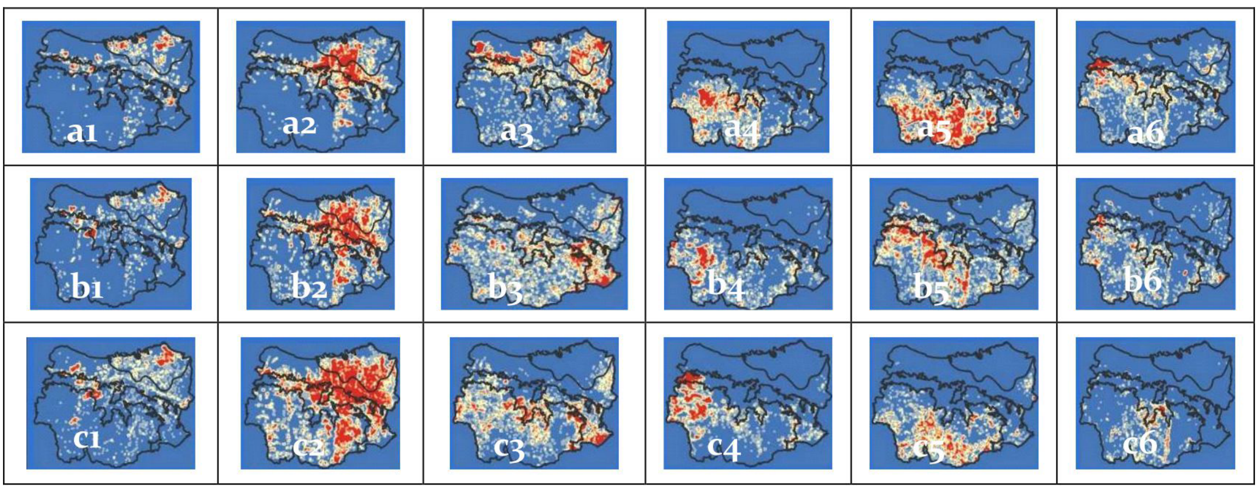

Figure 4. Spatial distribution of PLAND at class level in (a) 1996; (b) 2003; (c) 2016 For (1) non-residential buildings; (2) residential/mixed buildings; (3) wetland seasonal crops; (4) garden and mixed plants; (5) shrubs; and (6) forest. Source: Authors, 2017

D. Spatial Modelling of Landscape and Land Cover Pattern

Mathematical model of landscape/land cover change at Semarang City was build from its driving factors such as elevation, slope, land subsidence, population density, land ownership, land price, street density, drainage density, and distance from city center. From the mathematical model, we got the mathematical equation for each driving factor which integrated with GIS. Cross tabulation between landscape/land cover change actual condition (during period 1996-2016) with landscape/land cover change mathematical-spatial model shows that the accuracy of the model was 61,98% (Figure 5b). The model best applied at 100-500 MASL. This shows that the driving factors were more accurate to explain landscape/land cover change at 100-500 MASL. Figure 5c shows landscape/land cover change for each unit analysis, red means 'change' and blue means 'not change'.

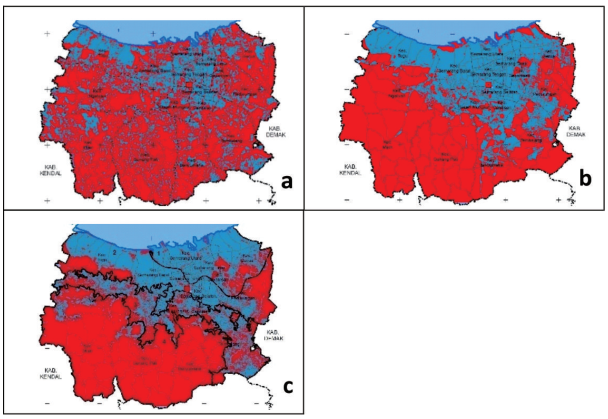

Figure 5. (a) Landscape/Landcover actual change; (b) Model 1; (c) Model 2
Source: Authors, 2017

Overall, the driving factors has significant correlation to landscape/land cover change. The factor that most influenced the landscape/land cover change is elevation. The probability of landscape/land cover change is higher if it was in a higher place of the city (100-500 MASL), flat slope (0-3%), high density of roads and rivers, low land price (<Rp. 1.000.000,-), land ownership is Usage Rights on Land (Hak Pakai) and Building Rights on Land (Hak Guna Bangunan), high population density, and far from the city center.

Study on landscape/land cover change cannot be separated from socio-economic factors, such as population density. According to Sandy (1995), the population and their livelihoods are things that are determinants in the pattern and direction of land use/land cover trends in an area. Furthermore, Sandy (1995) explained that the population generally gathered around flat slope with good water availability. In urban areas such as Semarang City, areas with high population density are found around the city center. However, changes in landscape and land cover are more common in hilly areas far from the city center. In these regions, many businesses still use land for agriculture. As for the downtown area, the low land use change is due to land limitations. This also explains that the distance from the city center seems not too significant to explain landscape/land cover change in Semarang City.

Other factors such as land ownership and land price are factors that cannot be ignored in the study of urban landscapes and land cover. According to Afanador (2016), there is a significant relationship between landscape structure and land ownership. Research conducted by Wear and Flamm (1993) concludes that land use activities on public land are less intensive when compared to land owned owned by individuals. In Semarang City, the probability of landscape/land cover change tends to be higher in land status in the form of Usage Rights on Land (HP) dan Bilding Rights on Land (Hak Guna Bangunan). While Government Regulation No. 40 of 1996 concerning Cultivation Rights on Land (HGU), Building Rights on Land (HGB) and Usage Rights on Land (HP) confirms that the right must be used in accordance with the purpose of granting such rights. So that the probability of change in these types of rights tends to be lower. Based on land parcel data, Usage Rights on Land (HP) have an area around 1.61% of the total area of Semarang City. And 52% of the total area of Usage Rights on Land (HP) in the city of Semarang is in the altitude of 100-500 MASL. And of these areas, 87%

experienced changes in land use/land cover. The most extensive changes is the changes into settlement/mixed building. Based on this, special attention is needed in the land management, particularly in the management of Usage Rights on Land (HP) in Semarang City.

E.Conclusion

Based on its unit analysis, Semarang City had a various land cover at 1996, meanwhile at 2003 and 2006, land cover become more uniform. In the period of 1996 to 2016, land at Semarang City become more fragmented with high levels of mixing and distribution among land covers. It happened mostly at 25-100 MASL at 1996-2003 and at 100-500 MASL at 2003-2016.

Spatial model of landscape and land cover pattern at Semarang City is best applied at 100-500 MASL. The most significant factor that influencing the model is elevation. Based on the model, the highest probability of landscape and land cover pattern happened at high and flat areas, relatively high density of rivers and roads, high population density, land status in the form of Use Rights and Building Use Rights, low land values, and relatively far distance from the city center.

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