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Erosion rate prediction model using SWAT and CA-Markov methods (case study: Upper Ci Catih Catchment Area)

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Abstract. Landuse has a vital role that affects the movement of water on hydrological cycle. Around Upper Ci Catih Catchment Area in the past 10 years, many of various industries (ranging from small-scale to large-scale industries) have increased. Increasing built-up area, especially settlements and industries can increase runoff that have an impact on land degradation such as erosion. This study focuses on the hydrological modelling made by SWAT (*Soil Water Assessment Tools*) and landuse change prediction using CA-Markov (*Cellular Automata-Markov Chain*) to find the effects of landuse changes on the erosion rate changes. Erosion rate prediction in 2032 based on landuse changes prediction in that year. This study shows that variations of Hydrologic Response Unit (HRU) conditions affects the erosion rate in every subwatershed. The result of accuracy and calibration test satisfied, which NS and R^2 mark for SWAT validation is 0,56 and 0,72, and kappa coefficient value for CA-Markov model validation by 89%. The changes of landuse especially forest and irrigated rice fields is predicted in 2032 will decrease in every Subbasin. It will affect the increase of average erosion rate in every Subbasin by 15% of the erosion rate in 2017 on Upper Ci Catih Catchment Area.

1. Introduction

Soil erosion is a complicated process that spatial and temporal variability of this process is affected by many factors. Land use change as the one of the factor can affect the dynamics of Hydrological Response Unit (HRU) in a catchment area [1]. Land use as a vital role in the hydrological cycle can affect the movement of water especially in reducing or increasing runoff, its because the level of evaporation, transpiration, and interception affected by the characteristic of land use in a catchment area [2]. Modeling soil erosion and land use evolution ability are important because soil erosion has an impact on the environment including loss of organic matter and nutrients, reduced ground productivity, and water quality at the downstream of a catchment area [3].

Upper Ci Catih Catchment Area (UCCA) is the part of Ci Catih Watershed that disemboque to Cimandiri Watershed. In the last decade, around UCCA especially in the upstream region began to grow dozens of the commercial bottled water industry, ranging from small-scale to large-scale industries [4]. However, high resources potentials without any conservation activities on the watershed will cause damage to the watershed. Shrub, rice fields, and mixed farming area have decreased in UCCA by 96,78%, 78,74% dan 74,50% in 2009 - 2014, consequently Regime Runoff Coefficient and Annual Runoff Coefficient which initially classified as moderate category increased to high and very

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high category [5]. Increasing runoff is assessed to affect the increase of erosion rate, so the modeling erosion and land use can be used as an alternative to give an overview about level of land degradation in a Watershed.

Various models for erosion have been widely practiced in literature. Collaboration between SWAT and CA-Markov models to predict the rate of erosion ever undertaken by Joab et al. (2016), the results show that sediment load was increased in different land use scenarios (1990 - 2030) [6]. This shows the effect of land use change on HRU that can impact on increasing erosion rate. Thus, this research is conducted to find out how land use change predicted in 2032 will affect the increase of erosion rate in the scenario of that year.

The land use prediction in this research is using CA-Markov model. Cellular Automata - Markov Chains (CA-Markov) can be used to predict spatial and temporal patterns of land use change along with evolution and simulation of future land use with quantitative method [7]. While for erosion rate estimation in this research using Soil Water Assessment Tools (SWAT) model. SWAT is feasible to predict erosion and surface runoff in watersheds that have a wide and complex scale with soil types, land use and varying management conditions over long periods [8]. Both of this models require some secondary data as an input model to run the model.

This study using soil data, slope and climate (relative air humidity, wind velocity, air temperature, solar radiation, rainfall) as a static variable that are assumed to remain until 2032. Land use is considered as a dynamic variable that has a different land use patterns in the predictive and actual year scenario, so will effect in the Hydrological Response Unit. Actual land use data and observational surface runoff are also used for calibration and validation purposes. Analysis of the final results of the model using comparative and descriptive spatial analysis. Descriptive spatial analysis explains how land use change affects the changes of the Hydrological Response Unit (HRU) and its contribution to increased erosion rates in each Subbasin as the unit of analysis.

2. Methodology

2.1 Study Area

This research was held in Upper Ci Catih Catchment Area (UCCA), that covers the area 91,07 km². UCCA is located in Sukabumi Regency, West Java that have a divers topography with elevation between 500 to 1000 masl. **Figure 1.** Shows the located of UCCA geographically.

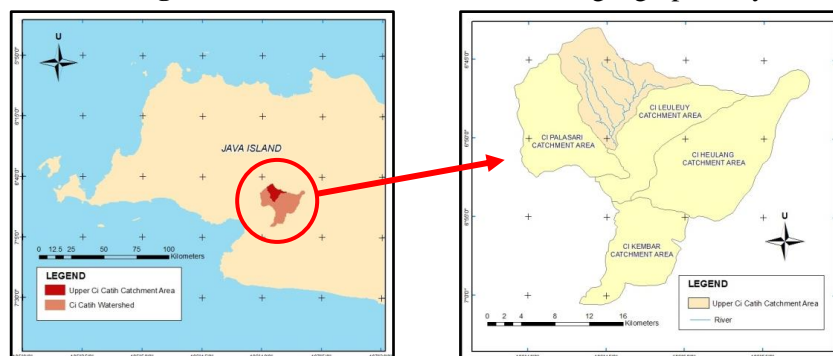


Figure 1. Upper Ci Catih Catchment Area Location

2.2 Data and Methods

Data in this research used to processing and analysis as an input data model. Primary data in this resarch are DigitalGlobe satellite image data of 2002, 2010 and 2017 which obtained from Google Earth Pro and Smart GIS 2018 software will be digitized in each year using ArcGIS 10.1 and Slope data which obtained from Digital Elevation Model SRTM 30 meters. Secondary data obtained from agency or institution website that are type of soil from soil map 1:50.000 Soil and Agroclimate Research Center Bogor and Rainfall, relative air humidity, air temperature, wind speed, Solar Radiation from Indonesian Agency for Meteorology, Climatology and Geophysics.

Data processing in this study was conducted to retrieve input data for SWAT and CA-Markov models. Driving factor, transition probability matrix for CA-Markov data input to generate land use prediction of UCCA in 2032 and Hydrological Response Unit (HRU), Weather Generator Data (WGN) and observation runoff to run SWAT model. Data processing can be seen in **Figure 2**.

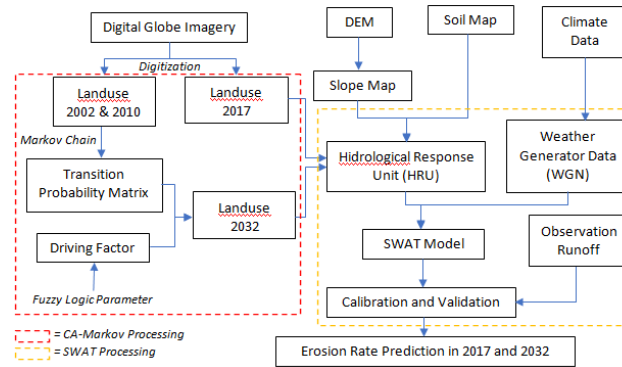


Figure 2. Data Processing Flow Chart

The CA-Markov model for process land use prediction requires a driving factor and a transition probability matrix as the model input. CA-Markov model accuracy level using Kappa Accuracy by comparing actual land use with simulated land use 2017. The Kappa Accuracy equation is as follows:

$$\text{Kappa Accuracy} = \frac{N \sum_{i=1}^T x_{ii} - N \sum_{i=1}^T (x_{i+} \times x_{+i})}{N^2 - N \sum_{i=1}^T (x_{i+} \times x_{+i})} \quad (1)$$

Erosion rate prediction in 2032 using Soil Water Assessment Tools (SWAT) model adopted Modified Universal Soil Loss Equation (MUSLE) with the following equation [7]:

$$\text{Sed} = 11,8 \cdot (Q_{\text{surf}} \cdot q_{\text{peak}} \cdot \text{area}_{\text{hru}})^{0,56} \cdot K_{\text{USLE}} \cdot C_{\text{USLE}} \cdot P_{\text{USLE}} \cdot LS_{\text{USLE}} \cdot \text{CFRG} \quad (2)$$

where, Sed is sediment yield (ton), Q_{surf} is volume of surface flow (mm/ha), q_{peak} is peak of surface flow discharge, $\cdot \text{area}_{\text{hru}}$ is area of HRU (ha), K_{USLE} is soil erodibility factor, C_{USLE} is land cover factor, P_{USLE} is land management factor, LS_{USLE} is topography factor, CFRG is roughness factor of fragments. Modeling using SWAT is done with four stages: Sub-basin delineation, making Hydrological Response Unit (HRU), Weather Generator Data (WGN), calibration and model validation. The accuracy of the SWAT model is tested by the Nash-Sutcliffe (NSE) efficiency equation and the Coefficient of Determination (R^2) that expected the NSE value exceeding 0.5 and the coefficient of determination close to 1.

3. Results and Discussion

3.1 Land use Change in Upper Ci Catih Catchment Area.

Land use Change in UCCA is impacts of human activities. Settlement, industries, and agricultural land generic increase widely during 2002 to 2017. Settlement (URHD) is the highest increasing area among with other types of landuse, which is 645.15 ha or about 7.1% within 15 years. Meanwhile, Irrigated rice field (RICE) in UCCA has the greatest widening area, which is 10,8% within 15 years.

Figure 3. shows that land use change in study area is influenced by increasing population and agricultural activities. The increase in the area of constructed land (settlements and industries) mostly derived from the conversion of irrigated rice and mixed farms, so urbanization and industrialization that removes agricultural land and tree cover can affect the balance of the hydrological response of a watershed and cause land degradation that increases the risk sedimentation and soil erosion.

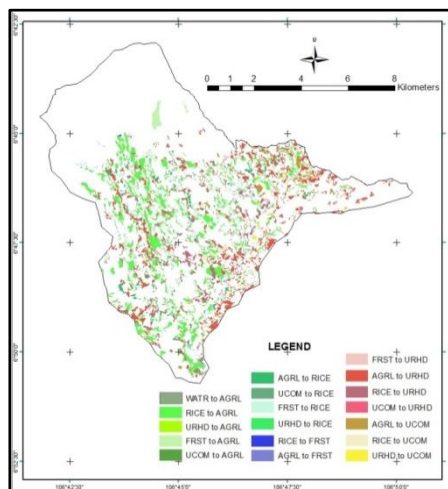


Figure 3. Landuse Conversion from 2017 to 2031 in UCCA

3.2 Land use Prediction in 2032

Land use prediction model in 2032 using land use in 2002 as the base and 2017 as the second year on input data model to obtain transition probability matrix. Driving factors in this research are used to predict the direction and magnitude of prediction land use (in this case built-up area) consist of several parameters. Parameters and its classification are used include: distance from road, distance from river, distance from public facility, slope and elevation.

Model validation for CA Markov Model is using kappa values by comparing actual land use with simulated land use in 2017. Validation aims to examine the degree of compatibility between the land use maps which obtain by CA-Markov modeling with actual conditions. Validation of land use simulation in 2017 using kappa values aimed as kstandard is 0.8934. Comparison of spatial distribution between actual and simulation land use in UCCA can be seen in **Figure 4(a)**.

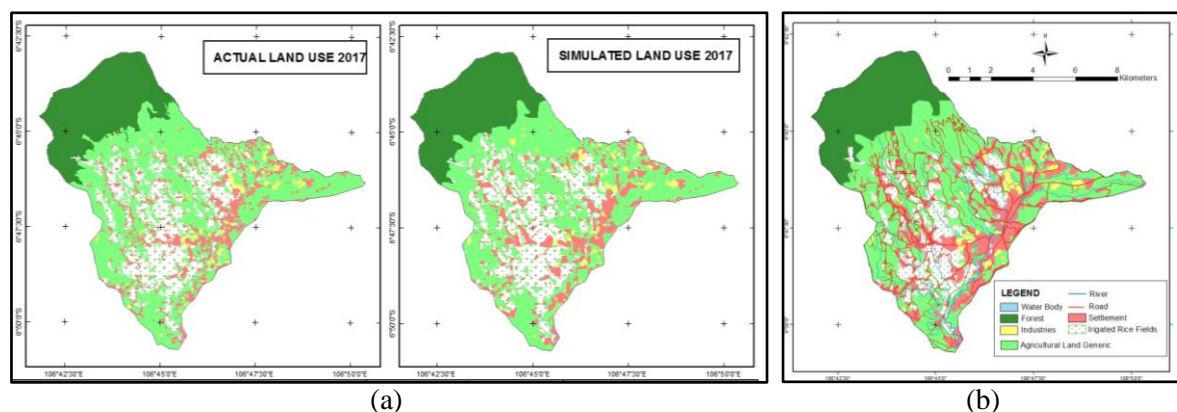


Figure 4. (a) Comparison of actual land use and simulation in 2017 (b) Land use Prediction in 2032

The prediction land use in 2032 performed the validation of CA-Markov model in actual year and simulation showed satisfactory kappa value. **Figure 4(b)**, prediction of land use change spatially in 2032. The area of irrigated rice fields in 2032 decreased by 29.23% of the total irrigated rice field in 2017, while the forest area decreased 5.49% of the forest area in 2017. Meanwhile, the use of settlements industrial and agricultural land generic increased, especially settlement area which increased by 49.87% of the total settlements in 2017. Other land uses of the industry increased by 25.7% and agricultural land generic increased by 0.61% of their respective land use in 2017.

3.3 Erosion Rate Prediction in 2032

The prediction model of erosion rate in UCCA was produced by using Soil Water Assessment Tools (SWAT) model. The form of erosion rate in SWAT model is sediment yield or sediment yield based on the application of MUSLE method (Modified Universal Soil Loss Equation) in tons / ha / year.

SWAT model validation and calibration results were tested using Nash-Sutcliffe Efficiency (NSE) and Coefficient of Determination (R^2). Nash-Sutcliffe Efficiency NSE test results is 0.69 which the value means is declared good, while the value of Coefficient Determination (R^2) is 0.71. Both values are declared good, so modeling can be used to estimate the erosion rate prediction in 2032.

Erosion rate prediction in 2032 by SWAT model in this research using prediction scenario of land use in 2032. The land use prediction in 2032 will affect HRU, so the rate of erosion rate and surface flow in each Sub-Basin is changing. The size of the erosion caused by rainfall, runoff, and human treatment to soil for their needs. The greater surface runoff, the higher erosion rate that indicated by the large increase of sediment yield in the area. Changes of land use in each Sub-Basin between 2017 and land use scenario in 2032 are presented in **Figure 5**.

Figure 5. shows that sub-basin with a high increase of settlements (URHD) occur in Sub-Basin 16, 5 and 13. Forest (FRST) and irrigated rice fields (RICE) are predicted in 2032 to decrease from area in actual land use 2017. While, settlement (URHD) and industries (UCOM) area tend to have an increasing area. Agricultural land generic (AGRL) undergoes a non-linear change in each sub-basin. The decrease of AGRL area in UCCA is usually accompanied by an increase of built-up area (URHD and UCOM) and the increase of AGRL followed by a decrease of RICE and FRST area with the high growth of non-settlements.

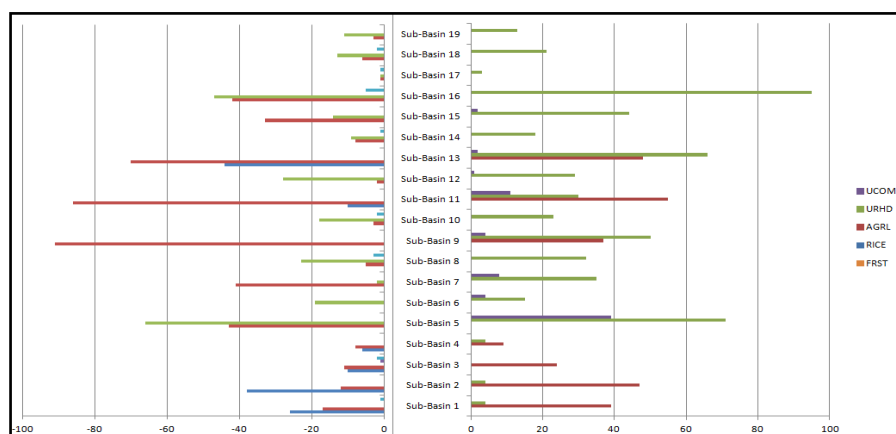


Figure 5. Changes of Land Use Area in Each Sub-Basin.

Increased erosion rates more than 20% are common in northern UCCA. This is because the area has decreased of forest area into agricultural land generic, as in Sub-Basin 1, 2, 3, 4 and 13. The five Sub-Basin are predicted to decrease the forest area from 10 ha to 38 ha in 2032. High canopy cover density levels such as forests can reduce the rate of falling water flow to the soil compared to low-density canopy vegetation, resulting in reduced sediment transport by water [8]. The increase of erosion rate is also affected by the dominant slope in that area by more than 40%. The slope is a topographical factor that affects erosion and if it is not protected by vegetation then the effect will be greater. In Sub-Basin 5 and 8, the built-up area in the forecast will increase by 110 ha and 29 ha respectively. However, changes in land use to built-up area do not contribute greatly to increasing erosion rate. This is because the both topographic characteristics are mostly located in areas classified as 0 - 8%. Topographical factors such as slope gradients can increase the transport energy of the surface flow to the sediment towards the bottom of the slope [9]. The more closer to flat in the area the sediment transport energy will be smaller.

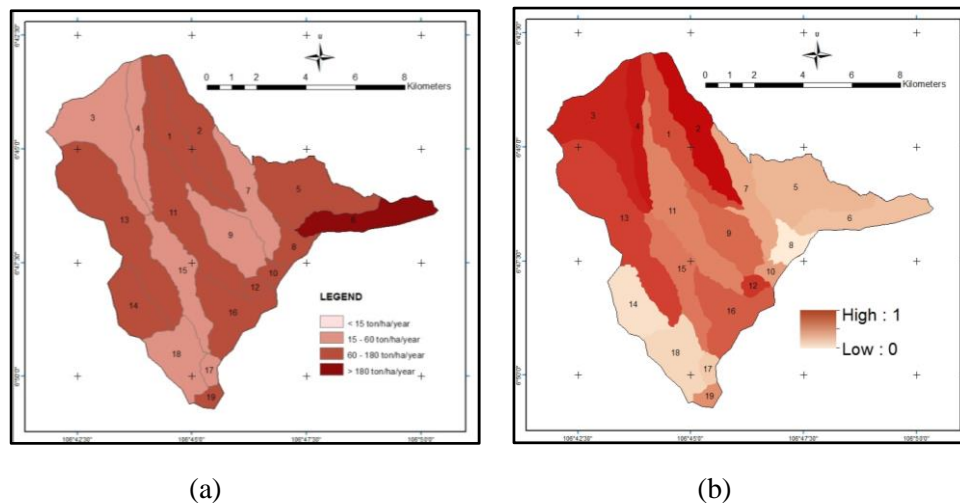


Figure 6. (a) Percentage of Increased Erosion Rate in Upper Ci Catih Catchment Area 2017 - 2032 (b) Erosion Rate Prediction in 2032

In contrast, increasing built-up area resulting from conversion of agricultural land generic and irrigated rice fields contributed substantially in Sub-Basin 7, 10, 12 and 16. Located on the dominant slopes by 0-15%, the increase of erosion rate in that Sub-Basin are high between 12.46% and 19.55%. Especially built-up area with asphalt land will disrupt the capacity of water flow in a flow area, the surface runoff received in short periods on built-up area can increase the effect of the sediment transport energy on soil [10]. Large amount of sediment yield that transported and deposited depict the eroded soil accumulation in the area. In Sub-Basin 9, 11 and 15, Irrigated rice field is converted to other landuse. The conversion of irrigated rice fields to other land use contributed substantially to the erosion rate increase of each Sub-Basin by 19%, 18% and 18.62%. This is because the sediment generated from irrigated rice field is less than by agricultural land generic and built-up area.. Mechanical methods on soil types of terraces commonly encountered in rice cultivation reduce the slope length and retain water, thereby reducing the speed and amount of surface flow, that will reduce the amount of erosion [9].

4. Conclusion

The physical characteristics of the Sub-Basin seen from the Hydrological Response Unit (HRU) affect the increasing of erosion rate prediction from 2017 to 2032 scenarios. Increasing the erosion rate in each sub-basin is generally due to the cover of vegetation land in areas with steep slopes tend to decrease and conservative measures are not applied in land management. The erosion rate is expected to increase from 2017 to 2032 with an average erosion rate increase in each Sub-Basins by 15%. SWAT model validation results using Nash-Suthcliffe (NSE) efficiency equation and Coefficient of Determination (R^2) 0.69 and 0.71. Both validation results indicate that modeling is feasible in Upper Ci Catih Catchment Area

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