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 4 is the map of the study area, it shows the research area boundaries, roads, rivers, and the location of the villages. The detail of the map is shown in Appendix 1.

Figure 4 Study Area Map

The study area is 6,408 ha and categorized as the Lindu Enclave where 26% from the enclave area is covered by the Lore Lindu Lake. It has an elevation of
513 – 1657 m asl with the topography as the lacustrine area. The lithology area is formed from the alluvium and new Lacustrine – Riverine. The following Figure 5 is the Lore Lindu Lake area.

Figure 5 Lore Lindu Lake
3.2. Types of Data and Sources

The following is the table to describe types data and source that were used in this research for wetland spatial data model.

<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></td>
</tr>
<tr>
<td>Landsat 7 ETM+ path/row 114/61</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 and panchromatic image one (1) band with spatial resolution 15 m.</td>
</tr>
<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>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 spatial image preprocessing (radiometric correction, geo registration and image classification).
- Idrisi Kilimanjaro V.14 is used for spatial model processing (Markov matrix analysis, Multi Criteria Evaluation (MCE), cellular automata model) 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 6 illustrates the general framework and specific flowchart to explain the objectives and the research questions.
Figure 6 General Research Methodology
3.4.1. Spatial Model Pre-Processing

3.4.1.1. Land Cover / Land Use Wetland Areas Image Processing

a. Image Correction

Landsat 7 ETM+ 28 Sept 2002 & 21 July 2006 were corrected by two categories of image correction: (1) radiometric correction and (2) geometric correction. The correction term is used as a means how to return the original conditions of the satellite imagery as well as the ground measurement, because the two satellite imageries will be compared to obtain land cover classification that can be used to show the change detection using markov chain model in the study area.

The radiometric correction was used to restore the image by using sensor calibration concerned with ensuring uniformity of output across the face of the image, and across time. Radiance Calibration was used to convert DN (Digital Number) to absolute radiance values that are important for comparative analysis of several images taken by different sensors (MSS and ETM imagery). The equation relating to DN in remotely sensed data to radiance is as follows:

\[
RTM_i = Bias_i + \left( \frac{L_{\text{max}_i} - L_{\text{min}_i}}{Q_{\text{cal max}_i} - Q_{\text{cal min}_i}} \right) DN_i
\]

......................... (2)

(Markham & Barker 1986):

Where: \(RTM_i\) is the radiance value for band \(i\); \(L_{\text{min}} = \text{Bias}\) is the minimum spectral radiance (the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * μm) can be seen from the header file; \(L_{\text{max}}\) is the maximum spectral radiance (the spectral radiance that is scaled to QCALMAX in...
watts/(meter sq)) can be seen from the header file; DN is the digital number; $Q_{calmax} = 255$; and $Q_{calmin} = 1$.

Two of Landsat satellite imagery were taken in this classification process as the data source for wetland classification map. These Landsat satellite imageries have acquisition date 2002 and 2006. Before these imageries were classified then are needed to rectify using radiometric correction in order to remove atmospheric noise. Geo registration process to rectify these two imageries with the same position each other is also done using polynomial method. After rectification process is finished then image classification process was created using maximum likelihood method. The following figure 7 explains the flowchart to obtain wetland classification map in the research area.
Figure 7. Wetland Classification Maps Process (Image Pre-processing)

Wetland Classification Map 2002 & 2006

Accuracy assessment

Yes

No

Image Supervised Classification

Training Area

Geometric Correction

Radiometric Correction

- Image Registration & Rectification
- Sensor Calibration & Dark Pixel Correction

Landsat 2002

RBI Map derived from aerial photography 1983

Landsat 2006

Lindu Enclave & Lindu Lake

- Field Work

Collect GCP

Yes

No

Maximum Likelihood

Landsat 2002

Lindu Enclave & Lindu Lake
Atmospheric correction using dark pixel correction method was also used to remove path radiance due to atmospheric scattering. The Dark Pixel Correction (DPC) is used to minimize the DN value to zero for all the dark objects.

The geometric correction was done for Landsat MSS and Landsat TM imagery. Image rectification was applied to Landsat TM image with Ground Control Point (GCP) that are obtained from the GPS (Global Positioning System), after that image registration was also done for the Landsat TM image to the 1983 aerial photography land use as the rectified image. This geometric correction is performed to obtain good accuracy if the two Landsat images are overlaid then the change detection area can be detected as well as the earlier image.

b. Field Work / Ground Check

Field work or ground check process was conducted in the Lore Lindu Lake area to obtain Ground Control Point (GCP) for Image Rectification process, Land Cover check to compare with the accuracy of image classification result, soil map was crosschecked in the field with the existing soil map. Furthermore, field observation was also performed to observe the type of the wetland area in the study area so the plotting of the geographic location can be known for each wetland type that can be inputted into the image classification type.

c. Image Classification

Classification is the process of developing spatial model map from Landsat TM 2006 image. As a consequence, classification is perhaps the most important aspect of image processing to obtain spatial model map as the input in markov chain and cellular automata process.
The processes to obtain land cover and wetlands classification map consist of;

- Define training sites

  The first step in undertaking a supervised classification is to define the areas that will be used as training sites for each land cover class and wetland types. In general, the training sites are taken at least 10 times as many pixels for each training class of each band will be classified. Thus, for a Landsat TM image with seven bands, at least 70 pixels per training class.

- Signature Extraction

  After the training site areas have been collected, the next step is to create statistical characterizations of each informational class. The signature file will contain a variety of information about the land cover classes they describe. These include the names of the image bands from which the statistical characterization was taken, the minimum, maximum and mean values on each band, and the full variance/covariance matrix associated with that multispectral image band set for that class. This statistical data could be used to analyze the training sites whether it can be used or not to classify the image.

- Classify the image

  Finally, after the training sites for each land cover class fulfilled the ground check result then the next step is to create image classification using maximum likelihood classification method.

  \textit{d. Accuracy Assessment}

  The final stage of the classification process usually involves an accuracy assessment. Traditionally this is done by generating a random set of locations
through ground check for verification of the true land cover type. A simple value file is then made to record the true land cover class (by its integer index number) for each of these locations. This value file is then used with the vector file of point locations to create a raster image of the true classes found at the locations examined. This raster image is then compared to the classified map. The tabulation is the relationship between true land cover classes and the classes as mapped. It also tabulates errors of omission and errors of commission as well as the overall proportional error. The size of the sample (n) to be used in accuracy assessment can be estimated using the following formula:

\[ n = \frac{z^2 pq}{e^2} \]  

(3)

Where;

- \( z \) is the standard score required for the desired level of confidence (e.g., 1.96 for 95% confidence, 2.58 for 99%, etc.) in the assessment
- \( e \) is the desired confidence interval (e.g., 0.01 for 10%)
- \( p \) is the a priori estimated proportional error, and

\[ q = 1 - p \]

3.4.1.2. Topography Image Processing

a. Slope Map

The slope class or gradient, of each portion of a landscape can be derived from an analysis of SRTM (Shuttle Radar Topography Mission) with spatial resolution of 90 meters. The slope class values are measurements that indicate the steepness of a landscape. The slope map was created to attain the possibility of the wetland area that usually occurs in the low slope area and then this slope map was
classified from the low to the high scale suitable map for wetland area that will be used in Multicriteria Criteria Evaluation (MCE) methods.

3.4.2. Spatial Model Processing

3.4.2.1. Markov Chain Analysis

The general procedure of using Markov Chain Analysis for wetland area can be seen from the following flowchart (Figure 8).

**Figure 8** Markov Chain Model for Wetland Classification

The markov chain is one application of change detection that can be used to predict future changes of wetland area in Lore Lindu Lake area based on the rates of past changes and on the probability that a given piece of wetland will change from one mutually exclusive state to another. These probabilities are generated from past changes and then applied to predict future changes.

The first step is to create a matrix cell/pixels expected to change between classes. The result is the cell/pixels expected to change from a class in 1983 to another class in 2002 out of all possible changes. The next step is to create a transition matrix probability change of pixels in each wetland class for two time...
1. Dividing the study area into small cells using Landsat data imagery. This is accomplished by dividing each cell value by its row total and basically the same as the cross-tabulation matrix that can be used for accuracy assessment. The main diagonal of the matrix contains pixels that have no changes, while other cells contain pixels that have changed.

**Table 7** Cells/pixels expected to change of wetland area for 1983 until 2002

<table>
<thead>
<tr>
<th></th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Class 5</th>
<th>sum1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
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<td>Class 2</td>
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<td>Class 5</td>
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<tr>
<td>sum 2002</td>
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<td></td>
</tr>
</tbody>
</table>

**Table 8** Transition Probability Matrix of wetland area for 1983 until 2002

<table>
<thead>
<tr>
<th></th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Class 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class 1</td>
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<tr>
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<td>Class 3</td>
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<tr>
<td>Class 4</td>
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</tr>
<tr>
<td>Class 5</td>
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<tr>
<td>1983</td>
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</tr>
<tr>
<td>Class 1</td>
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<td>Class 2</td>
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<td>Class 5</td>
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</tbody>
</table>
3.4.2.2. 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.

\[ S = \Sigma W_i X_i \] (Voogd, 1983) ………………………. (4)

Where  
\[ S = \text{suitability} \]
\[ W_i = \text{weight of factor } i \]
\[ X_i = \text{criterion score of factor } i \]

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.

\[ S = aX_1 + bX_2 + cX_3 \] ………………………………….. (5)

Where  
\[ S = \text{suitability area for wetland} \]
\[ X_1 = \text{Slope map derived from Digital Elevation Model (DEM)} \]
\[ X_2 = \text{Soil map} \]
\[ X_3 = \text{Land cover map for wetland area from 1989 until 2002 derived from Landsat image} \]
\[ a, b, c = \text{Weighting factors for each variable} \]

After getting the suitability map of wetland area using MCE method then the next step is to create the cellular automata model process. For spatial simulation, the Lore Lindu Lake was created as the constraint area assuming that the area will not change for the time period of 19 years from now.
3.4.2.3. Cellular Automata Model

By definition, a cellular automaton is an agent or object that has the ability to change its state based upon the application of a rule that relates to the new state to its previous state and those of its neighbors (Eastman 2003). Based on this definition, markov probability transition matrix and the suitability map for wetland area obtained from MCE model was inputted into Cellular Automata model to attain the spatial prediction map for wetland area.

A cellular automaton not only depends on the previous state (Markovian process), but also on the state of the local neighborhood so the filter class 3 X 3 will be used in this case. Due to the use of Conway’s Game of Life rules for cellular automata so the alive or dead automata follow the criteria as mentioned below:

A cell assumed as the wetland area becomes alive if there are three living automata as wetland areas in the 3x3 neighborhood (known as the Moore neighborhood) surrounding the cell. The cell will stay alive so long as there are 2 or 3 living neighbors. Fewer than that, it dies from loneliness or it can be said that wetland area will change to another land cover type if only one cell is assumed as the wetland area; in addition it will compete with other resources.

Cellular automata model needs the wetland classification map as the input that will be projected, while the transition area file was produced by markov analysis from analysis of 1983 aerial photography land use and Landsat TM 2002 images. Furthermore, the suitability map for wetland area obtained from MCE model is also used as the suitability map expressing the suitability of a pixel for wetland area under several considerations.
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 9 is the markov cellular automata model for wetland change prediction area.

Figure 9 Markov Cellular Automata Model
3.4.3. Spatial Model Validation

As mentioned previously, an important stage in the development of any predictive change model is validation. Typically, the power of the model is used to predict some period of time when the land cover conditions are known. This is then used as a test for validation. The comparative analysis on the basis of the Kappa Index of Agreement is used as the base for validation. Kappa is essentially a statement of proportional accuracy, adjusted for chance agreement. However, unlike the traditional Kappa statistic, the validation is generated into several components, each with a special form of Kappa or associated statistic (based on the work of Pontius (2000)):

- Kappa for no information = $K_{no}$
- Kappa for location = $K_{location}$
- Kappa for quantity = $K_{quantity}$
- Kappa standard = $K_{standard}$
- Value of Perfect Information of Location = $V_{PIL}$
- Value of Perfect Information of Quantity = $V_{PIQ}$

Based on this, the spatial prediction model from cellular automata for wetland 2002 and 2006 classification map are validated using Kappa Statistic Validation (same as above) to evaluate the spatial model that is satisfy or not.