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Research Title : Wetland Change Prediction Using Markov Cellular Automata Model in Lore Lindu National Park Central Sulawesi Province, Indonesia

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Time : 13.00 – 14.00
Place : Classroom A, MIT Building – SEAMEO BIOTROP Jl. Raya Tajur Km 6, Bogor
WETLAND CHANGE PREDICTION USING MARKOV CELLULAR AUTOMATA MODEL IN LORE LINDU NATIONAL PARK
CENTRAL SULAWESI PROVINCE, INDONESIA

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ABSTRACT

Lore Lindu National Park (LLNP) is located between 119°90' - 120°16' East and 1°8' - 1°3' South and administratively, located in Poso District and Donggala District, in Central Sulawesi Province, Indonesia. Topographically, Lore Lindu National Park has two enclaves: Lindu Enclave (13.093 ha) and Besoa Enclave (5.085 ha). Lindu enclaves have high growing socio-economic activities that can threaten Lore Lindu National Park as a tropical rainforest that requires the stability of rainforest margin area. If agricultural and built up area (settlement area) in Lindu enclaves is always increase every years then the water availability to support Lore Lindu National Park will decrease so the stability of rainforest becomes worst. Wetland as ecological component is important to be maintained, monitored and modeled to support the stability of rainforest margin area. Therefore, Wetland change prediction is needed to predict what will happen in the future. The objectives of this research are: 1) to identify the threatening factors affecting the wetland area in Lindu Enclave area & Lindu Lake, 2) to predict the changes of wetland area in Lindu Enclave area & Lindu Lake using Markov Cellular Automata Model.

Land cover 1983 from aerial photography, Landsat TM 2002 and 2006 are used as the spatial model data. Image correction is also performed in order to acquire well ground spatial estimation. Afterward, markov chain is used to get rate value per years of wetland change area in Lindu area. Multicriteria evaluation for wetland area created with soil map, topography map, and land cover map as the variables for suitable wetland area criteria that will be used in cellular automata model. Finally, markov chain probability values for each class and multicriteria evaluation map is merged with cellular automata model with 3 x 3 cell neighbors analysis then spatial wetland change prediction map for 2021 can be created.

The results of this research show that Lindu enclaves have two wetland types; natural wetland (marsh and bush land) and construction / man - made wetland (paddy field and fish pond). The changes of wetland area in Lindu enclave area for natural wetland (marsh) was - 66.01 hectares (1983-2002) with – 0.1 % annual change rate and 343.94 hectares area for human made / construction wetland area (paddy field) with 1.0 % annual change rate. The suitable area for wetland was located in every enclave area, however the most suitable area was located at the Southern part of Lindu enclave area. The prediction of spatial distribution for natural wetland area in 2021 will disappear with an annual change rate of -0.1 %. However, human made wetland such as paddy field area has increased to 1,729.06 hectares in 2021 with 0.7 % annual change rate.

Keyword: Lore Lindu National Park, Lindu Enclaves, Wetland, Markov Cellular Automata Model

1 The paper is a part of master thesis, submitted for seminar and examination of MIT Program
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1. Introduction

1.1 Background

Lore Lindu National Park (LLNP) is located between 119°00' - 120°16' East and 1°8’ - 1°3’ South and administratively, located in Poso District and Donggala District, in Central Sulawesi Province, Indonesia. Topographically, Lore Lindu National Park has two enclaves: Lindu Enclave (13.093 ha) and Besoa Enclave (5.085 ha). Lindu enclaves have high growing socio economic activities that can threaten Lore Lindu National Park as a tropical rainforest that requires the stability of rainforest margin area. If agricultural and built up area (settlement area) in Lindu enclaves is always increase every years then the water availability to support Lore Lindu National Park will decrease so the stability of rainforest becomes worst. Wetland as ecological component is important to be maintained, monitored and modeled to support the stability of rainforest margin area. Therefore, Wetland change prediction is needed to predict the changes in the future using Markov Cellular Automata Model.

1.2 Objectives

The main objectives of this research are as follows:
- To identify the threatening factors affecting the wetland area in Lindu Enclave area & Lindu Lake
- To predict the changes of wetland area in Lindu Enclave area & Lindu Lake using Markov Cellular Automata Model

1.3 Research Questions

- Where are the spatial distributions of the wetland area in 1983 and 2002 classification map?
- How big the changes occurred to the wetland area in Lindu Enclaves & Lindu Lake from 1983 until 2002?
  - Where are the suitable wetland community areas in Lindu Enclaves?
  - Where are the predicted spatial distributions of wetland area in 2021 and how big the rate of the changes will occur from 2002 until 2021 in Lindu Enclaves?

2. Literature Review

2.1 Wetland

2.1.1 Definition of Wetland

Wetland definition given by (Cowardin 1979) meets “lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water”. This definition includes a higher range of possible habitats than other classification systems that use with two basic criteria: vegetation and soil. The following figure 1 is the natural wetland area (marsh) in Lindu Enclaves area.
Types of Wetland

In trying to categorize the wide range of wetlands encompassed by the Ramsar definition, Scott (1989) defined 30 groups of natural wetlands and nine man made ones. However, for illustrative purposes it is possible to identify five broad wetland systems:

- **Estuaries**: where rivers meet the sea and salinity is intermediate between salt and freshwater (e.g., deltas, mudflats, salt marshes)
- **Marine**: not influenced by river flows (e.g., shorelines and coral reefs)
- **Riverine**: land periodically inundated by river overtopping (e.g., water meadows, flooded forests, oxbow lakes)
- **Palustrine**: where there is more or less permanent water (e.g., papyrus swamp, marshes, and fen)
- **Lacustrine**: areas of permanent water with little flow (e.g., ponds, kettle lakes, volcanic crater lakes)

Wetlands are dynamic ecosystems which are defined by federal regulating agencies as possessing three essential characteristics: (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology, which are the driving force creating all wetlands (Federal Interagency Committee for Wetland Delineation, 1989). Under most circumstances, at least one positive field indicator of each parameter will be apparent at any given wetland. In the following section, each of these parameters will be examined individually.

Wetland Vegetation

The vegetation criterion in wetland definitions requires an area to have over 50 percent of its dominant species classified within a broad range of wetland plants (Washington State Wetlands and Delineation Manual, 1997).

Wetland Soils

Hydric soils are saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions in the upper part. In just a few days to a week, flooding of soil causes a rapid depletion of oxygen and the onset of an anaerobic environment. The diffusion of dissolved oxygen in waterlogged soils is 10,000 times slower than in unflooded soil. If oxygen does make its way into a flooded soil, it is rapidly used by microbes that can use either oxygen or oxidized soil components to support their respiration.
2.4 Wetland Hydrology

Wetland hydrology refers to conditions of permanent or periodic inundation, or soil saturation to the surface where hydrology conditions are the driving forces behind wetland formation. Numerous factors influence the wetness of an area, including precipitation, stratigraphy, topography, soil permeability, and plant cover (Federal Interagency Committee for Wetland Delineation, 1989).

2.5 Wetland Delineation Using Remote Sensing and Geographic Information System

Remote Sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed without direct contact (Hashimoto et al., 1993). Moreover, Geographic Information System (GIS) is defined as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986). Based on these two definitions, remote sensing technology and GIS are expected to provide efficient tools for monitoring wetland environment with spatial approach and computer system.

2.6 Markov Chain

A Markovian process is one in which the state of a system at time 2 can be predicted by the state of the system at time 1 given as matrix of transition probabilities from each cover class to every other cover class (Eastman 2003).

2.7 Cellular Automata Model

Cellular Automata are dynamic models which operate in raster data spaces. States within the raster space can be defined as binary (for example, alive/dead), or as discrete, multilevel. Cellular automata are dynamic systems whose behavior is completely specified by local relationships (Toffoli and Margolus, 1987).

The characteristic of cellular automata model is described with the five (5) characters (Sirakoulis et al., 2000):

- How many the spatial dimension (n)
- Width / distance for each side from a cell composition (w). Wj is the width from side to j from a cell composition, where j = 1, 2, 3, …..n (total of the cells) j
- Width from the closest neighbour cell (d). dj is the closest neighbour distance along j side from j cell composition.
- Each cell condition of cellular automata
- Cellular automata rule, as the arbitrary function F

Cell X condition, at time t = 1, is calculated based on F. F is the function from cell X condition at time (t) and the condition of surrounding cells at time (t) is known with rule as the change transition. The simple description from the two dimension cellular automata (n = 2), with the nearest neighbored distance d1 = 3 and d2 = 3, as the follow (figure 2)

\[
\begin{array}{ccc}
   i - 1, j - 1 & i - 1, j & i - 1, j + 1 \\
   i, j - 1 & (i,j) & (i, j + 1) \\
   i + 1, j - 1 & i + 1, j & i + 1, j + 1 \\
\end{array}
\]

Figure 2 The nearest neighbored from cell (i,j) is formed from cell (i,j) itself and eight (8) cell at it the adjacent (Sirakoulis et al., 2000).
3. Methodology

3.1 Time and Study Area

The research was conducted from March until August 2007. The study area is located in the surrounding of Lore Lindu Lake (0°50’S – 2°04’S and 119°40’E – 120°30’E) in the North part of Lore Lindu National Park, Central Sulawesi, Indonesia. Specifically, the study area is in Kulawi Sub District and Donggala District. There are four (4) surrounding villages bordering the study area namely Puroo, Langko, Tomado and Anca. The following figure 3 is the map of the study area, it shows the research area boundaries, roads, rivers, and the location of the villages.

![Figure 3 Study Area Map](image)

3.2 Types of Data and Sources

<table>
<thead>
<tr>
<th>Data type</th>
<th>Acquisition and Data source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Digital Data</td>
<td>28 Sept 2002 &amp; 21 July 2006, USGS</td>
<td>Multispectral image six (6) bands (visible, IR, middle-IR, far-IR) with spatial resolution 30 m, thermal image two (2) bands (band61 and band62) with spatial resolution 60 m</td>
</tr>
</tbody>
</table>

Table 1 Types of data and sources
and panchromatic image one (1) band with spatial resolution 15 m.

<table>
<thead>
<tr>
<th>Land use/ land cover map scale 1 : 50.000</th>
<th>1983, National Mapping and Coordination Survey Agency.</th>
<th>Derived from Aerial Photographic 1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Elevation Model</td>
<td>2000, Shuttle Radar Topography Mission</td>
<td>Digital elevation data obtained from X/C bands, SRTM sensor, spatial resolution 90 m.</td>
</tr>
<tr>
<td>Topography map sheet 2114- 41, scale 1 : 50.000</td>
<td>1983, National Mapping and Coordination Survey Agency.</td>
<td></td>
</tr>
<tr>
<td>Soil map scale 1 : 50.000</td>
<td>Balai Besar Litbang Sumberdaya Lahan Pertanian</td>
<td></td>
</tr>
</tbody>
</table>

3.3 Hardware and Software

The supporting tools in terms of software and hardware used include:

a. Software
   - GRASS 6.2.1 (*Geographic Resource Analysis Support System*) is free open source software for image processing, GIS work, and spatial analysis (spatial model pre-processing).
   - Idrisi Kilimanjaro V.14 is used for spatial model processing and spatial model validation.

b. Hardware
   - Notebook Centrino 1.7 MHz 256 MB RAM,
   - Global Positioning System (GPS) for field work
   - Printer for printing writing proposal, report, photo, and map

3.4 Methods

The following Figure 4 illustrates the general framework and specific flowchart to explain the objectives and the research questions.
Figure 4 General Research Methodology
Figure 5 Wetland Classification Maps Process (Image Pre-processing)
3.4.1 Markov Chain Analysis

The general procedure of using Markov Chain Analysis for wetland area can be seen from the following flowchart (Figure 6).

![Flowchart of Markov Chain Analysis]

**Table 2** Transition Matrix of wetland area for 1983 until 2002

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>sum 1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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<tr>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>sum 2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 3** Transition Probability Matrix of wetland area for 1983 until 2002

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tr>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.4.2 Multi Criteria Evaluation (MCE)

Multi-Criteria Evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation (Eastman 2003). A weight linear
Combination is used to obtain suitability map for wetland area, the factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map.

\[ S = \sum Wi Xi \quad (Voogd, 1983) \] ........................................ (1)

Where

- \( S \) = suitability
- \( Wi \) = weight of factor i
- \( Xi \) = criterion score of factor i

Based on this equation, the suitability map for wetland area was developed using several parameters for wetland area that are; topography map (slope map), soil map for wetland area, and the probability of land cover map for wetland area.

\[ S = X1 + X2 + X3 \] .................................................. (2)

Where

- \( S \) = suitability area for wetland
- \( X1 \) = Slope map derived from Digital Elevation Model (DEM)
- \( X2 \) = Soil map
- \( X3 \) = Land cover map for wetland area from 1983 until 2002 derived from Landsat image

3.4.3 Cellular Automata Model

The first step is the wetland area classification map derived from aerial photography 1983 which will be predicted until 2002, and then the result of prediction map for 2002 is validated using wetland classification map 2002. The second step is to predict again from 1983 until 2006 and is validated using wetland classification map 2006 after it has fulfilled the standard Kappa Index then wetland prediction model is created for 2021. Kappa index is used to check the results whether the model is true or not (usually the Kappa Index for the standard agreement is > 70 %). If the model has the Kappa Index less then 70 % then the suitability map for the wetland area should be repeated again based on several considerations, otherwise, if the model result is more than > 70 % then the last step is to create the spatial model for 2021. The following figure 7 is the markov cellular automata model for wetland change prediction area.

Figure 7 Cellular Automata Model
4. Result and Discussion

4.1 Wetland in Lindu Enclaves

4.1.1 Image Correction

Due to atmospheric path, Landsat imageries were corrected as the atmospheric correction with dark pixel correction method. This method assumes that every dark pixel should have digital number value 0. The following figures 8a and 8b show the scatter plot that is displayed for Landsat imagery before and after atmospheric correction.

![Figure 8 Atmospheric Correction](image)

The geo registration process was done in order to obtain good accurate image position for each class as the wetland change detection. Therefore, polynomial method was used as the geo coding type while polynomial order used linear transform. The following figures 9a, 9b and table 9 show geo registration process and RMS (Root Mean Square) error that have been done for these two imageries.

![Figure 9 Geo registration process](image)
Total number of GCPs: 10  
Number turned on : 10  
Warp order : 1  
GCP CORRECTED map projection details:
Map Projection: SUTM51  
Datum : WGS84  
Rotation : 0.000

Table 4 Root Mean Square table for geo registration process

<table>
<thead>
<tr>
<th>Point</th>
<th>On Locked</th>
<th>Cell-X</th>
<th>Cell-Y</th>
<th>To-X</th>
<th>To-Y</th>
<th>To-Z</th>
</tr>
</thead>
<tbody>
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<td>Yes</td>
<td>No</td>
<td>926.597</td>
<td>389.965</td>
<td>177753.5830889</td>
<td>9858647.5782064</td>
</tr>
<tr>
<td>&quot;2&quot;</td>
<td>Yes</td>
<td>No</td>
<td>627.557</td>
<td>950.068</td>
<td>173269.8915186</td>
<td>9850245.7970855</td>
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<tr>
<td>&quot;3&quot;</td>
<td>Yes</td>
<td>No</td>
<td>921.556</td>
<td>704.028</td>
<td>177680.6325194</td>
<td>9853935.2062721</td>
</tr>
<tr>
<td>&quot;4&quot;</td>
<td>Yes</td>
<td>No</td>
<td>646.540</td>
<td>487.039</td>
<td>173554.8944412</td>
<td>9857190.0585492</td>
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<td>&quot;5&quot;</td>
<td>Yes</td>
<td>No</td>
<td>522.626</td>
<td>793.444</td>
<td>171692.8926607</td>
<td>9852602.5398201</td>
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<tr>
<td>&quot;6&quot;</td>
<td>Yes</td>
<td>No</td>
<td>601.468</td>
<td>580.065</td>
<td>172870.8140289</td>
<td>9855783.2003116</td>
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<tr>
<td>&quot;7&quot;</td>
<td>Yes</td>
<td>No</td>
<td>824.489</td>
<td>958.940</td>
<td>176213.9299294</td>
<td>9850131.3460247</td>
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<tr>
<td>&quot;8&quot;</td>
<td>Yes</td>
<td>No</td>
<td>744.680</td>
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<td>175022.2900345</td>
<td>9857089.0092023</td>
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<td>&quot;9&quot;</td>
<td>Yes</td>
<td>No</td>
<td>841.049</td>
<td>442.011</td>
<td>176463.7437931</td>
<td>9857878.4234494</td>
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<tr>
<td>&quot;10&quot;</td>
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<td>No</td>
<td>931.221</td>
<td>451.968</td>
<td>177825.3450250</td>
<td>9857734.2977896</td>
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## RMS error report:  
**Warp Type - Polynomial**

<table>
<thead>
<tr>
<th>Point</th>
<th>---ACTUAL---</th>
<th>---PREDICTED---</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
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<td>&quot;1&quot;</td>
<td>926.597</td>
<td>926.635</td>
<td>0.4041</td>
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<td>627.557</td>
<td>627.845</td>
<td>0.4030</td>
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<td>&quot;3&quot;</td>
<td>921.556</td>
<td>921.830</td>
<td>0.8301</td>
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<td>&quot;4&quot;</td>
<td>646.540</td>
<td>646.758</td>
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<td>&quot;5&quot;</td>
<td>522.626</td>
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<td>&quot;6&quot;</td>
<td>601.468</td>
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<td>841.049</td>
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<td>&quot;10&quot;</td>
<td>931.221</td>
<td>931.430</td>
<td>0.6802</td>
</tr>
</tbody>
</table>

**Average RMS error: 0.531**

**Total RMS error: 5.309**

Based on the above tables, the RMS error for this geo registration is 0.531 and the total RMS error is 5.309. Analytically, it can be said that the result for this geo registration process still meets the standard geo registration process that should have minimum RMS error of 1.
4.1.2 Image Classification

After geo registration process has been done, the next step is to classify the Landsat TM 2002 & Landsat TM 2006 with supervised classification. In this classification, the imagery is classified with maximum likelihood method. Training samples areas were collected based on field work ground check and minimum sample size per class is 70 pixels. The results of classification image based on maximum likelihood supervised method are displayed in the following figure 10a and 10b.

![Wetland Classification Map 2002 & 2006](image)

**Figure 10 Wetland Classification Maps 2002 & 2006**

**Table 5 Area calculation for Wetland Classification Map 2002 & 2006**

<table>
<thead>
<tr>
<th>Classification Class</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Body</td>
<td>3418.1</td>
</tr>
<tr>
<td>Non Wetland Area</td>
<td>5829.552</td>
</tr>
<tr>
<td>Natural Wetland</td>
<td>2603.532</td>
</tr>
<tr>
<td>Human Made Wetland</td>
<td>1450.2</td>
</tr>
</tbody>
</table>

(a) Wetland Classification Map 2002

<table>
<thead>
<tr>
<th>Classification Class</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Body</td>
<td>3414.1</td>
</tr>
<tr>
<td>Non Wetland Area</td>
<td>5903.2</td>
</tr>
<tr>
<td>Natural Wetland</td>
<td>2555.6</td>
</tr>
<tr>
<td>Human Made Wetland</td>
<td>1540.8</td>
</tr>
</tbody>
</table>

(b) Wetland Classification Map 2006

On the other hand, classification map that has been obtained from aerial photography in 1983 is also portrayed in the following figure 11 and table 6 as 1983 wetland spatial distribution and area calculation.
Figure 11 Wetland Classification Map 1983

Table 6 Area calculation for Wetland Classification Map 1983

<table>
<thead>
<tr>
<th>Classification Class</th>
<th>Hectares</th>
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</tr>
<tr>
<td>Natural Wetland</td>
<td>2669.54</td>
</tr>
<tr>
<td>Human Made Wetland</td>
<td>1106.257</td>
</tr>
</tbody>
</table>

Figure 12 Graphic of Wetland area Calculation 1983
# Table 7: Area statistics for Wetland annual change rate in Lindu Enclave area 1983 - 2002

<table>
<thead>
<tr>
<th>Class</th>
<th>Area 1983 (Ha)</th>
<th>Area 2002 (Ha)</th>
<th>Change 1983 - 2002</th>
<th>% rel Change 1983 - 2002</th>
<th>Annual Change Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Body</td>
<td>3418.11</td>
<td>3418.1</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>121.7</td>
<td>279.69</td>
<td>157.99</td>
<td>56.49</td>
<td>3.0</td>
</tr>
<tr>
<td>Marsh &amp; Bush land</td>
<td>2669.54</td>
<td>2603.53</td>
<td>-66.008</td>
<td>-2.54</td>
<td>-0.1</td>
</tr>
<tr>
<td>Coffee</td>
<td>970.85</td>
<td>1047.59</td>
<td>76.74</td>
<td>7.33</td>
<td>0.4</td>
</tr>
<tr>
<td>Forest</td>
<td>4952.745</td>
<td>4203.95</td>
<td>-748.8</td>
<td>-17.81</td>
<td>-0.9</td>
</tr>
<tr>
<td>Paddy Field</td>
<td>1106.257</td>
<td>1450.2</td>
<td>343.943</td>
<td>23.72</td>
<td>1.2</td>
</tr>
<tr>
<td>Settlement</td>
<td>62.19</td>
<td>298.327</td>
<td>236.137</td>
<td>79.15</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Based on the above tables and graphics, the forest area changed from 1983 until 2002: 4952.75 hectares to 4203.95 hectares or an annual change rate of 0.8%. Natural wetland area (marsh) had also decreased from 1983 until 2002 (from 2669.54 hectares to 2603.53 hectares or an annual change rate of -0.1 %). Otherwise, settlement area has increased significantly from 62.19 hectares to 298.33 hectares or a significant annual change rate of 3.4 %. Agriculture has also increased from 121.70 hectares into 279.70 hectares or 2.5 % annual change rate. Human construction wetland (paddy field) from 1983 until 2002 has increased from 1106.257 hectares to 1450.2 hectares or 1 % annual change rate. Human intervention has affected Lindu enclaves. The changes are from forest to the wetland area especially construction wetland area. The change happened as the forest was converted to areas with more social economic value such as paddy field and fish ponds.

## 4.1.3 Multi Criteria Evaluations for Wetland Area

The following figure will explain the result of the multi criteria evaluation model (MCE) as the suitable area for wetland. Multi criteria evaluation for wetland area was obtained from three variables that were overlaid together into one output suitable area. The three variables consist of slope (topography area), soil, and land cover area. The results of multi criteria evaluation model for Lindu Enclaves are shown in the following figures.
4.1.4 Markov Chain Analysis for Wetland Area

Matrix transition probability that has been obtained from 1983 aerial photography and 2002 Landsat imagery classification is the reflection for 2021 of Lindu Enclaves activities. Matrix configuration was calculated with 19 years intervals. Furthermore, the result of matrix transition that as shown in the following table was also used as the basic wetland change prediction model simulation to predict the change that will occur within 19 years from 1983.

**Table 8 Probability Change**

<table>
<thead>
<tr>
<th>Given: Probability of changing to:</th>
<th>Cl. 1</th>
<th>Cl. 2</th>
<th>Cl. 3</th>
<th>Cl. 4</th>
<th>Cl. 5</th>
<th>Cl. 6</th>
<th>Cl. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl. 1 Water</td>
<td>0.0002</td>
<td>0.1579</td>
<td>0.2439</td>
<td>0.2091</td>
<td>0.1244</td>
<td>0.1337</td>
<td>0.1309</td>
</tr>
<tr>
<td>Cl. 2 Agriculture</td>
<td>0.0107</td>
<td>0.0619</td>
<td>0.5885</td>
<td>0.0107</td>
<td>0.0253</td>
<td>0.0509</td>
<td>0.2520</td>
</tr>
<tr>
<td>Cl. 3 Marsh &amp; Bush land</td>
<td>0.0172</td>
<td>0.1250</td>
<td>0.3125</td>
<td>0.0639</td>
<td>0.0448</td>
<td>0.1545</td>
<td>0.2820</td>
</tr>
<tr>
<td>Cl. 4 Coffee</td>
<td>0.0023</td>
<td>0.0401</td>
<td>0.1642</td>
<td>0.0210</td>
<td>0.0106</td>
<td>0.1206</td>
<td>0.6412</td>
</tr>
<tr>
<td>Cl. 5 Forest</td>
<td>0.0374</td>
<td>0.2009</td>
<td>0.4883</td>
<td>0.0450</td>
<td>0.0773</td>
<td>0.0560</td>
<td>0.0950</td>
</tr>
<tr>
<td>Cl. 6 Paddy Field</td>
<td>0.0077</td>
<td>0.2315</td>
<td>0.2606</td>
<td>0.2654</td>
<td>0.0785</td>
<td>0.0950</td>
<td>0.0612</td>
</tr>
<tr>
<td>Cl. 7 Settlement</td>
<td>0.9861</td>
<td>0.0064</td>
<td>0.0038</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0000</td>
<td>0.0029</td>
</tr>
</tbody>
</table>

**Table 9 Cells/pixels expected to change**

<table>
<thead>
<tr>
<th></th>
<th>Cl. 1</th>
<th>Cl. 2</th>
<th>Cl. 3</th>
<th>Cl. 4</th>
<th>Cl. 5</th>
<th>Cl. 6</th>
<th>Cl. 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl. 1 Water</td>
<td>24</td>
<td>24314</td>
<td>37552</td>
<td>32200</td>
<td>19161</td>
<td>20584</td>
<td>20157</td>
</tr>
<tr>
<td>Cl. 2 Agriculture</td>
<td>371</td>
<td>2139</td>
<td>20347</td>
<td>369</td>
<td>874</td>
<td>1761</td>
<td>8714</td>
</tr>
<tr>
<td>Cl. 3 Marsh &amp; Bush land</td>
<td>2525</td>
<td>18395</td>
<td>45976</td>
<td>9409</td>
<td>6591</td>
<td>22736</td>
<td>41498</td>
</tr>
<tr>
<td>Cl. 4 Coffee</td>
<td>30</td>
<td>535</td>
<td>2189</td>
<td>280</td>
<td>142</td>
<td>1608</td>
<td>8550</td>
</tr>
<tr>
<td>Cl. 5 Forest</td>
<td>466</td>
<td>2507</td>
<td>6092</td>
<td>562</td>
<td>965</td>
<td>699</td>
<td>1186</td>
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<tr>
<td>Cl. 6 Paddy Field</td>
<td>327</td>
<td>9792</td>
<td>11024</td>
<td>11226</td>
<td>3321</td>
<td>4019</td>
<td>2588</td>
</tr>
<tr>
<td>Cl. 7 Settlement</td>
<td>184764</td>
<td>1192</td>
<td>976</td>
<td>91</td>
<td>57</td>
<td>6</td>
<td>552</td>
</tr>
</tbody>
</table>
4.1.5 Wetland Change Prediction Area

Wetland change prediction area using markov cellular automata model was obtained from three variables that have been overlaid as markov cellular automata model process. It needs a few factors as the input files such as basis land cover image (Wetland classification map 1983 derived from aerial photography), markov transition areas file, transition suitability image, which is derived from Multicriteria evaluation process, number of projection year (i.e. 19 years), and cellular automata filter type (standard 3 x 3 contiguity filter). The result of the land cover change prediction area and wetland change prediction area based on markov cellular automata model can be seen in the following figure 12 which describes detailed information about Lindu Enclaves.

Figure 14 Wetland Classification Maps 1983, 2002, 2006 and Wetland Change Prediction Map 2021 as Markov Cellular Automata Model Results
Table 10 Area statistics for Wetland annual change rate in Lindu Enclave area 2002 - 2021

<table>
<thead>
<tr>
<th>Class</th>
<th>Area 2002</th>
<th>Area 2021</th>
<th>Change 2002 - 2021</th>
<th>% rel Change 2002 - 2021</th>
<th>Annual Change Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Body</td>
<td>3418.1</td>
<td>3412.1</td>
<td>-6</td>
<td>-0.18</td>
<td>0.0</td>
</tr>
<tr>
<td>Agriculture</td>
<td>279.69</td>
<td>375.997</td>
<td>96.307</td>
<td>25.61</td>
<td>1.1</td>
</tr>
<tr>
<td>Marsh &amp; Bush land</td>
<td>2603.532</td>
<td>2543.3</td>
<td>-60.232</td>
<td>-2.37</td>
<td>-0.1</td>
</tr>
<tr>
<td>Coffee</td>
<td>1047.59</td>
<td>1232.54</td>
<td>184.95</td>
<td>15.01</td>
<td>0.6</td>
</tr>
<tr>
<td>Forest</td>
<td>4203.945</td>
<td>3590.6</td>
<td>-613.35</td>
<td>-17.08</td>
<td>-0.7</td>
</tr>
<tr>
<td>Paddy Field</td>
<td>1450.2</td>
<td>1729.06</td>
<td>278.862</td>
<td>16.13</td>
<td>0.7</td>
</tr>
<tr>
<td>Settlement</td>
<td>298.327</td>
<td>417.802</td>
<td>119.475</td>
<td>28.60</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Figure 15 Graphic of Wetland Change Area from 1983 - 2021

Based on the above spatial wetland model prediction 2021 and area calculation, the natural wetland area (marsh area) will decrease from 2,603.532 hectares to 2543.3 hectares in 2021 or -0.1 % annual change rate. Forest area was predicted to decrease in 2021 from 4203.945 hectares to 3590.6 hectares or -0.7 % annual change rate. In this case, forest has the
highest annual change rate and if this always occurs then forest area will disappear in Lindu enclaves as well as natural wetland area (marsh area) with -0.1% annual change rate. On the other hand, construction (man-made) paddy field wetland area will increase from 1450.2 hectares to 1729.06 hectares or 0.7% annual rate change in 2021. This will also happen to agricultural and cacao/coffee area that have an annual rate change of 1.1% and 0.7% per year. In addition, settlement area is predicted to increase each year from 298.327 hectares to 417.802 hectares or 1.2% annual change rate. Annual change rate of 1.2% is the highest for Lindu enclave. Therefore, it can be concluded that settlement area always increases every year and social economic factor has high impact to increase social economic land use such as cacao/coffee and agriculture sector. Man-made wetland area (i.e. paddy field area) is also predicted to increase in 2021, assuming that paddy field area has high economic value for local people. On the contrary, marsh area as natural wetland area and forest area will decrease due to land conversion for higher socio economic valued agriculture by the local communities.

5. Conclusion and Recommendation

5.1 Conclusions

- Lindu enclaves have two wetland types; natural wetland (marsh and bush land) and construction/man-made wetland (paddy field and fish pond). It consists of 2,669.54 hectares of natural wetland area (marsh) and 1,106.257 hectares of man-made/construction wetland area (paddy field) in 1983. After that, in 2002 Lindu enclave area consists of 2,603.53 hectares of natural wetland area (marsh) and 1,450.2 hectares man-made/construction wetland area (paddy field). Natural wetland (marsh and bush land) dominated the spatial distribution in the Southern and Western parts of the Lindu enclave area. On the other side, man-made/construction wetland spreads in all areas, with the largest paddy field area located in Kanawu sub-district. (South Eastern area of Lindu Enclave).

- The changes of wetland area in Lindu enclave area for natural wetland (marsh) was -66.01 hectares (1983-2002) with -0.1% annual change rate and 343.94 hectares area for human made/construction wetland area (paddy field) with 1.0% annual change rate. Therefore, construction wetland (paddy field) can be analyzed as having good socio economic value for local people but for ecological value it gives negative impacts. The same is true to natural wetland area (marsh) that will give positive impact from ecological side however this area always decreases every year.

- The suitable area for wetland was located in every enclave area, however the most suitable area was located at the Southern part of Lindu enclave area.

- The prediction of spatial distribution for natural wetland area in 2021 will disappear with an annual change rate of -0.1%. Because Lindu enclave area has slow rate of change area both from socio economic and hydrologic factors. However, human made wetland such as paddy field area has increased to 1,729.06 hectares in 2021 with 0.7% annual change rate. Markov Cellular automata model can be used to predict wetland change area in Lindu enclave area. The accuracy of simulation result was determined from Markov probability transition and existing spatial suitable area for wetland area.

5.2 Recommendation

The result of this spatial simulation model for wetland area can be used as the base spatial planning map to predict what will happen in the future. Water availability for Lore
Lindu National Park can be assessed through its ecological and socio economic assessments. This model can be used for local government, stakeholders, and local people / community in Lindu Enclave. It is important to maintain and preserve natural resources in a sustainable way.

6. References


STATEMENT

I, Wen Wen, here by stated that this thesis entitled:

Wetland Change Prediction Using Markov Cellular Automata Model in Lore Lindu National Park, Central Sulawesi Province, Indonesia

are results of my own work during the period of January 2007 until December 2007 and that it has not been published before. The content of the thesis has been examined by the advising committee and the external examiner.

Bogor, January 2008

Wen Wen
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First, I would like to express my grateful to my GOD for everything that has been given to me. And I would like also to give my highly appreciation to STORMA (Stability of Rainforest Margin in Indonesia) as an Indonesian – German collaboration research funded by German Research Foundation (FDG) to support my research in Lore Lindu National Park and for the following people that give a high contribution and help to finish my thesis:

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4. My friend in MIT IPB for helping and supporting me in finishing my thesis.

5. MIT secretariat and all staff for helping me to arrange the administration, technical and facilities.

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Finally, I would like to give my special thanks to my father, my mother, my sister and all of my family for all of their support during finishing my master degree.
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Since August 2007, he has joined with The Nature Conservancy – Coral Triangle Center Program (Non Government Organization) as Information System Officer.
ABSTRACT


Lore Lindu National Park (LLNP) is located between 119°90’ - 120°16’ East and 1°8’ - 1°3’ South and administratively, located in Poso District and Donggala District, in Central Sulawesi Province, Indonesia. Topographically, Lore Lindu National Park has two enclaves: Lindu Enclave (13.093 ha) and Besoa Enclave (5.085 ha). Lindu enclaves have high growing socio economic activities that can threaten Lore Lindu National Park as a tropical rainforest that requires the stability of rainforest margin area. If agricultural and built up area (settlement area) in Lindu enclaves always increase every year then the water availability to support Lore Lindu National Park will decrease so the stability of rainforest is threatened. Wetland as ecological component is important to be maintained, monitored and modeled to support the stability of rainforest margin area. Therefore, wetland change prediction is needed to predict what will happen in the future so that it can help decision maker in designing a strategies plan. The objectives of this research are: 1) to evaluate and assess the wetland area in Lindu Enclave area & Lindu Lake, 2) to predict the changes of wetland area in Lindu Enclave area & Lindu Lake using Markov Cellular Automata Model.

Land cover 1983 from aerial photography, Landsat TM 2002 and 2006 are used as the spatial model data. Input image correction is also performed in order to acquire well ground spatial estimation. Afterward, markov chain is used to get rate value per years of wetland change area in Lindu area. Multicriteria evaluation for wetland area created with soil map, topography map, and land cover map as the variables for suitable wetland area criteria that will be used in cellular automata model. Finally, markov chain probability values for each class and multicriteria evaluation map are merged with cellular automata model with 3 x 3 cell neighbors analysis then spatial wetland change prediction map for 2021 can be determined.

The results of this research show that Lindu enclaves have two wetland types; natural wetland (marsh and bush land) and construction / man - made wetland (paddy field and fish pond). The changes of wetland area in Lindu enclave area for natural wetland (marsh) was -66.01 hectares (1983-2002) with – 0.1 % annual change rate and 343.94 hectares area for human made / construction wetland area (paddy field) with 1.2 % annual change rate. The suitable area for wetland was located in every enclave area, however the most suitable area was located at the Southern part of Lindu enclave area.

The prediction of spatial distribution for natural wetland area in 2021 will decrease with an annual change rate of -0.1 %. However, human made wetland such as paddy field area has increased to 278.86 hectares in 2021 with 0.7 % annual change rate.
Hak cipta milik IPB (Institut Pertanian Bogor)
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