SPATIAL MODELING OF LAND USE / LAND COVER CHANGES FOR FLOOD HAZARD ANALYSIS ON PADDY FIELDS AND THEIR IMPACT ON RICE PRODUCTION

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ABSTRACT

Almost in every rainy season some parts of Indonesia face the same problem that is flood disaster. Floods continue to recur from year to year, suspected as a natural disaster caused by human activity. The contribution of each factor to floods in different regions will be different; one important factor is the change in land use associated with paddy fields. Rapid environmental changes such as population growth will require food, shelter, clean water and so on. The 2010-2015 population growth rate of 1.37% or the population grew 6.86% from 2010. Population growth and the development of industrial areas, increasing the need for housing, roads and industrial infrastructure that encourage the conversion of agricultural land for land use/land cover purposes other. The use of Markov chain analysis method in spatial modeling of land use/land cover change informed decreasing of paddy field and widening of settlements or industrial estates. The expansion of settlements and industrial areas has reduced the area of wetland from 51.41% in 2015 to 45.81% in 2031. The objective of this study is to implement spatial modeling of land cover changes and flood hazard analysis that can occur in paddy fields as well as its impact on rice production.

Keywords: decreasing, flood hazard, karawang, Markov, paddy fields.

1. INTRODUCTION

Population growth in Karawang regency averaged (r) 1.37% per year, with the standard consumption of rice is 98.5 kg / capita / year (BPS, 2016) resulted in increasing demand for rice. One of the geospatial-based alternative approaches is remote sensing techniques whose analysis results provide information on changes in agricultural land use, identification of flood area and food production estimates.

The development of industrial area related to Presidential Decree No. 53 of 1989 about industrial area was directed to Karawang regency, as the starting point for the expansion of settlements and industrial estates, increasing the need for housing, roads and industrial infrastructure that encourage the conversion of agricultural land for land use/land cover purposes other. The use of Markov chain analysis method in spatial modeling of land use/land cover change informed decreasing of paddy field and widening of settlements or industrial estates. The expansion of settlements and industrial areas has reduced the area of wetland from 51.41% in 2015 to 45.81% in 2031. The objective of this study is to implement spatial modeling of land cover changes and flood hazard analysis that can occur in paddy fields as well as its impact on rice production.

Analysis of land use change performed with overlay method between thematic map in 2000, Landsat image in 2006 and Landsat image in 2015. The basic thematic map was compiled from the result of land cover extract from topography map of year 2000. Landsat image in 2006 was used as basis for updating map of 2000, resulting a thematic map in 2006. Landsat images in 2015 were analyzed by Normalized Difference Vegetation Index (NDVI) and The Tasseled Cap Transformation (TCT) methods. To recognize wetland as an indication of flood hazard areas, the Topographic Wetness Index (TWI) method was used. TWI was processed using TerraSAR-X DSM data. Flood hazard maps covered with land cover thematic maps will provide information on flood hazard areas in paddy fields that will have an economic impact on farmers. The Markov method was used to calculate the projection of wetland degradation up to 2031. The purpose of this study is to analyze changes in land use/land cover and the floods hazard that can occur in paddy fields and possibly result in the loss that will occur.
2. MATERIAL AND METHOD

2.1 Study sites

The study was conducted in Karawang Regency which located at Longitude 107º02’-107º40’ East and 5º56’-6º34’ South. Location of the study shown in Figure-1. Morphology of Karawang regency in the form of lowland with an average of air temperature 27 ºC, it has variation of slope region between 0% to 2%, 2% to 15% and a small part with slope above 40%. Elevation of the northern region between 0 to 25m msl, and a small part of the southern region with an elevation of 26m to 1200m msl and an annual mean rainfall of 728 mm (BPS 2016).

![Figure-1. Research location map.](image)

2.2 Materials

Materials used in this study include Topographic map scale 1:25.000 published 2000, Landsat TM Image Year 2006, Landsat 8 OLI Year 2015, DSM TerraSAR-X in 2011 and statistics. The software used in this study were Microsoft Office, Global Mapper, ER Mapper, Idrisi, Ilwis dan ArcGIS.

2.3 Methods

Statistics data obtained from Central Bureau of Statistics Karawang regency and the spatial data were collected by sharing from Geospatial Information Agency (Topographic map in 2000 and DTM TerraSAR-X in 2011), downloading Landsat TM in 2006 and Landsat-8 images in 2015 from http://glovis.usgs.gov/. Land cover analysis were carried out to determine the land cover area in 2000, 2006, and 2015. The land cover data were analyzed using NDVI (normalized difference vegetation index) enhancement and TCT (The tasseled cap transformation) methods. The flood hazard areas were identified using TerraSAR-X DSM data with the TWI (The topographic wetness index) method. TWI analysis describe an area with flood hazard potential or an area with flood potential that can be assumed to have a high probability of flooding (Riadi et al. 2017). Projected future land cover changes are made with the predicted changes in the present approach through spatial modeling (Figure-2). The prediction model uses CA-Markov, to predict future land use changes of 16 years or in 2031 by simulating land cover changes (Eastman 2009). The degradation of paddy fields resulted in the decreasing of rice production that can be calculated based on existing wetland area multiplied by productivity (6.9 tons / ha).

2.4 Data analysis

2.4.1 Projected population

Based on data of population in 2010 - 2015, it can be seen that the average population growth rate during 5 years (2010 - 2015) is equal to 1.37%. With the value of \( r \) an average of 1.37% using the Geometric Method (BPS, 2016) projected population growth in the following years can be calculated, with the following formula:

\[
P_t = P_0 \left(1 + \frac{r \cdot t}{100}\right)
\]

Explanation:
- \( P_t \) = Number of residents in the final year
- \( P_0 \) = Population in the base year (2015)
- \( t \) = Time period (e.g.: \( t = 2031 - 2015 \))
- \( r \) = Population growth rate (1.37 %)

![Figure-2. Flow chart of research methods.](image)

The needs of population consumption of rice per year can be calculated by using the formula:

\[
KK = SK \times Pt
\]

Conversion of grain to rice is 62.74% (BPS, 2016)

\[
KG = \frac{KK}{100/62.74}
\]

Explanation:
- \( KK \) = Needs of rice consumption of the population
- \( SK \) = Standard consumption (kg/capita/year)
- \( Pt \) = Population year (Projected population t year)
- \( KG \) = Grain Consumption

2.4.2 Land used/land cover changes analysis

The land cover thematic maps was extracted from topographic maps of 1: 25,000 scale in 2000, this thematic map used as and initial reference for spatial analysis. The Landsat TM imagery was analyzed to update the basic thematic maps, resulting in a 2006 land cover map.

Landsat-8 Image Record data on October 18, 2015, performed an enhancement process by transforming...
From topography map extract, it is found that the area of Karawang regency is 191.577 hectares with rice for Landsat 8.

The Topographic Wetness Index (TWI) method, which is derived data generated from DEM data under steady state-using flow accumulation and slope function (Chapman et al. 2005). The Topographic Wetness Index is a wetness index determined from the previously calculated surface variables with the following equation:

\[ TWI = \ln \frac{\alpha}{\tan \beta} \]  

Where: \( \alpha = \text{Flow Accumulation} \) and \( \tan \beta \) are slopes.

In general, the delineation result of boundary areas of flood hazard need to be generalized by conducting selection, simplification, merging, and magnification. Selection is done for objects that need to be eliminated and/or combined, because they do not meet geometry specifications or do not fit into the classification of elements that can be displayed on the map scale. Selection is done by removing and/or aggregating segments of polygon at least 0.5 mm x 0.5 mm (BIG 2014). To recognize the flood hazard areas overlay NDVI and TCT maps with TWI maps, will show the distribution of flood hazard areas. Criteria of high flood hazard areas are in the area of the flooding frequency occurring each year, inundation height over 70 cm (>70 cm) and flood duration of more than 7 days (>7 days).

3. RESULTS

3.1 Population growth in Karawang regency and rice consumption need

The population growth of Karawang regency averages 1.37% per year with rice production in 2015 is 1,489,429 tons. The population of 2015 is 2,273,579 people with rice consumption of 98.5 kg / capita / year (BPS, 2016) the need for rice to be 223,947 tons or equivalent to 356,945 tons of grain requirement. Thus, in 2015 the grain surplus in Karawang regency is 1,489,429 tons minus 356,945 tons, which is equal to 1,132,484 tons equivalent to 710,520 tons of rice. Projected population growth until 2031 using Formula 1. The population of 2015 is 2,273,579 people with rice consumption of 98.5 kg / capita / year therefore there is an increase in wet area information that may indicate a flood hazard area (Buchanan et al. 2014). DSM TerraSAR-X is analyzed by Topographic Wetness Index (TWI) method, which is derived data generated from DEM data under steady state-using flow accumulation and slope function (Chapman et al. 2005). The Topographic Wetness Index is a wetness index determined from the previously calculated surface variables with the following equation:

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2.4.4 Identification of flood area

TerraSAR-X signals have sensitivity to wet areas, thus there is an increase in wet area information that may indicate a flood hazard area (Buchanan et al. 2014). DSM TerraSAR-X is analyzed by Topographic Wetness Index (TWI) method, which is derived data generated from DEM data under steady state-using flow accumulation and slope function (Chapman et al. 2005). The Topographic Wetness Index is a wetness index determined from the previously calculated surface variables with the following equation:

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3.2 Land used/land cover change

From topography map extract, it is found that the area of Karawang regency is 191.577 hectares with rice...
field area of 120,371 ha (62.83%) in 2000 (Figure-3). Landsat TM image analysis for topographic map update obtained information on rice field area 112,878 (58.92%) at 2006 (Figure-4), more details are presented in Table-1.

Landsat-8 Image Record data on October 18, 2015, an enhancement process was performed by transforming the Normalized Difference Vegetation Index (NDVI) and Tasseled Cap Transformation (TCT) spectral values, NDVI giving vegetation land cover (Figure-5) and TCT giving local indication information wetland.

The result of transformation process of spectral value with Tasseled Cap Transformation (TCT) gives three bands created are commonly held to represent Brightness, Greenness and Wetness. Transformation of multi-temporal color composite (RGB) values can separate the fields of rice fields with non-visible rice fields (Figure-6). Blue color associated with water, red color associated with open area, settlement, dry land, open land. For green color associated with vegetation. Table-1. Shows the results of the analysis, states that the decrease in wetland area from 2000 to 2015. Existing wetland area of 98,462 hectares (year 2015).

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Area ha</th>
<th>%</th>
<th>Area ha</th>
<th>%</th>
<th>Area ha</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field, open area</td>
<td>18,805</td>
<td>9.82</td>
<td>15,064</td>
<td>7.66</td>
<td>22,563</td>
<td>11.78</td>
</tr>
<tr>
<td>Plantation</td>
<td>5,414</td>
<td>2.83</td>
<td>13,640</td>
<td>6.56</td>
<td>11,725</td>
<td>6.12</td>
</tr>
<tr>
<td>Settlement</td>
<td>20,301</td>
<td>10.60</td>
<td>18,757</td>
<td>9.79</td>
<td>25,611</td>
<td>13.37</td>
</tr>
<tr>
<td>Forest</td>
<td>7,038</td>
<td>4.11</td>
<td>5,218</td>
<td>2.72</td>
<td>5,814</td>
<td>3.03</td>
</tr>
<tr>
<td>Ponds</td>
<td>4,484</td>
<td>2.34</td>
<td>12,184</td>
<td>6.36</td>
<td>20,839</td>
<td>10.88</td>
</tr>
<tr>
<td>Waterbody, swamp</td>
<td>14,325</td>
<td>7.48</td>
<td>13,836</td>
<td>7.22</td>
<td>1,311</td>
<td>0.68</td>
</tr>
<tr>
<td>Rice fields</td>
<td>120,371</td>
<td>62.83</td>
<td>112,878</td>
<td>58.92</td>
<td>98,462</td>
<td>51.41</td>
</tr>
<tr>
<td>Industrial area</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5,223</td>
<td>2.73</td>
</tr>
<tr>
<td>Total Area</td>
<td>191,577</td>
<td></td>
<td>191,577</td>
<td></td>
<td>191,577</td>
<td></td>
</tr>
</tbody>
</table>

Source: Spatial analysis
3.3 Land use/land cover modeling

To predict changes in land use/land cover in the next few years is done by modeling CA-Markov. The result of spatial modeling of land cover changes 2015 (Figure-7). Was validated by linear regression to measure whether the Markov modeling results correlated with existing land cover or not (Table-2).

Table-2. Relationship between modeling results with land cover existing.

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Existing 2015</th>
<th>Result Markov 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area ha</td>
<td>%</td>
</tr>
<tr>
<td>Settlement, others</td>
<td>53,426</td>
<td>14.36</td>
</tr>
<tr>
<td>Plantation</td>
<td>11,725</td>
<td>6.12</td>
</tr>
<tr>
<td>Forest</td>
<td>5,814</td>
<td>3.03</td>
</tr>
<tr>
<td>Ponds</td>
<td>20,839</td>
<td>10.88</td>
</tr>
<tr>
<td>Swamp</td>
<td>1,311</td>
<td>0.68</td>
</tr>
<tr>
<td>Rice fields</td>
<td>98,462</td>
<td>51.41</td>
</tr>
<tr>
<td>Total</td>
<td>191,577</td>
<td></td>
</tr>
</tbody>
</table>

Source: Spatial analysis

Markov land cover modeling correlation resulted in a R square value of 0.9772 or 97.72% (Figure-8), it states if Y significantly affects X.

Figure-8. Linear regression of spatial modeling.

For further modeling for land cover change up to 2031 (Figure-9). The variables used in this prediction are settlement, built up area, open area and rice field, up to 2031 the remaining wetland area is 45.81% (88,007 ha) (Table-3).

Table-3. Predicted land cover change up to 2031.

<table>
<thead>
<tr>
<th>Land Cover</th>
<th>Markov 2015</th>
<th>Predicted Markov 2031</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area ha</td>
<td>%</td>
</tr>
<tr>
<td>Settlement, others</td>
<td>61,007</td>
<td>31.75</td>
</tr>
<tr>
<td>Plantation</td>
<td>4,357</td>
<td>2.41</td>
</tr>
<tr>
<td>Forest</td>
<td>8,697</td>
<td>4.66</td>
</tr>
<tr>
<td>Ponds</td>
<td>24,107</td>
<td>12.64</td>
</tr>
<tr>
<td>Swamp</td>
<td>303</td>
<td>0.16</td>
</tr>
<tr>
<td>Rice fields</td>
<td>93,107</td>
<td>48.38</td>
</tr>
<tr>
<td>Total</td>
<td>191,577</td>
<td></td>
</tr>
</tbody>
</table>

Source: Spatial analysis

3.4 Identification of flood hazard areas

The flood hazard area analysis is done by integrating the spatial modeling data of TWI with historical data of flood events. The historical data
parameters of flooding in paddy fields consisting of the frequency of flood events, the average height of the puddle, and the average length of the inundation in the overlay by giving the attributes of each parameter in accordance with its influence. The TWI map is overlaid on the TCT map, indicating that the flood hazard in Karawang regency occupies the rice fields area (Figure-10).

From the analysis results, areas with high flood hazard with an area of 7,489 ha (7.61%), moderate flood hazard level 19,188 ha (19.49%) and low flood hazard with 1,689 ha (1.72%). The level of flood hazard shows that the danger of flooding in paddy fields is 71.19% of land is at non-vulnerable level. Flood incidents recorded each year result in crop failure and decreased production of rice crops in Karawang regency (Riadi et al. 2017).

Figure-10. Flood hazard map.

Flood incidents recorded each year caused in the crop failure and a decline in rice crop production in Karawang regency (Table-4).

Table-4. Inundation area, crop failure area, productivity and loss of harvest.

<table>
<thead>
<tr>
<th>Year</th>
<th>Inundation area (ha)</th>
<th>Crop failure area (ha)</th>
<th>Productivity ton/ha</th>
<th>Loss of harvest ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>12.462</td>
<td>6.346</td>
<td>5.968</td>
<td>37.873</td>
</tr>
<tr>
<td>2011</td>
<td>1.722</td>
<td>1.952</td>
<td>6.042</td>
<td>11.794</td>
</tr>
<tr>
<td>2012</td>
<td>3.254</td>
<td>6.175</td>
<td>5.846</td>
<td>37.853</td>
</tr>
<tr>
<td>2013</td>
<td>7.677</td>
<td>4.547</td>
<td>6.156</td>
<td>27.991</td>
</tr>
<tr>
<td>2014</td>
<td>11.550</td>
<td>7.700</td>
<td>5.953</td>
<td>45.838</td>
</tr>
<tr>
<td>2015</td>
<td>1.574</td>
<td>415</td>
<td>6.448</td>
<td>2.676</td>
</tr>
<tr>
<td>2016</td>
<td>10.272</td>
<td>810</td>
<td>6.448</td>
<td>5.223</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

Changes in rice fields in Karawang from 2000 to 2015 decreased by 21,909 ha. In this area there are areas with high flood hazard with an area of 7,489 ha, medium flood hazard 19,188 ha. Every year the average loss of rice production due to floods reached 24,178 tons. Predicted until 2031, the paddy field will experience a reduction and leave 88,007 ha, while the population increases 2,826,579 people. Assuming fixed rice production, and the population continues to increase, flood harvest failure always occurs. In the next few years the need for rice for Karawang regency can still be fulfilled but the surplus of rice for the national food stock needs will decrease.

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We Would like to thank the Geospatial Information Agency for assistance Terra SAR-X DTM data, topographic maps and USGS Website for the ease of data access Landsat and The Faculty of Geo-Information Science and Earth Observation (ITC) for open source ILWIS 3.8 software and All parties who helped in this study, so this article can be resolved.

REFERENCES


