Land use change impacts on discharge analysis using SWAT model at Ciherang Pondok DAM catchment area

M A Utamahadi, N H Pandjaitan, M I Rau
Department of Civil and Environmental Engineering, Faculty of Agricultural Technology, Bogor Agricultural University, IPB Darmaga Campus, PO BOX 220, Bogor 16002, Indonesia
Email: norahp@apps.ipb.ac.id

Abstract. The prompt increase of population influenced the requirement for new regions to fulfill people’s primary needs. Its increased land use change and caused many impacts on the environment, including watersheds as well. Ciherang Pondok DAM catchment area is part of Cisadane watershed and was selected as the research area. This research aimed to analyse the water supply and water discharge change caused by the Urban Planning (RTRW) in 2020. The analysis was conducted using soil and water assessment tools (SWAT) model. Stages of this research were catchment area delineation, HRU identification, calibration and validation of models, and prediction of discharge and water demand. The result showed that RTRW of 2020 increased the maximum discharge of 1.6 m$^3$/s and decreased the minimum discharge of 0.01 m$^3$/s, hence the maximum and minimum discharge ratio increased 0.26% from 2016. Output discharge in 2020 at Ciherang Pondok Dam Catchment Area was classified as well, with discharge of 6.72 – 126.2 m$^3$/s, and could fulfil water demand. For the best result, it is better to use climate data from weather stations inside the study area and it is required an improvement in data archiving system.

1. Introduction
The prompt increase of population influenced the requirement for new regions to fulfill people’s primary needs. This concern lead to a condition where lands were developed inappropriately and had themselves beyond their carrying capacity [1]. Consequently, this will affect the hydrologic system of a certain watershed [2-4]. In 1984, from 458 watersheds in Indonesia, there were 20 watersheds indicated as super priority and this condition keeps increasing to 60 watersheds in 1999, one of such is Cisadane Watershed [5-6]. From the review result by the Ministry of Forestry of Indonesia [7], in 2015, the handling of critical lands in Cisadane Watershed was not much, so that interferences and damages increased were caused by numerous human activities, especially within the upstream region of the basin.

Focusing in a narrower region, one of the areas influenced in the upstream region of Cisadane Watershed is Ciherang Pondok Dam Catchment Area, which is the main water resources for the local communities and the provision of raw water by water supply company (PDAM) Tirta Pakuan Bogor. This research is aimed to undertake analysis of water availability and the change of river discharge at Ciherang Pondok Dam Catchment Area using geographic information system (GIS)-based software, i.e. soil and water assessment tools (SWAT). The SWAT model has been utilized and proved as an effective yet efficient tool for undertaking research in analyzing the response between hydrological cycle and land use change [8-11].
2. Methodology

The research was undertaken in May 2017 in Ciherang Pondok Dam Catchment Area, Central Management of Regional River Flow (BPDAS) of Bogor Regency, and Development Planning Agency (BAPPEDA) of Bogor Regency. Tools used within this research include laptop with Microsoft Office, SWAT, ArcGIS 10.1 with ArcSWAT 2012 plug-in, Google Earth, SWAT-CUP 5.1.6, minitab, calculator, and global positioning system (GPS). Material used were digital elevation model (DEM) of Cisadane Watershed with 30x30 m resolution, river map of Cisadane Watershed, boundary map of Cisadane Watershed, soil type of Bogor Regency, administrative area of Bogor Regency, landuse map of Bogor Regency, 2020 RTRW of Bogor Regency, daily climate data and rainfall of 2007-2016, water level data of Cisadane River for 2012-2016, outlet point coordinate, and population number per Bogor District for 2010-2016. Steps undertaken for this research included data acquisition, catchment area delineation, establishment of hydrological response unit (HRU), calibration and validation model, and river discharge and water demand prediction. Detail research steps are given in Figure 1.

Within the simulation process, DEM SRTM map was initially projected from geographical coordinates to universal transverse mercator (UTM) WGS 48S projected system using ArcGIS 10.1. The data for the delineation of the catchment area used was the river and coordinate point of Ciherang Pondok Dam Catchment Area. Afterwards, HRU establishment was done by inserting 2007-2016 climatic and rainfall data to SWAT 2012, where the results were the daily simulations with warming up period of 2 years.

Prior undertaking calibration process, Nash-Sutcliffe (NS) and R² value are required to be attained from the SWAT daily discharge simulation. NS is defined as the objective function and can be calculated using Equation (1) [12]. The simulation result could be categorized as a good performance if NS > 0.75 and satisfactory performance if 0.36 < NS < 0.75 [13]. However if NS < 0.36, it is then categorized as unsatisfactory performance and needed to be re-calibrated. On the other hand, to portray the pattern accuracy of the model output with the observation values, coefficient of linear R² equation was used (Equation (2)). If R² reaches 1, this condition indicates a close relationship pattern between the resulted model predictions with the field observation result.

\[ NS = 1 - \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y})^2} \]  
\[ R^2 = \left[ \frac{\sum_{i=1}^{n} (Q_{obs,i} - \bar{Q}_{obs}) (Q_{cal,i} - \bar{Q}_{cal})}{\sum_{i=1}^{n} (Q_{obs,i} - \bar{Q}_{obs})^2 \sum_{i=1}^{n} (Q_{cal,i} - \bar{Q}_{cal})^2} \right]^2 \]

Calibration and validation were undertaken using SWAT-CUP. The SWAT model used more than 500 hydrological parameters, however, not all parameters were used. The selection of parameters was done by studying the literature from various publications and sorting the most frequent parameters used in the SWAT model. Afterwards, the sensitive parameters were selected using p-value analysis. The smaller the value of p-value, the parameters became more sensitive to changes in the value of NS and R². Calibration was done by inputting the discharge data of 2009-2016 SWAT simulation result and observation discharge data from the conversion result of 2015 water level data, whilst validation was done using the 2016 water level data. Then, trial and error was undertaken to obtain the best parameter values, indicated by NS and R². Finally, re-simulation was done using 2020 RTRW with additional input of the best parameter value from validation result on SWAT editor, in order to attain the change of discharge value and water availability as an outcome from the 2020 RTRW.
Figure 1. Research methodology steps.
3. Results and Discussions

3.1. General
Cisadane Watershed starts from Salak Mountain at the southern region of Bogor Regency towards Java Sea with length of 137.8 km. Cisadane River is one of the main rivers in Banten and West Java Province. Ciherang Pondok Dam Catchment Area is part of the upstream area of Cisadane Watershed. Ciherang Pondok Dam Catchment Area is within the humid tropical rainy climate type in the Koppen climate classification [14]. The selected outlet was the raw water tapping building or Ciherang Pondok intake, located at 06.68° South Latitude and 106.81° East Longitude with an elevation of 380 meters above sea level. Furthermore, some weather stations and rain gauges are likely to affect the hydrology system in the watershed. There are some rain gauges that enter the research area but due to constraints, the data was then not used. The general solution used was to utilize the nearest station data. This means that the rainfall data from the closest station to the research location was used for the analysis [15]. The weather stations used in this study were Dramaga Weather Station, Katulampa Rain Gauge, Citeko Weather Station, and Gunung Mas Rain Gauge.

3.2. Watershed Delineation and HRU Establishment
Watershed Delineation basically divided the Sub-Basin into several hydrological catchment areas. Based on the delineation result, the area of Ciherang Pondok Dam Catchment Area was 17,066.97 ha or about 20% of the area of Upper Cisadane Watershed (85,256.19 ha) and about 11.03% of Cisadane Watershed (154,654 ha). The catchment area was subdivided into 3 sections with an area of 804.08 ha, 6,024.71 ha, and 10,238.17 ha respectively. The research outlet went to Ciherang Pondok Dam Catchment Area section 1, so that the discharge value is considered only in that particular area. The delineation result map is presented in Figure 2.

![Figure 2. Delineation result of Ciherang Pondok Dam Catchment Area.](image)

Within HRU establishment step, DEM, landuse map, soil type map, and slope classification data were all overlain using threshold by percentage method. For land use, 10% threshold was used, 5% threshold for soil type and 5% threshold for slope in accordance with Cisadane Watershed’s land rehabilitation plan and soil conservation. HRU establishment can also be used to assess the effectiveness of a reforestation / rehabilitation effort as well as other efforts to improve the quality of water resources and the recharging area of a specific region.
Land use at Ciherang Pondok Dam Catchment Area was divided into 7 types, among which the largest was 9192.27 ha (53.86%) of agricultural land, secondary forest, forest, settlement, rice field, and the smallest among others was shrubs of 6.83 ha (0.04%). The land use map is presented in Figure 3.

Based on the land distribution map in Figure 4, there were only 2 types of soil at Ciherang Pondok Dam Catchment Area. Most of the soil type in this area was brook andosol association of 9,605.57 ha (56.28%) and the rest was brook latosol of 7,461.41 ha (43.72%).

![Landuse map of Ciherang Pondok Dam Catchment Area in 2016.](image)

Figure 3. Landuse map of Ciherang Pondok Dam Catchment Area in 2016.

![Soil type map of Ciherang Pondok Dam Catchment Area.](image)

Figure 4. Soil type map of Ciherang Pondok Dam Catchment Area.

For this research, the slope was divided into 5 classes, i.e. 0-8% (flat), 8-15% (declivous), 15-25% (rather steep), 25-45% (steep), and >45% (very steep) [16]. The position of the area distribution is given in Figure 5. The result of the HRU establishment provided information regarding landuse, soil,
slope, total area, and percentage of HRU within a sub-basin. In this research, 150 HRUs within 3 sub-basin were gathered.

3.3. SWAT Simulation and Validation Model

Based on simulation results with landuse data in 2016, the maximum daily discharge which occurred was 216.70 m³/s, with minimum discharge of 0.61 m³/s, and an average discharge of 18.59 m³/s. Ciherang Pondok Dam Catchment Area water level data was initially converted into discharge value, in order to determine the value of NS and R² simulation results. Based on the data calculation results, NS value was -4.05, whereas R² was 0.20. The value was not satisfactory, hence, calibration was required.

The calibration and validation process were done using Sequential Uncertainty Fitting (SUFI 2) method with daily observation data in 2015 (for calibration) and 2016 (for validation). Calibration and validation were done as much as 32 times of iteration and simulation of 50-1000 times for each iteration. The number of final parameters used in this stage were 10 parameters, i.e. ALPHA_BF.gw, GW_DELAY.GW, GWQMN.gw, ESCO.hru, OV_N.hru, SLSOIL.hru, SLSUBBSN.hru, GW_REVAP.gw, REVAPMN.gw, and SURLAG.bsn.

Based on the calibration result, R² and NS value were 0.53 and 0.50, respectively, whilst the value of R² and NS validation were 0.60 and 0.54, respectively. The values were eligible and it could be concluded that the data were valid and satisfactory. The calibration and validation results are shown in Figures 6 and 7.
3.4. Effect of Landuse Change on River Discharge

The landuse change used was in accordance with the 2020 RTRW, which is presented in Figure 8. In the 2020 RTRW, forest land was reduced by 481.29 ha (2.82%) and agricultural land area of 2,392.79 ha (14.02%) from 2016. Most of the lands were transformed into residential and industrial land. Settlement area increased by 2,481.54 ha (14.54%) and there was land conversion into industrial land covering 421.55 ha (2.47%) from 2016. Paddy field was transformed into residential area according to 2020 RTRW.

Afterwards, SWAT simulation re-modelled with 2020 landuse and the sensitive parameters of validation result. Based on the results of data processing using the SWAT model, the value of discharge in 2020 was obtained. Based on the simulation results in Table 1, the maximum discharge of 2020 rose by 1.6 m$^3$/s, while the minimum discharge decreased by 0.01 m$^3$/s from 2016.

To assess the level of water availability based on the 2020 RTRW, predictive information of water demand was required. The number of population in 2010-2016 was used to obtain the water requirement. It was assumed that water requirement were 150 m$^3$/person/day with duration of water use of 9 hours/day. The prediction was done using minitab application. The utilization of raw water by Tirta Pakuan PDAM was 1.8 m$^3$/s and the value of water demand in 2020 was 5.74 m$^3$/s. Based on analysis results, the discharge of Ciherang Pondok Dam Catchment Area in 2020 could still meet 100% of PDAM water needs and was classified as uncritical (IK < 50%) [17].
3.5. Strategic Environmental Assessment (SEA)

In this research, the performance of catchment area was performed by parameter of river regime coefficient (KRS) and vegetation cover in accordance with the Forestry Minister Decree No P. 61 2014. Assessment results could be input into evaluation of government policies and planned as a function of strategic environmental studies, so that environmental impacts can be minimized [18].

The coefficient of river regime (KRS) showed fluctuations between the maximum and minimum discharge on the river. The sharp fluctuation of the discharge indicated that the watershed function was not performing well, which meant that the quality of the watershed was low [19]. Based on the calculation data, the value of both KRS in the study sites were included in the criteria very well, according to the specific flow discharge criteria [20]. There was an increase in the value of KRS from 2016 to 2020 by 0.26%. However, it did not mean much since the value was very small but still consider as a very good category. The calculated data were presented in Table 1.

| Parameter | 2016 | 2020 |
|-----------|------|------|
| Q max (m³/det) | 124.6 | Very Good | 126.2 | Very Good |
| Q min (m³/det) | 6.73 | Very Good | 6.72 | Very Good |
| Q ave (m³/det) | 20.21 | Very Good | 20.20 | Very Good |
| Qmax/Qmin Ratio | 18.51 | Very Good | 18.77 | Very Good |

Based on 2020 RTRW, the vegetation cover of Ciherang Pondok Dam Catchment Area decreased by 16.69% in 2016, but was still classified as good with 70%. Most of the vegetation land were transformed into residential and industrial land. The impact of this on a large scale will increase the fluctuation of river discharge in the rainy season but river discharge will be very low in the dry season [21].

4. Conclusion

Land-use changes based on the 2020 RTRW resulted a maximum discharge increase of 1.6 m³/s and a minimum discharge decrease of 0.01 m³/s, hence the ratio of the maximum-minimum discharge value of 2020 increased by 0.26% from 2016. The value of output discharge in 2020 at Ciherang Pondok Dam Catchment Area was still categorized as good, i.e. 6.72 - 126.2 m³/s, and met 100% of PDAM water needs.

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