Spatial model of land use/land cover change dynamics and projection of Cisadane Watershed

R Wulandari1,3, K Murtilaksono2, K Munibah2
1 Graduate student of Natural Resources Management and Environment Department, Faculty of Graduate Studies, IPB University
2 Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University
E-mail: rina.wulandari@yahoo.com

Abstract. One of the major problems in watershed management is to balance the ecological function and fulfillment of human needs in a limited area. Rapid land-use changes often occurred as a result of human activities. Regular monitoring of land-use change dynamics is needed to help the government in making a decision within the area. Cisadane watershed is one of 15 priority watersheds in West Java Province, which categorized as very critical. This study aims to: 1) analyze land use/land cover (LULC) change dynamics and patterns in Cisadane watershed from year 2003, 2009, 2013, and 2018, 2) develop LULC projection for year 2033 based on historical patterns using Markov chain algorithm, and 3) analyze LULC change pattern and projection towards the spatial planning. The study reveals that the most significant changes during the last 15 years is the increase in built-up areas (47%). On the other hand, forest and paddy field classes are experiencing a decrease of 7% and 31%, respectively. LULC projection under business as usual (BAU) condition resulted in the continuous increase of built-up areas up to 36% in the year 2033, which most of the changes come from the conversion of paddy field and dryland farming. LULC map of year 2018 and regency’s spatial planning was overlaid to confront the consistency within both maps. The overlaid shows inconsistency between current LULC and land allocation in spatial planning. The inconsistency mostly occurred in the area allocated as plantation (86%). The built-up area has the largest allocated areas in Cisadane watershed, while it is only 51% of the areas that had been utilized as a built-up area. The result of this study indicates the need to strengthen land allocation policy within the watershed, in particular, to control the development of the built-up area.

Keywords: Cisadane, land-use change, land use projection, Markov Chain

1. Introduction
One important problem in the management of natural resources and the environment, especially on limited land, is to balance between the fulfillment of human needs with the preservation of natural resources, then continuously maintain the balance [1,2]. Interactions between human activities and ecosystem functions are reflected in land use patterns, which can be changing over time. Dynamics of LULC describes the processes related to biophysical, social, economic and related institutions on the landscape [3]. In watershed ecosystems, land use patterns can greatly affect the ecological functions of...
the watershed that monitoring LULC dynamics becomes very important. In addition to describing historical processes, understanding of land use dynamics is also important to project future land use. LULC projections can support in decision-making processes, especially in the land allocation of spatial planning.

Cisadane watershed is one of the 15 priority watersheds that need to be recovered immediately [4]. Land use in Cisadane watershed is changing rapidly, in particular, the expansion of the built-up areas, mostly in the middle area of the watershed. Previous studies show that in the period of five years (2001 - 2006), there was an increase in the settlement area of 6,431 ha [5]. Meanwhile, between 1978 and 1995 there was a 64.83% land change within the Cisadane watershed and between 1995 and 2012, there was a change in land use by 56.04% [6].

There are at least three variables triggering the LULC change in the Cisadane watershed, namely population density, distance to the center of activity, and climate conditions (precipitation) [6]. The location and ease of access to DKI Jakarta has caused urbanization patterns to increasingly shift to buffer zones, including Bogor Regency, which is located in the upstream area. Expansion of the built-up areas in the upstream is triggered by the need for housing, good accessibility, and the lack of understanding of protected land that has been established in the spatial plan [7].

The study aims to: (i) map and analyze the dynamics of LULC change in Cisadane watershed in 2003, 2008, 2013 and 2018, (ii) develop a projected LULC of Cisadane watershed in year 2033 using the Markov Chain model, and (iii) map and analyze LULC and projected land use against the spatial planning of the regency/municipality included in the Cisadane watershed area.

2. Study area
The study was conducted in Cisadane watershed, located in 106°20'50” – 106°28’20” E and 6°0’59”-6°47’02” S, covering a total area of 150 km². Based on the morphology, the watershed is divided into four sub-watersheds, namely Cianten and Cisadane Hulu in the upstream, Cisadane Tengah sub-watershed in the middle part, and Cisadane Hilir sub-watershed in the downstream area. Based on administrative boundary, Cisadane watershed is a cross-provincial watershed (West Java and Banten), consist of five regencies: Bogor Regency and Bogor City (West Java Province), and Tangerang Regency, Tangerang City, South Tangerang City (Banten Province).

![Figure 1. Location of the study area.](image-url)
3. Methodology

Data used in this study consists of primary and secondary data. Secondary data consists of LULC data for 2003, 2009, 2013 from Ministry of Environment and Forestry (MOEF); forest status for West Java and Banten Provinces from MOEF; Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (SRTM) 30m; Indonesia Base map scale 1: 25,000 from Geospatial Information Agency (BIG); Population data, density, population growth rate from Indonesia Statistic Agency (BPS) year 2017, and spatial planning maps at regency/city level. Primary data in this study is a 2018 land cover map obtained from the interpretation of Landsat 8 satellite imagery acquired on July 6, 2018. Satellite imagery and GIS data processing carried out using ArcGIS software version 10.5, while LULC projection was done using Terrset software. The processing method and data analysis stages are illustrated in Figure 2.

![Figure 2. Workflow of the study.](image)

3.1. Analysis of historical land use

The dynamics of LULC change is done using the spatial analyst tool in ArcGIS software version 10.5. LULC change analysis was carried out for each monitoring period between 2003 and 2009, 2009 and 2013, as well as 2013 and 2018. Patterns of change were analyzed for sub-watershed locations using the spatial overlay method in ArcGIS version 10.5.

3.2. Land use projection

LULC projections are carried out using the Land Change Modeler (LCM) module in Terrset software. The algorithm used is the Markov Chain, where the projected LULC in a particular year \((t+1)\) is a function of existing land use \(t\). The Markov Chain algorithm is a stochastic model that describes land-use changes over different periods, through a potential transition matrix \([8,9]\). This model requires two periods of LULC maps to analyze historical changes and create a potential transition matrix. This algorithm has been used extensively in various studies related to the dynamics of LULC change and projections \([5,10,11]\).
In this study, the LULC projection model is carried out under Business as Usual (BAU) condition. This scenario assumes the trend of change will occur as the historical trend, triggering by accessibility, slope, and distance from the center of activity. All data used in the model is converted to raster data with a 10m x 10m grid. The effect of the drivers of change is represented in terms of distance for each variable. The closer the distance to a certain variable, the greater the chance of land use to experience a change.

LULC projections are carried out in two stages: the first stage aims to assess model accuracy by projecting the LULC to the year 2018. This stage is carried out using historical data in 2009 and 2013. The results were then overlaid with the actual land use year 2018 to assess the accuracy of the model. Model validation is done using Kappa analysis using random sample points for each land cover class. The accuracy required for the model is at least 75% [8]. The second stage is carried out once the required accuracy has been achieved by projecting LULC to the year 2033, which is the same year with the end of spatial planning implementation of the regencies in Cisadane watershed.

3.3. Analysis of land use and spatial planning
Conformity analysis is done by comparing the actual land use year 2018 and the projected LULC year 2033 with the spatial planning of the five regencies/cities that are included in the Cisadane watershed. Comparisons are made using the spatial overlay, then a descriptive analysis is carried out to describe the suitability between the existing and projected LULC with spatial planning.

4. Result
4.1. Analysis of historical land use
The total area that changed during the period from 2003 to 2018 was 28% of the total Cisadane watershed area. Of all the types of changes that occur, the increase in built-up areas is a dominant type of change (13% of the total watershed area). Other changes in the watershed are the decrease of dryland farming (3%), paddy fields (6%), and forests (2%) (Table 1).

| Land Use /Land Cover         | Area (ha) | 2003 | 2009 | 2013 | 2018 | land change 2003 - 2018 |
|------------------------------|-----------|------|------|------|------|------------------------|
| Forest                       |           | 27,288 | 27,023 | 26,158 | 24,344 | -2,944                 |
| Plantation                   |           | 4,132  | 3,754 | 2,788 | 5,132 | 999                    |
| Shrub/ Bush                  |           | 4,279  | 4,141 | 1,797 | 181  | -4,099                 |
| Dryland Farming              |           | 59,548 | 59,850 | 65,968 | 55,441 | -4,107                 |
| Paddy Field                  |           | 30,933 | 30,840 | 25,411 | 21,459 | -9,474                 |
| Built Up Areas               |           | 19,594 | 20,392 | 24,583 | 39,231 | 19,636                 |
| Bare Land                    |           | 966    | 735   | 29    | 1,298 | 332                    |
| Waterbody                    |           | 3,981  | 3,985 | 3,985 | 3,637 | -344                   |

Based on the upstream-downstream watershed location, the most dynamic land-use change occurred in the middle part of the watershed, where the type of land change is dominated by the expansion of built-up areas. Land change in the upper part of the watershed is dominated by conversion from other land use into dryland farming, while in the downstream area, land-use change is mostly conversion from paddy field into built-up areas. Changes that need to be highlighted are the continuous decrease of forest cover and paddy field. Based on the LULC data year 2018, the remaining forest cover in Cisadane watershed is 16% of the total area. These findings are not aligned with Indonesia regulation (Law No. 26 Year 2007 on Spatial Planning, article 17), which requires a...
minimum of 30% forest cover in the watershed area. Decreasing of the paddy field could also become a serious problem as most of the paddy field has been converted into built-up areas. The continuous decrease of the paddy field could threaten food security, in particular within the West Java and Banten Province.

4.2. Land use projection
The first stage land cover projection model is carried out to estimate accuracy. Projections are made for 2018 then the results are compared against the actual 2018 land use map. Validation is done using 80 sample points taken randomly on the map and produces an accuracy value of Kappa of 89.9%. This value exceeds the required value so that the projected land cover can be continued up to the year 2033. The second stage modeling is done based on BAU conditions. The result shows that the dominant LULC in the Cisadane watershed for the year 2033 is still dryland farming. It is also found that the increase of built-up areas is mostly occurred in the middle and upstream areas, especially in Cisadane Hulu sub-watershed.

The trends in LULC change in 2033 are similar to historical trends. Forest cover and paddy fields in the Cisadane watershed are projected to continue to decrease over the next 15 years. Decreasing of forest area in 2033 is estimated to occur as much as 13%, while paddy fields are estimated to have decreased by 43%. Meanwhile, the increase of the built-up areas is estimated at 36%, which reaches 53,276 ha (Figure 3).

![Figure 3. Historical LULC dynamics and LULC projection year 2033 under BAU condition.](image)

Based on the upstream-downstream watershed, there are different change patterns in each sub-watershed segment. In the upstream part, the projected patterns of land-use change in the Cianten Sub-watershed are dominated by the increase of dryland farming and decreasing of forest cover. Meanwhile, in the Cisadane Hulu Sub-watershed, the dominant land-use changes experienced by the significant increase in built-up areas and the decreasing of paddy fields. The differences in land-use patterns is assumed because of the population density and growth factors in the Cisadane Hulu sub-watershed are higher than the Cianten Watershed. Sub-districts with high population density in the Cisadane Hulu Sub-watershed are Bogor City, Dramaga District, and Ciomas District [12]. In Cisadane Tengah Sub-watershed, increasing of built-up areas is projected to occur, along with the decreasing of forest cover, plantations and paddy fields. While in the Cisadane Hilir Sub-watershed,
the dynamics of land-use change patterns occur is the increase of built-up areas and the reduction of paddy fields.

![Figure 4](image-url)  
**Figure 4.** Existing LULC year 2018 (a) and projected LULC under BAU Condition (b) in Cisadane watershed.

### 4.3. Analysis of land use and spatial planning

In general, the spatial pattern in the Cisadane watershed according to the regency/city spatial plan is divided into five zones: forest area (23%), pond (0.4%), built-up areas (47%), plantations (9%), and agricultural land (21%). Overlapping LULC data in 2018 with regency/city spatial plan shows that most of LULC in the Cisadane watershed are already aligned with its designation, however, there are still discrepancies in some parts of the watershed. Most discrepancies occur in the allocation for plantation land (86%), and forest land (35%). Inappropriate land use for forest land allocation is dominated by dryland farming and plantations. Land use projections in 2033 illustrate that inappropriate LULC in the forest area will increase to 40% under BAU condition. This is important to be aware of since the forest allocation in the spatial plan is only 23% or below the value required by the law which is 30%.

The largest land allocation in the Cisadane watershed is built-up land. However, based on the LULC year 2018, the current utilization has only reached 51%. Other land uses in the built-up areas allocation are dominated by dryland farming and paddy fields. Projected LULC in the next 15 years shows an increase of built-up areas by 7% in the appropriate land allocation. Meanwhile, inappropriate built-up areas are projected to occur mostly in agriculture land allocation (16%) (Table 2).

| LULC             | Land Allocation in spatial planning |
|------------------|-------------------------------------|
|                  | Forest Area | Pond | Built-Up Area | Plantation | Agriculture |
|                  | 2018 | 2033 | 2018 | 2033 | 2018 | 2033 | 2018 | 2033 |
| Waterbody (pond) | 1,112 | 1,114 | 474 | 517 | 1,651 | 2,017 | 54 | 54 | 435 | 438 |
| Shrub            | 171 | 97 | 13 | 13 | 0 | 0 |
| Forest           | 22,573 | 19,756 | 110 | 96 | 1,183 | 882 | 516 | 486 |
| Built Up         | 1,075 | 1,377 | 14 | 1 | 36,001 | 46,441 | 583 | 836 | 2,083 | 5,200 |
| Plantation       | 2,693 | 3,329 | 688 | 987 | 1,778 | 2,177 | 22 | 81 |
| Dryland Farming  | 6,790 | 8,909 | 3 | 21,871 | 15,196 | 8,745 | 8,845 | 17,973 | 20,096 |
| Paddy Field      | 273 | 94 | 15 | 24 | 9,643 | 6,114 | 503 | 41 | 11,104 | 5,979 |
| Bare land        | 15 | 24 | 41 | 1,015 | 128 | 38 | 48 | 208 | 61 |
5. Discussion
In the period of 2003 to 2018, there was a change in LULC of 28% in the Cisadane watershed. Of these, most of the land change was an increase in built-up areas (47%). Meanwhile, forests and paddy fields experienced a significant decrease of 7% and 31%, respectively. Based on the upstream-downstream watershed division, the expansion of the built-up area occurs mostly in the upstream and middle part of Cisadane watershed. Most contributors to the expansion of built land are the conversion of dryland farming (53%) and the conversion of paddy fields (23%).

Projected LULC for the year 2033 under BAU condition shows that the trend of land change in the Cisadane watershed will be similar to the historical LULC change. Built-up areas are projected to increase by 36%, while forests and paddy fields will continue to experience an area of 13% and 43% decline respectively.

Analysis of LULC and spatial plans indicate a mismatch between land allocation and land use. The largest discrepancy occurred in the allocation of plantation land (86%), while the smallest discrepancy was in the allocation of agricultural land (10%). Expansion of built-up areas is expected to continue to grow, considering that the current utilization of space has only reached 51%, so there is a 49% allocation of unused land. However, there are also built-up areas in non-allocated land so supervision and control of built-up areas expansion in Cisadane watershed are important to be improved.

6. Conclusion
Understanding of historical land use/land cover change is very important for better land-use planning. In Cisadane watershed, this study shows that the dynamics of land-use change over the last 15 years are dominated by the increase of built-up areas. Land-use projection using a Markov chain algorithm finds out that, under business as usual condition, built-up areas will continue to increase until the year 2033. Along with the increase of built-up areas, forest and paddy fields are experiencing a significant decrease in Cisadane watershed.

The result of this study also shows the mismatch between land use and land allocation. This indicates the need for harmonization between spatial planning and its implementation, as well as land-use planning strategy for Cisadane watershed rehabilitation. Recommendation for future works includes the prioritization of areas that need to be rehabilitated in the watershed, as well as to determine interventions that need to be implemented to improve the condition of the watershed.

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