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Changes in Land Use in the Lombok River Basin and Their Impacts on River Basin Management Sustainability

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Abstract. Sustainable management in water resources development strategies depends on the knowledge of phenomena of changes in land use in the river basin as a significant tool in understanding the interactions of environment and human activities. Changes that occur within a certain period on the land cover or land use impacts the basin characteristics, which will ultimately affect river basin management. This paper studies the change of land use in the Lombok river basin in Indonesia based on the Moderate Resolution Imaging Spectroradiometer (MODIS) land use/land cover data version 6 from the years of 2001, 2010, and 2016 which were derived using MODIS Terra and Aqua reflectance supervised classification data. Land use data was then classified into fifteen land use categories according to SWAT classification. QGIS and MapWindow software were applied to analyse the features of land use in the study area, and the SWAT simulation model was applied to simulate the impacts of changing land use in the sub-basin. The study concludes that areas with occurrences of changes in land use impacted the river runoff in the sub-basin. Analysis of river basin land use, when combined with simulation in water resources management, will contribute to optimal and sustainable river basin planning.

Keywords: Land use, sustainability, simulation, basin management.

1. Introduction

Modelling of hydrology phenomena and water management simulations become presently-used tools with advances in computer programming. Some models have been developed and widely applied as simulation tools in water resource systems and modelling of watershed behaviour, such as WEAP [1], SWAT [2], and MODSIM [3]. Using the tools, simulation of the dependence between various factors in river management predictions can be solved accurately and efficiently to help scientists in their research.

Changes of land use in a river basin, along with year-to-year variation in climate conditions, cause uncertainties in predicting water balance in a watershed. In the end, these uncertainties will influence the sustainability of water resource system management. Water resource systems in water management are known as common systems that accept one or more inputs and then generates one or more outputs in a watershed. Several studies have been carried out regarding the impacts of land use on water balance in the river basin [4, 5, 6, 7, 8]. All the conducted studies discuss some impacts on the variability of the hydrologic cycle in watershed caused by changes of land use within some period of time.
In this study, the SWAT model is applied to simulate the impacts of changes in land use in the climatology condition periods from 2001 to 2016 and from 1990 to 2017 on the monthly runoff of the Lombok river basin, with GIS tools as a supporting model. The study focuses on the simulation of the runoff prediction in the Babak watershed of the Lombok river basin, utilizing calibrated parameter values for the SWAT model. Calibrated parameters for the SWAT simulation model are verified by comparing simulated and observed values, and considering parameter sensitivity in the model. The calibrated parameters were used in further simulation with various land use map data on the time-series of climatology data.

2. Materials and Methods

2.1. Study Approach

This study was implemented with the following steps: (a) changes of land use in the study area were analysed with available map data and processed by the GIS tools; (b) the impacts of changes in land use are investigated from year to year with climatology data, which are combined with land use map data of different years using the SWAT model; and (c) the results of the simulation were compared to assess the magnitude of the runoff change difference due to changes of land cover in each period of time.

2.2. Study Site

The area of the study is the Lombok river basin in the Province of West Nusa Tenggara, Indonesia. Geographically, the river basin is located between latitudes 8°15’ S to 9°10’ S and longitudes 116°00’ E to 116°45’ E. The area of the Lombok river basin is 7.619.80 km², consisting of 4738 km² land area and 2881.18 km² water area, with a total of 3,394,280 people as the population in 2016 [9]. The average rainfall on the Lombok river basin ranges from 564.2 to 2156 mm annually with an average temperature of 23.7 to 26.5 °C per year [10]. Slightly wetter climatology conditions are experienced in the western region of the island than in the east due to the monsoon starting earlier in the west, hence a higher mean annual dry rainfall in the eastern region (458 mm) than in the western region (259 mm); in the wet season, the values are relatively similar for east and west (1113 mm and 1110 mm respectively) and the mean annual rainfall for the eastern region is 1571 mm, higher than the western part, which is 1368 mm [11].

In this article, the study of impacts of changes in land use was specifically conducted in the Babak watershed, one of the sub-basins of the Lombok river basin. The Babak watershed has a catchment area of 258.41 km² and 15 tributaries, with the length of the main river being 54.89 km, spanning the regencies of Lombok Timur, Lombok Tengah, Lombok Barat, and Lombok Utara. Rainfall data from two stations (Lingkok Lime and Jurang Sate), climatology data from the Lombok International Airport station, and water level gauge data from Keru Presak were used to simulate runoff in the watershed.

2.3. SWAT Model Description

The SWAT (Soil and Water Assessment Tool) is a model with continuous-time operation with daily or sub-daily time step simulation, and is physically based and semi-distributed. The SWAT model has been developed by USDA to simulate hydrological processes and to predict the effects of the implementation of land management, with runoff, water quality, and sediments as the elements that impact varying soil types and land use conditions in large and complex watersheds [2]. The SWAT model is a flexible tool to simulate land cover conditions and land management problems in a catchment area [12].

The Soil and Water Assessment Tool model is constructed on a water balance equation for the profile of soil, and infiltration, surface runoff, evaporation (ET), lateral flow, and percolation process are simulated. The water balance formula applied for the Soil and Water Assessment Tool model is shown as the following equation [2]:

\[
SW_t = SW_0 + \sum_{i=1}^{t} \left( R_{\text{day}} - Q_{\text{surf}} - E_a - W_{\text{seep}} - Q_{\text{gw}} \right)
\]  

\( (1) \)
where \( SW_i \) and \( SW_0 \) are respectively the final and initial soil water content in mm; \( i \) is the time of the simulation period \( t \) (days); \( Q_{\text{surf}}, R_{\text{day}}, W_{\text{seep}}, \) and \( E_s \) are the amount of surface runoff, precipitation, percolation and ET respectively; and \( Q_{\text{gw}} \) is the return flow on day \( i \) (cumecs).

In this article, the method of SCS curve number was utilized to estimate runoff in the watershed based on daily rainfall data, and the Penman-Monteith equation was chosen to simulate potential evapotranspiration. In the SWAT model, the river basin is split into several sub-basins and then subdivided into HRUs, which consist of soil types, land use, and management types of sub-basins.

Application of the SWAT model can be broken down into these steps: (a) data preparation, (b) watershed delineation, (c) HRU development, (d) parameter sensitivity analysis, (e) parameter validation, (f) parameter validation, and (g) analysis of uncertainty [7].

2.4. Data Collection and Processing

Spatially explicit datasets of maps of topography, land cover or land use, soil type characteristics, and climatology data needed by the Soil and Water Assessment Tool model were obtained and processed with the following steps: (a) the 30m DEM (digital elevation model) raster derived from 30 arc-second spatial resolution USGS/NASA SRTM (Shuttle Radar Topographic Mission) data was used to delineate the river basin catchment boundaries and generate the river network using the MWSWAT tool for the MapWindow software; (b) the soil type and characteristics for SWAT model input was extracted from the FAO soil map in the GeoTIFF format with a scale of 1:500000 raster, by which according to the FAO soil map, soil in the Lombok river basin was classified into seven types (Figure 1); (c) map data of land use in 2001, 2005, and 2010 were obtained from MODIS Land Cover version 6 [13] (Figure 3); (d) daily rainfall data series in Babak watershed at two rainfall stations and the daily observed streamflow discharge at Keru Presak station were collected from the Nusa Tenggara I River Authority; (e) meteorological data at the Lombok International Airport climatology station from 1971 to 2017 were collected from the Meteorological, Climatological, and Geophysical Agency (BMKG), including daily data for wind speed, humidity, solar radiation, minimum temperature, and maximum temperature.

![Figure 1. Soil classification in the Lombok river basin](image)

2.5. Sub-Basin and HRU Delineation

The MWSWAT tool for MapWindow GIS divided the Babak watershed into sub-basins based on topographic conditions derived from the DEM map and classified them into HRUs depending on the type of land use and the soil type within the sub-basin. From this step, the Babak watershed in the Lombok river basin as the study site was split into 39 sub-basins and 43 HRUs to be used further in SWAT model analysis (Figure 2).
2.6. Calibration and Validation

Streamflow data from the Keru Presak gauging station data were split from 1994 to 1999 as the period of calibration and from 2005 to 2009 as the period of validation. The Sequential Uncertainty Fitting 2 (SUFI-2) algorithm was used to calibrate and analyse the uncertainty for the SWAT parameters [14].

Model Performance was examined by Nash-Sutcliffe efficiency (NSE), relative error (Pbias), and RSR using the following formulas:

\[
NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}
\]

(2)

\[
Pbias = \frac{\sum_{i=1}^{n}P_i - \sum_{i=1}^{n}O_i}{\sum_{i=1}^{n}O_i} \times 100\%
\]

(3)

\[
RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}(O_i - P_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}}
\]

(4)

where \(O_i\) is observed value and \(P_i\) is simulated value, \(\bar{O}\) is the mean of observed data value, and \(n\) is the number of data points.

Pbias measures the mean of simulated data trends with observed counterparts [15]. Pbias indicates accurate model simulation if the Pbias value is zero. Nash-Sutcliffe efficiency represents how the observed data plot fits in comparison with simulated data results, with perfect performance reached if NSE = 1. RSR shows the error index, obtained from the root-mean-square error with the observed standard deviation of the data; the value of RSR ranges from 0 to 1, with a low value indicating a good model performance.

Figure 2. Changes in land use and number of sub-basins used in simulation for the Babak watershed.
2.7. Evaluation of Impacts of Climate Conditions and Changes in Land Use on Runoff

This research utilized the map of land use or land cover conditions from the years of 2001, 2010 and 2016. The climate conditions of the region were described by the monthly climate data during the study period. Simulation of the impacts of change in land use on runoff in the climatic condition of the Lombok river basin used scenarios of land use maps from 2001, 2010, and 2016 in combination with climate data. The simulation was performed using climate data from 1990 to 2017 to indicate the river basin climate conditions.

3. Results and Discussion

3.1. Changes in Land Use

At the Lombok river basin, evergreen broadleaf forests, croplands, and savannahs were the main types of land use in the years of 2001, 2010 and 2016 (Figure 3 and Table 1). Spatially, most upstream areas were filled by savannahs and evergreen broadleaf forests, while the middle to downstream parts had a large spread of other land use types.

In the years from 2001 to 2010, there were increased areas of woody savannahs (482.16%) and grassland (49.68%), which became the most evident changes in land use, while deciduous broadleaf forest areas decreased (37.50%); from 2010 to 2016, the most evident changes in land use were that deciduous broadleaf forests (24%) and grasslands (69.50%) increased, while mixed forests (38.46%) decreased.

Figure 3. Change in land use type areas in 2001, 2010, and 2016 in the Lombok river basin
Generally, changes in land use from 2001 to 2016 were indicated by decreased areas of mixed forests (-42.86%), deciduous broadleaf forests (-22.50%), croplands (-22.38%) and savannas (-15.09%) but increased areas of woody savannas (610.83%) and grasslands (153.72%). Conversion from savannas to evergreen broadleaf forests was the major land cover change type of land use conversion.

Land use change at Babak watershed from 2001 to 2016 were indicated by decreased areas of savannas (-40.869%), natural vegetation (-7.270%), and croplands (-81.151%), but increased areas of evergreen broadleaf forests (48.135%) and grasslands (18.612%). Based on the land use map, urban and built-up lands during the period did not change significantly from 2010 to 2016 (0.14% of the area of Babak watershed).

**Table 1.** Land use types area change in 2001, 2010 and 2016 at Lombok river basin

| Land use type                        | Area (x km²) | 2001       | 2010       | 2016       | 2001-2010 | 2010-2016 | 2001-2016 |
|--------------------------------------|--------------|------------|------------|------------|-----------|-----------|-----------|
| Bodies of Water                      | 16.18        | 15.65      | 15.30      | -3.26      | -2.25     | -5.44     |
| Evergreen Needleleaf Forests         | 2.64         | 1.93       | 2.99       | 26.66      | 54.54     | 13.33     |
| Evergreen Broadleaf Forests          | 1191.97      | 1303.98    | 1316.29    | 9.40       | 0.94      | 10.43     |
| Deciduous Needleleaf Forests         | 0.00         | 1.05       | 1.05       | -          | -0.01     | -         |
| Deciduous Broadleaf Forests          | 28.13        | 17.59      | 21.81      | -37.50     | 24.00     | -22.50    |
| Mixed Forests                        | 7.39         | 6.86       | 4.22       | -7.14      | -38.46    | -42.86    |
| Closed Shrublands                    | 0.18         | 0.18       | 0.00       | 0.00       | -100.00   | -100.00   |
| Open Shrublands                      | 0.00         | 0.00       | 0.00       | 0.00       | 0.00      | 0.00      |
| Woody Savannas                       | 22.68        | 132.05     | 161.24     | 482.16     | 22.10     | 610.83    |
| Savannahs                            | 673.61       | 666.22     | 571.98     | -1.10      | -14.15    | -15.09    |
| Grasslands                           | 56.62        | 84.75      | 143.65     | 49.68      | 69.50     | 153.72    |
| Permanent Wetlands                   | 98.64        | 97.41      | 109.19     | -1.25      | 12.09     | 10.70     |
| Croplands                            | 1306.61      | 933.33     | 1014.21    | -28.57     | 8.67      | -22.38    |
| Urban and Built-Up Lands             | 205.37       | 209.07     | 218.74     | 1.80       | 4.63      | 6.51      |
| Cropland/Natural Vegetation Mosaic   | 965.31       | 1106.69    | 996.27     | 14.65      | -9.98     | 3.21      |
| Non-Vegetated Land                   | 8.44         | 7.03       | 6.86       | -16.67     | -2.50     | -18.75    |

**Table 2.** Land use change at Babak watershed in the periods of 2001-2010, 2010-2016 and 2001-2016

| Time Periods | Savannas | Evergreen Broadleaf Forests | Grasslands | Natural Vegetation | Croplands | Urban and Built-Up Lands |
|--------------|----------|-----------------------------|------------|--------------------|-----------|--------------------------|
| 2001-2010    | -33.841  | 49.558                      | -81.686    | -10.402            | -81.782   | 0.000                    |
| 2010-2016    | -10.623  | -0.951                      | 547.638    | 3.496              | 1.466     | 0.000                    |
| 2001-2016    | -40.869  | 48.135                      | 18.612     | -7.270             | -81.515   | 0.000                    |

3.2. **Model Calibration and Validation**

Model calibration and validation were performed by comparing the observed and simulated streamflow values that resulted from the model. The estimation of the range of model parameters utilized the SUFI-2 algorithm, with consideration of sensitivity analysis for each parameter.

Six parameters were calibrated for the parameter effects on runoff. The parameters were composed of CN2, ALPFA_BF, GW_DELAY, GWQMN, GW_REVAP, and REVAPMIN. Among the other parameters, GWREVAP and CN2 input were the two most sensitive parameters in this simulation with p-values of 0.593 and 0.202 respectively. The calibrated range value parameters for the SWAT model input were used further in the simulation process, and are shown in Table 3.

Figure 4 shows the calibration and validation of simulated and observed monthly streamflow. Pbias, NSE, and RSR values during the calibration were -3.1, 0.63, and 0.61 respectively, and for the validation, the Pbias, NSE, and RSR values were 12.3, 0.56, and 0.66 respectively. These values showed that there was a good correlation between simulated and observed monthly runoff [16].
Table 3. Minimum and maximum values of the parameters of the SWAT model resulting from the calibration and validation process

| Parameter | Description                                                                 | p-value | Minimum | Maximum | Method |
|-----------|-------------------------------------------------------------------------------|---------|---------|---------|--------|
| CN2       | SCS runoff curve number                                                      | 0.202   | -0.498  | -0.086  | Relative |
| ALPHA_BF  | Base flow alpha factor, in days                                              | 0.114   | 0.228   | 0.297   | Replace |
| GW_DELAY  | Groundwater delay, in days                                                   | 0.118   | 375.2   | 443.33  | Replace |
| GW_QMN    | Threshold water depth in the shallow aquifer required for occurring return flow, in mm | 0.015   | -0.213  | 0.296   | Replace |
| GW_REVAP  | Groundwater revap coefficient                                                | 0.593   | 0.072   | 0.196   | Replace |
| REVAPMN   | Threshold water depth in the shallow aquifer for “revap” to occurring revap, in mm | 0.128   | 213.36  | 500     | Replace |

Figure 4. Monthly observed and simulated streamflow calibration and validation in Babak watershed at Lombok river basin

3.3. Impacts of Changes in Land Use on Runoff
Impacts of changes in land use on streamflow in Babak watershed in the Lombok river basin were simulated using the SWAT model. A simulation was performed for climatology data from 1990 to 2017 with land use map data from 2001, 2010, and 2016. From the analysis using the years from 2001 to 2016, annual runoff increased in sub-basins 6, 8, 9, 10, 11, 14, 23, 24, 25, 27, 29, 30, 31, 33, 34, 35, 36, 37, 38, and 39 and annual runoff decreased in sub-basins 6, 16, 27, 28, 29, 31, 34, 35, and 36 with the maximum and minimum difference occurring in sub-basin 39 in August and December, respectively. Differences of annual runoff ranged from -0.107 to 0.223 cumeecs, with the largest at sub-basin 39 as the Babak watershed outlet.
Figure 5. Runoff difference between SWAT simulation results using land use map year 2010 and 2016 and 1990-2017 climatology data at reach 39

The monthly runoff difference may be due to the major changes in land use in Babak watershed for the years from 2001 to 2016, with increased evergreen broadleaf forests (48.135%) and decreased grasslands (18.612%) savannas (-40.869%), natural vegetation (-7.27%) and croplands (-81.515%) (Table 2). Comparing with impacts of changes in land use among three simulated land uses (Figure 5 and Figure 6), the monthly runoff increased in the rainy seasons from 2001 to 2010 and from 2001 to 2017. Increased evergreen broadleaf forests and decreased grasslands, natural vegetation, and croplands impacted by increasing the monthly runoff in the dry season and decreasing the runoff in the rainy season. Meanwhile, decreased evergreen broadleaf forests and increased grasslands, natural vegetation and croplands affected by decreasing monthly runoff in the dry season and increasing monthly runoff in the rainy season, which is shown by the simulation from 2010 to 2016.

Figure 6. Runoff differences between SWAT simulation results using land use maps from 2001, 2016, and 2017 and climatology data from 1990-2017
4. Conclusion

To simulate the effects of changes in land use, the SWAT model was applied to the Babak watershed in the Lombok river basin, Indonesia. The simulation was conducted to assess the effects of changes in land use on monthly runoff with variations of climatology and land use map data series. Calibration and validation of the model were performed to determine the most appropriate values of parameters to be used further in the simulation model. With monthly periods, the calibrated SWAT model generated good simulation results.

Based on MODIS land use map analysis, changes in land use for the entire river basin from 2001 to 2010 occurred where deciduous broadleaf forest areas decreased to 37.50%, and the area of woody savannas and grasslands increased by 482.16% and 49.68% respectively. Meanwhile, increased areas of deciduous broadleaf forests (24%) and grasslands (69.50%) occurred at the basin from 2010 to 2016 while mixed forest areas increased to 38.46%.

At the Babak watershed, as part of the Lombok river basin, from the years of 2001 to 2010, evergreen broadleaf forest areas increased to 49.558% and there was decreased areas of grassland (-81.686%) savannas (-33.841%), natural vegetation (-10.402%) and croplands (-81.782%). Changes in land use at the Babak watershed from the years of 2010 to 2016 involved decreased areas of evergreen broadleaf forests and savannas by -0.951% and -10.623% respectively and increased areas of grasslands, natural vegetation, and croplands by 547.638%, 3.496% and 1.466% respectively.

Changes in land use in the periods from 2001 to 2010, from 2010 to 2016, and from 2001 to 2016 simulated by the SWAT model indicated changes in monthly runoff in the Babak watershed. The change in runoff was more distinct due to increased or decreased land use areas in the watershed.

When the land use changed, the monthly runoff increased in some sub-basins and decreased in other sub-basins. The variation of monthly runoff results from the combination of impacts of changes in land use, climate conditions, and sub-basin locations in the watershed.

In conclusion, the study results show that changes in land use contributes to runoff variations in a watershed. Furthermore, the location of sub-basins in a watershed also leads to variations in the magnitude of runoff. The availability of water in the context of time and space in the watershed as obtained from the simulation can be optimized to manage the water in a sustainable manner.

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