Simulation of land cover changes in the hydrological characteristics of The Central Citarum Sub-Watershed

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Abstract. The availability of water in the reservoirs in the Central Citarum sub-watershed must be sustainable because it is the mainstay of irrigation water, electricity, and drinking water in parts of West Java and DKI Jakarta. This study aims to determine the effect of land cover change on hydrological parameters by simulating the SWAT (Soil and Water Assessment Tool) model. The research area covering an area of 273,240.85 ha, based on observations of Spot imagery in 2019, has a forest cover of 20.16%. The surface runoff calculation shows that the Flow Regime Coefficient (KRA) is very high (128). Based on the simulation with SWAT, the KRA value will be better (79) if the 2019 RTRW is fulfilled. The results of several land cover scenarios show that an increase in the forest area of 10 – 12% will increase infiltration by about 8-9% and reduce surface runoff by about 8%, and groundwater recharge will be better. The flow of the Citarum river fluctuates and fills the Jatiluhur Cirata Reservoir with an average of 800,081,212.0 m³/year. One way to improve the hydrological function is to convert some dryland agriculture, streamlining urban forest plants to obtain a forest area of 37%.

1. Introduction
The 2020-2024 National Mid-Term Development Plan states that the Citarum River Basin is still a priority watershed that must be restored to health along with the other 5 Priority Watersheds due to declining land and hydrological conditions. Weaknesses in the management of the Citarum watershed cause high levels of erosion, runoff, flooding, landslides, drought, and pollution that occur in the watershed area. One of the causes of natural disasters related to water resources is the drastic decrease in the carrying capacity of the watershed as an ecosystem. The process in the watershed in converting inputs into outputs is influenced by many complex factors, some of which are land use and soil conditions. The process in the watershed in converting inputs into outputs is influenced by many complex factors, some of which are land use and soil conditions [1]. Changes in land and forest cover in the downstream, middle to upstream watershed areas have resulted in open, degraded, and critical lands so that erosion, flooding, and drought have become customers for the upstream and downstream areas of the Citarum.

The conversion of forest land into functional areas will eliminate the role of the middle, upstream areas as water catchments and protection of the area below. 2015 land cover map analysis [2] shows that the forest area in the Citarum watershed is 110,211.6 ha (15.96%), each distributed in the upstream, middle and downstream areas of 34,095.25 ha (4.94%), 57,178.70 ha (8.28%), and 18,937.65 ha (2.74%). There is only 4.94% forest in the upstream area, a very small number because the upstream watershed area should be an air catchment area. This area should have a larger forest cover area when
compared to other uses. It is better if based on the mandate of Law no. 41 of 1999 concerning forestry, which enforces the forest area in a watershed area is 30 percent of the watershed area and or islands with a proportional distribution, so the condition of this upstream area is very important.

The results of previous studies have shown that the presence of forest can significantly affect the watershed water system, although the optimal area of cover (forest) in each region varies depending on the biophysics of the watershed (region) [3]. For example, BPTKP research in the Solo watershed based on peak discharge and sedimentation of teak forests in Cepu, pine forests in Gombong, and protected forests in Tawangmangu shows that the optimal forest area is 45-47%, 31-37%, and 64% of the total watershed area, respectively. Thus, it is expected that the implementation of regional spatial planning takes into account the minimum forest area in a sub-watershed or 30% or more [4].

The decline in water resources in the Citarum watershed shows the need for realignment of the watershed components in it, especially land cover in the middle and upstream areas of the watershed. A model that can simulate processes in a watershed well is a distributed model where the characteristics are also considered in the model's input. Several distributed physical process-based models are HEC, IHDM, WATFLOOD, and SWAT. These models can simulate hydrological processes spatially and temporally. The Soil Water and Assessment Tool (SWAT) model is one of the most widely applied and studied models in simulating processes in watersheds [5]. More research is needed, especially regarding the calibration process when using water flow observations in the watershed [6], because it will provide an opportunity to develop better hydrological modeling.

This study aims to determine the effect of changes in forest land cover area on the hydrological parameters of the central Citarum watershed through a SWAT model simulation. The results of this study are expected to be input for the parties in carrying out watershed management planning and evaluating regional spatial planning.

2. Research Metode

2.1 Research Time and Location
The research was conducted in 2020 in the Central Citarum sub-watershed, which includes 16 (sixteen) small sub-watersheds. Geographically it is located between 107°22'50.606"L – 107°56'46.297"L and 6°45'40.112"LS – 7°14'27.018"LS, as shown in Figure 1. Administratively is located in Bandung Regency, Purwakarta Regency and Sumedang Regency, Cianjur Regency, Bogor Regency, West Java Province.

![Figure 1. Research Location.](image)

2.2 Materials and tools
Materials and tools used in this research include GPS, a computer set equipped with ArcGis 10.2 software, ArcSwat 2012, ring infiltrometer and soil sampling equipment, meters, other field equipment, and stationery.
2.3 Data Collection
The secondary data used include a 1:25 000 digital map of Indonesia, an 8 m resolution DEM (Digital Elevation Model) map, a soil type map (scale 1:100,000 from Puslittanak Bogor), and a 2019 land cover map with a scale of 1:100,000 interpretation results. Spot imagery, climate data (monthly max and min temperatures, relative humidity, duration of sun exposure, monthly average wind speed) obtained from the Meteorology, Climatology and Geophysics Agency from the nearest station, daily rainfall data and daily discharge obtained from Jasa Tirta and the Department of Water Resources Management of West Java Province.

2.4 Use of the SWAT Model.
The SWAT model analysis was conducted to estimate the impact of changes in land/forest cover area on the hydrological response. The steps shown in Figure 2 include data preparation according to a predetermined format into the input data file, delineation of the research area (watershed boundaries), formation of HRU (Hydrological Response Unit), running SWAT, model calibration and validation, and model simulation.

\[ Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \]  
\[ S = 25.4 \left( \frac{100}{CN} - 10 \right) \]

Where:
- \( Q_{surf} \) = surface runoff accumulation
- \( R_{day} \) = daily rain
- \( I_a \) = early abstraction
- \( S \) = Retention
- \( CN \) = Curve Number

Figure 2. Stages of SWAT Analysis.
Acceptance of the model is determined from a simple statistical test of the coefficient of determination and the Nash–Sutcliffe Efficiency (ENS). Below is a simple statistical calculation formula used [8].

\[
R^2 = \left( \frac{\sum_{i=1}^{n}(Q_{Mi} - \bar{Q}_m)(Q_{Si} - \bar{Q}_S)}{\sum_{i=1}^{n}(Q_{Mi} - \bar{Q}_m)^2 \sum_{i=1}^{n}(Q_{Si} - \bar{Q}_S)^2} \right)^2
\]

\[
E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{Mi} - \bar{Q}_m)^2}{\sum_{i=1}^{n}(Q_{Mi} - \bar{Q}_m)^2}
\]

Where:

- \( R^2 \) = Determinansi coeffition
- \( E_{NS} \) = Nash-Sutcliffe coeffition
- \( Q_{Si} \) = Model simulation value
- \( Q_{Mi} \) = Observation value
- \( (\bar{Q}_m) \) = Average observation value
- \( n \) = Total data

The making of watershed boundaries automatically uses the automatic watershed delineation facility in the ArcSWAT program. The input in this stage is a DEM map on the UTM system projection for the 48S-datum WGS84 zone. The process is continued by forming a hydrological response unit with inputs in the form of land cover maps, soil types, and slope classes. The next stage is to run (running) SWAT and save the results for calibration.

The calibration and evaluation are based on the \( R^2 \) value and the efficiency of the NSE (Nash Sutcliffe Efficiency) model, while the model validation is carried out on the discharge data, namely by entering the calibrated parameters into the simulation data. Next, compare the observation data and the results of the calibrated discharge simulation. The statistical method used is the Pearson correlation coefficient (R) and the Nash–Sutcliffe coefficient of efficiency (NSE). The NSE statistical criteria for validation are the same as for calibration. NSE statistical value criteria i.e 0.75 <NSE<1.00 (very good); 0.65<NSE<0.75 (good); 0.50<NSE<0.65 (satisfactory); and NSE≤0.50 (unsatisfactory). [9] Use of the SWAT Model.

The flow regime coefficient reflects the condition of the watershed, calculated using the provisions issued by the Ministry of Forestry in document 5 monitoring the watershed evaluation, namely the Regulation of the Minister of Forestry of the Republic of Indonesia number P.61/Menhut-II/2014 [10].

\[
KRA = \frac{Q_{max}}{Q_{min}}
\]

Where:

- \( Q_{max} \) = Maximum discharge
- \( Q_{min} \) = Minimum discharge or \( Q_a = 0.25 \times \) monthly average discharge

| Value | Qid | Category          |
|-------|-----|-------------------|
| ≤ 20  |     | Very Low (SR)     |
| 20 < Qid ≤ 50 |   | Low (R)           |
| 50 < Qid ≤ 80 |   | Medium (S)        |
| 80 < Qid ≤ 110 |  | High (T)          |
| > 110 |     | Very high (ST)    |

Source: [12]

The model application is carried out by simulating several scenarios of forest area, dryland agriculture, and settlements, which are land cover parameters that have the most influence on watershed management so that they become dominant in the simulation. Scenarios are prepared based on several considerations, namely: Scenario 2019 (existing) is a condition based on land cover in 2019 which is
considered scenario 1, scenarios 2 to 4 are the opposite of the current trend, namely returning forests from dry land agriculture, shrubs and settlements in forest areas with us. Changes the area variable. Scenario 5 leads to the Provincial RTRW by converting dryland agriculture, shrubs, and open land into the forest up to 37%. Scenario 5 is structured close to the spatial pattern of the 2019 West Java Province RTRW, where the forest area reaches 37% (protected area reaches 50.59%). The simulated scenarios are shown in Table 2.

**Table 2.** Scenarios of forest area, dryland plants, and settlements

| Scenario (area, %) | Forest | Dryland, Bush | Settlement | Paddy field |
|-------------------|--------|---------------|------------|-------------|
| 1 (Lcov 2019)     | 20,1   | 26,9          | 23         | 23          |
| 2                 | 26     | 23            | 22         | 22          |
| 3                 | 29     | 22            | 21         | 21          |
| 4                 | 32     | 19            | 20         | 29          |
| 5                 | 37     | 15            | 20         | 28          |

3. Results and Discussion

3.1 Characteristics of the Central Citarum SubWatershed

The Central Citarum Sub-watershed area consists of 16 (sixteen) Sub-watersheds with outlets in the Jatiluhur Reservoir. The results of the delineation of DEM data with the SWAT model are 273,240.85 ha consisting of Cilawang, Cipada, Cibalagung, Cihalang, Ckareo, Citarum 108 and 58, Cimanggu, Ciburial, Cisokan, Cikidang, Cipatunjang, Cimurah, Cisubah, Cibungur, and several sub-watersheds. The distribution of rainfall is uneven, with annual rainfall varies between 1,566 – 2,600 mm. The wettest moon reaches 300 mm. The climate watershed is generally classified as type C according to the Schmidth and Fergusson classification or Am type according to the Koppen classification [11].

Soil types in the middle Citarum watershed consist of 15 soil types, dominated by brown Andosol Association soil type and brown Regosol covering an area of 59,824 ha (35.4%) then grayish brown Alluvial, mainly in the north to east area of Bandung Regency. Alluvial soils are soils resulting from sediment, erosion, and flooding, with poor aeration and drainage. Andosol soil is a soil that developed from tuff parent material and intermediate volcanic ash, mainly found in hilly and mountainous areas with a relatively high elevation [12], has a deep solum, rich in organic matter, fast drainage, and has high permeability.

Based on the 2019 land cover analysis results using SPOT images, the central Citarum watershed is dominated by dryland agriculture of 71,042.62 ha (25.98%) and rice fields of 64,812.72 ha (23.72%). Meanwhile, the production and natural forest area is 20.19% (55,167.32 ha), consisting of primary/secondary dryland forest and plantation forest. However, the reality of land cover that year was far from the expectations of the 2019 RTRW (Spatial Pattern Plan).

3.2 Results of SWAT Model Simulation

3.2.1 Hydrological Respon Unit

At the HRU formation stage, land cover, soil, and slope data are inputted for overlaying. HRUs are generally used for SWAT runs because of the simplification of the run model by combining all areas with the same soil type and land use into a single response unit. Furthermore, the definition of HRU (HRU definition) is carried out to determine the specific criteria that will be applied in the HRU. In defining HRU, the threshold by percentage method is used. This method is used to determine how large the threshold for soil types, land cover, and slopes in the sub-watershed is ignored by the model in the formation of the HRU. In this running, more than 789 HRU were obtained, and 57 subwatershed were obtained. Figure 3. In this subbasin, it will be known which areas will show large to small runoff classes to be used as a reference in selecting biophysical management priorities.
3.2.2 Runoff model and Calibration

Observation data used for calibration is data in January-December 2016 from the outlet after the Jatiluhur reservoir. Some experience [13] suggested involving data from the wet and dry periods in the calibration and validation processes. This research used data from the wet and dry months throughout the year. The results of plotting the observed discharge data and the simulation results are presented in Figure 4 below.

![Figure 4](image)

**Figure 4. Observation & Simulation Value Plot.**

Basically, the value of $R^2 0.5$ is considered acceptable [9], so the model can be used to simulate the desired scenario. The results of the plot in Figure 4 show the value of determination $R^2 = 0.71$.

While the NSE value lies between 0 to 1, with NSE = 1 being the optimal value, a value between 0.0 and 1.0 is generally seen as an acceptable level of model performance. After being calibrated and validated, the Nash-Sutcliffe coefficient (NSE) calculation results between the monthly discharge of observations and predictions is 0.68 (good). The estimated discharge of this model using climate data and land cover maps in 2016 is shown in the following graph in Figure 6. The graph shows that the model discharge tends to be smaller than the observed discharge, but the curve pattern or shape is almost the same. The difference occurs because there is an additional inflow from the sub-watershed above/upstream, namely the discharge flow from the Saguling reservoir outlet. The model discharge tends to be earlier in forming the peak flow than the observed flow discharge, although the peak is smaller.
3.2.3 Simulation of Land Coverage and flow rate

The comparison of observational discharge data and model discharge has met the requirements, namely with an NSE value of 0.68 (good category). Furthermore, several land cover scenarios were applied to select the best flow regime coefficient (KRA) with this model.

The graph in Figure 6 shows that scenario 1 is runoff based on existing land cover in 2019, then scenarios 2 to 4 are an overview of the simulated forest cover area. Furthermore, scenario 5 is a forest cover simulation based on the 2019 RTRW. The graph also shows that an increase in rainfall tends to be followed by an increase in surface runoff. There is a time lag between the peak of rainfall and the peak of the flow hydrograph as there is a lag in the travel time of runoff water to the outlet, and some of it infiltrates into the soil.

![Figure 6](image)

**Figure 6.** Graph of direct flow discharge according to five (5) scenarios of forest cover area.

The next process is that after there is enough rain, the river flow will rise and fall again after the rain is over. The amount and variation of river discharge depend on the thickness of the rain, the intensity of the rain, the duration of the rain, and the distribution of rainfall. Rainfall that directly becomes running water can be caused by several factors, including slopes and vegetation cover (land cover). As much as 41.29% of the Central Citarum watershed area is a slightly steep slope area. According to Asdak (2014), the greater the slope of a watershed, will accelerate the runoff rate so that the watershed response to rainfall will be faster. Vegetation cover and land use also affect the amount of runoff because each type of land cover will respond differently to rainfall. Covers in the form of forests with canopy, branches/twigs, roots, and even litter can slow down the runoff rate and hold water longer above the soil surface so that it can be infiltrated first.

The difference in runoff results based on existing conditions in 2019 with the 2019 spatial plan shows a gap or imbalance in the success of the spatial planning target with the conditions that occur. With this situation, it is necessary to make further adjustments to the forest area and conservation areas, and dry land needs to be considered for reforestation.

3.2.4 Hydrology Regimes

The flow regime coefficients presented in Table 3 are calculated using the provisions issued by the Ministry of Forestry in document 5 monitoring the watershed evaluation, namely the Regulation of the Minister of Forestry of the Republic of Indonesia number P.61/Menhut-II/2014.

| Scenario | Qmax | Qmin | Value Qid |
|----------|------|------|-----------|
| 1        | 193  | 1,5  | 128       |
| 2        | 192  | 2    | 96        |
| 3        | 191  | 2,1  | 90,95     |
| 4        | 189  | 2,37 | 79,74     |
| 5        | 190  | 2,4  | 79,1      |

Source: Analysis results 2020
The Flow Regime Coefficient (KRA) value based on existing land use in 2019 is 128 or in the poor category. From the five scenarios, the best score was 79.1, including the medium category. The implementation of this scenario can be fulfilled if the 2019 spatial pattern is implemented properly. While the maximum and minimum debit ratio below 50 is a good category which is not easy to fulfill in the current conditions to fulfill the Minister of Forestry Regulation No. P.61/Menhut-II/2014 concerning Monev DAS. Land conversion in the middle Citarum watershed is very high, so that it affects discharge fluctuations and can increase the KRA value of the watershed. However, apart from being influenced by land use change, the KRA value is also influenced by the pattern and variety of rainfall [14].

### 3.2.5 Central Citarum Water Yield and Reservoir Water Needs

Rainfall results and land cover simulations based on spatial planning in 2019 show that of the 1,744 mm of total rain that falls in a year, 40.99% runs off as surface runoff; infiltrated into baseflow, lateral flow, and percolation of approximately 30.29%, 9.54%, and 21.65% respectively. Rainfall in the North Bandung and Cianjur areas is quite high but uneven throughout the year, so that it also affects the fluctuation of discharge and the value of KRA.

The average annual water yield based on hydrological parameters scenario by the analysis of the Swat model in the middle Citarum watershed is presented in Table 4.

**Table 4.** The results of Hydrological Parameters based on Simulation in Central Citarum

| Simulation   | Water Yield (mm) | Direct Surface flow (mm) | lateral flow (mm) | Percolation (mm) | Evapotran (mm) |
|--------------|------------------|--------------------------|------------------|-----------------|---------------|
| 2019 (Exist) | 1836.23          | 913.83 (51%)             | 168.43           | 434.45          | 349.91        |
| Scenario 2   | 1798.74          | 835.37 (47%)             | 165.47           | 381.61          | 397.29        |
| Scenario 3   | 1804.93          | 792.57 (44%)             | 167.25           | 476.31          | 402.80        |
| Scenario 4   | 1758.80          | 773.17 (43%)             | 159.07           | 484.46          | 400.10        |
| **Scenario 5** | **1744.38**     | **715.19 (40.9%)**       | **166.41**       | **528.37**      | **377.66**    |

Table 4 shows that decreasing forest cover area can increase runoff and runoff. Conversely, if there is an increase in forest area, it will increase soil infiltration and evapotranspiration. Scenario 5 shows a fairly good result of the hydrological process, while the worst scenario is scenario 1, which is a 20% reduction in forest cover from the plan (2019). As for Scenario 3, namely increasing forest cover by 19%, it is somewhat able to improve the hydrological condition of the watershed but has not achieved good results, so it needs to be followed by the application of soil and water conservation techniques, both civil and technical, vegetative or a combination of both on lands agriculture. Scenario 4 and 5 have a moderate C value, while the other scenarios are high even in scenario 1 it is very high. The decrease in forest area due to conversion to dryland agriculture and settlements causes a reduction in water catchment areas, resulting in a decrease in water retention capacity. This condition can cause increased erosion and drought, but the presence of the Jatiluhur, Cirata reservoir can stabilize water reserves and accommodate sediment.

In Scenario 1, it is simulated that a forest area of 20% and a residential area of 22% increase runoff by 24.9%. The decrease in forest cover causes 58% of the rainwater that falls to run off so that it can trigger flooding, especially when the rainfall intensity is high. Land conversion causes changes in surface runoff (overland flow), total runoff, and fluctuations in river flow. The surface runoff condition of an area depends on the characteristics of the rain and the biophysical conditions of the land surface [15-16]. The distribution of the surface flow map in central Citarum is shown in next figure 7.
The large evapotranspiration value will not affect the river flow because the average rainfall in the Citarum watershed is more than 1,500 mm/year. Fluctuation in the flow of the Citarum River is also caused by the management of agricultural land that has not applied adequate soil and water conservation techniques and land use that is not following the carrying capacity of the land.

The increase in river flow can also occur due to the degradation of the physical properties of the soil due to the conversion of forest functions to Other Use Areas (APL). The more watershed areas are built, the process of infiltration of surface water into groundwater will be disrupted. This triggers an increase in river discharge during the rainy season so that it can cause flooding and have an impact on the minimum river discharge in the dry season which can further reduce the quality of river water [17-18].

The annual water yield in each scenario is shown in table 3, has a less significant difference because the intensity of the rain also determines the water yield. However, watershed management is declared successful if the percentage of water absorption in the form of infiltration, percolation, and lateral flow is relatively large because it will increase baseflow.

The water yield or total flow in Scenario 5 or according to the spatial pattern of RTRWP scenario 5 is 1,579.93 mm, and this condition can reduce the total runoff by 3.5%. This flow accumulates in a year calculated at 800,081,212.0 M3/yr, presented in Figure 8.

The distribution of monthly water yields throughout the Central Citarum Sub-watershed illustrates the monthly available water reserves in the area. Special attention is that two large reservoirs supply irrigation water needs; raw water for drinking and power plants must be met from water harvests in the middle and upstream sub-watersheds. Most of the water harvest will flow and fill the volume of two continuous reservoirs/cascades, namely Jatiluhur, with a cumulative total volume of 2,448 million m3, Cirata of 1,900 million m3 for water supply for these various needs.

The decline in river discharge in the dry season has occurred in several areas in West Java, even in some upstream areas experiencing periods of water deficit at certain times. One of them is the Citarik Sub-watershed which has the longest period of water deficit, which is for 11 months and the surplus month only occurs in December [11].

4. Conclusion
An increased forest area in Central Citarum Subwatershed about 10–12% will increase infiltration by about 8-9% and reduce surface runoff by about 8%, with approximately the same lateral flow. Increasing forest area in the Central Citarum sub-watershed by around 10-12% will improve the coefficient of flow regime from 128 (high) to 79.7 (medium). The results of the calibration of the SWAT model show the $R^2$ and NSE values of 0.72 and 0.68 (good), respectively, and the model validation results are 0.71 and 0.67 (good). The implementation of Scenario 5 will improve the hydrological condition of the Sub-watershed by converting dryland agriculture into the forest and improving urban forest so that a total of 37% forest is obtained.
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