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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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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°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 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.
2.1.2 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.

2.2 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).

2.3 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 soils. 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 the characteristics 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)

```
<table>
<thead>
<tr>
<th>i - 1, j - 1</th>
<th>i - 1, j</th>
<th>i - 1, j + 1</th>
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</thead>
<tbody>
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<td>(i,j)</td>
<td>(i, j + 1)</td>
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<tr>
<td>i + 1, j - 1</td>
<td>i + 1, j</td>
<td>i + 1, j + 1</td>
</tr>
</tbody>
</table>
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*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></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>
<tr>
<td>Landsat 7 ETM+</td>
<td>28 Sept 2002 &amp; 21 July 2006, USGS</td>
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<tr>
<td>Land use/ land cover map scale 1 : 50.000</td>
<td>15 m. Derived from Aerial Photographic 1983</td>
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<tr>
<td>Digital Elevation Model</td>
<td>2000, Shuttle Radar Topography Mission</td>
<td></td>
</tr>
<tr>
<td>Topography map sheet 2114- 41, scale 1 : 50.000</td>
<td>Digital elevation data obtained from X/C bands, SRTM sensor, spatial resolution 90 m.</td>
<td></td>
</tr>
<tr>
<td>Soil map scale 1 : 50.000</td>
<td>Balai Besar Litbang Sumberdaya Lahan Pertanian</td>
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</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.
Problem Identification & Objectives

Literature Review

Field Work

Data Collection

Spatial Data

Spatial Model Pre-Processing (Image Restoration & Classification)

Spatial Model Processing (Markov Chain Analysis, Multi Criteria Evaluation, Cellular Automata Model)

Spatial Model Validation (Kappa Statistic Value)

Analysis

Result

**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](Wetland types Image classification For 1983) ![Flowchart of Markov Chain Analysis](Wetland types Image classification For 2002) Transition Matrix Trend / Prediction

**Figure 6** Markov Chain Analyses

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

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

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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