Landuse change analysis for hydrology response and planning management of Cibeet Sub-Watershed, West Java, Indonesia

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Abstract. Cibeet Sub-watershed is located in downstream of Citarum watershed and categorized as Priority I. Land use change is an environmental issue which causes damage of that watershed ecosystem. Land use change can also affect the hydrological conditions of the watershed. The results of the SWAT (Soil Water Assessment Satellite) model simulation in the Cibeet Sub-watershed used LISAT (LAPAN IPB Satellite) imagery show that KAT (Coefficient Run off) value is a very high (0.54). Based on land use in RTRW (Regional Land Use Planning) West Java 2025 the value of KAT decreased to 0.49 in the high category. Application of Soil and Water Conservation (KTA) techniques to land use of the LISAT imagery 2017 by Water Infiltration Wells were able to reduce surface flow by 63.49% and KAT values to 0.4 medium categories.

1. Introduction

Watersheds [1] have an important role in the hydrological cycle as a catchment area and channel water. Therefore, good watershed management planning is needed, so that the watershed is maintained and the water availability around the watershed area is fulfilled. Ecosystem damage to watersheds causes the watershed hydrological function to be worse and the environmental services provided will decrease.

This watershed damage is one of them caused by unplanned land use changes. The number of watersheds in Indonesia which are categorized as damaged is increasing from year to year and requires priority in handling them. In 1984 out of 458 watersheds in Indonesia there were 20 priority watersheds (priority I) and increased to 37 in 1992. In 1999, the number of watershed priority I increased to 60 watersheds. Based on the Decree of the Minister of Forestry Number: SK.328 / Menhut-II / 2009, the number of priority watersheds increased to 108 watersheds. One of them is the Cibeet Sub-watershed which is part of the Citarum Watershed, including the priority 1 watershed category.

The Cibeet sub-watershed was chosen as the research location because this watershed is part of the lower Citarum watershed that supports energy and food security in West Java. The Citarum watershed is currently designated as a watershed with critical conditions. Based on data from BPDASHL Citarum-Ciliwung (2013), soil erosion potential in the Cibeet Sub-watershed reaches 112.85 million tons/year and the sedimentation rate reaches 0.82 million tons/year. The Citarum Downstream Basin has many build area and rice fields so it has a very critical level of critical erosion which is 14.157 Ha (4.62%). The cause of damage to watershed ecosystems is land use change. Changes in land use cause increased fluctuations in river discharge and sedimentation (Rahman, 2009). It affect the main function of the watershed as a regulator of the hydrological cycle. Therefore, land and water conservation based land management planning is needed. Various efforts have been made by the BPDASHL Citarum-Ciliwung...

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watershed in improving the biophysical Citarum watershed such as Forest and Land Rehabilitation program and the application of Water Absorption Wells. Watershed management planning can be done with the SWAT (Soil Water Assessment Tool) hydrological model. The SWAT hydrological model is an alternative tool for determining the best watershed management planning conditions (Junaidi and Tarigan, 2010). The SWAT model is able to assess landuse change use in terms of the hydrological characteristics of a large watershed with a long period of time. The objectives are: 1) To determine the effect of Landuse change from 2011 to 2017 which is characterize the hidrological condition in Cibeet; 2) To determine the effect of land allocation on the Spatial Plan Spatial Plan of West Java Province in 2025 in the Cibeet Sub-watershed area on the hydrological characteristics. 3) Providing recommendations for proper management of the Cibeet Sub-watershed. This research is useful as a consideration for stakeholders related to regional planning, so that it can formulate the best and sustainable regional planning around the Cibeet Sub-watershed.

2. Methods

2.1. Study site

Activity of the SWAT model research in the Cibeet Sub-watershed was from February 1, 2017 until June 30, 2017. The Cibeet Sub-watershed geographically is located at 107°15'0"E - 60°36'0"S. The Cibeet watershed has an area of 90,204.24 Ha. The Cibeet sub-watershed is a downstream part of the Citarum watershed. The Cibeet Sub-watershed is included in the Priority Watershed in Indonesia (BPDASHL Citarum-Ciliwung, 2013).

Figure 1. Study area.
2.2. Material and tools
The material used in this study is in table 1. The tools used are computers with software applications ArcGIS 10.1, ArcSWAT 2012 version, Microsoft Office 2007, Global Positioning System (GPS), stationery, and supporting equipment, e.g (digital cameras and data storage devices).

| No | File Types | File Source |
|----|------------|-------------|
| 1. | - Rainfall date for 2004-2017 | PUSAIR West Java |
|    | - Climate date : air temperature, air humidity, wind speed, and solar radiation 2007-2017 | BMKG (Meteorological, Climatological, and Geophysical Agency) Citeko and Geofisika Bandung |
| 2. | Daily river flow 2013 and 2014 | BBWS Citarum |
| 3. | Map of landuse in 2011 and 2014 of Landsat satellite | Ditjen Planologi MoEF (Ministry of Environment and Forestry) |
| 4. | Map of landuse in 2017 image of LISAT IPB | LAPAN IPB Satellite |
| 5. | Map of Regional Spatial Planning of West Java 2025 | Bapeda Jawa Barat |
| 6. | Map of soil types scale 1 : 250.000 | Balai Besar Sumberdaya Lahan |
| 7. | DEM (Digital Elevation Model) 30M | USGS Glovis |

2.3. Data processing
The procedure of this study was carried out in two step. The first step is collecting secondary data. This secondary data is used for making SWAT database inputs such as land data, landuse and climate. The second stage is to simulate the SWAT model which consists of several processes including: 1) the process of watershed delineation (formation of river and sub-basin networks); 2) Hydrology Response Unit (HRU) analysis; 3) climate generator database input; 4) build climate data; 5) running SWAT models; 6) calibration and validation process; 7) simulation of SWAT hydrological parameters.

The statistical method used in the calibration and validation process is the coefficient of determination ($R^2$) and Nash-Sutcliffe Efficiency (NSE). The calibration process is a step to determine the accuracy result of the SWAT model output using the statistical method, so that the output of the model can approach the real condition of the watershed being tested. Model calibration is done by selecting values for input parameters of the SWAT model carefully by comparing the model prediction data (output) for a set of conditions assumed by observation data in the same conditions [2]. Calibration in the SWAT model is done by adjusting the combination of parameter values that affect the hydrological conditions of the watershed, the model results (discharge output models) are approached to the measurement results (discharge observation). The discharge data used in the calibration process is the 2014 daily debit data. The point of the outlet used in the Cibeet-Bendung SPAS. The results of the model output are tested for accuracy with the coefficient of determination ($R^2$) and Nash-Sutcliffe Efficiency (NSE). The determination coefficient is the square value of the correlation coefficient based on Bravais-Pearson. $R^2$ value can be calculated using the formula:

$$R^2 = \frac{(X - \bar{X})^2 - (X - Y)^2}{(X - \bar{X})^2}$$  (1)

Where

$X$ = Observation Data,
$\bar{X}$ = Observation Data Average
$Y$ = Simulation Data

$R^2$ value between 0 and 1 illustrated how much the distribution of observation data can be explained by simulation data. If the value is higher, it indicates a low error variant. The value of $R^2 = 0$ means there is no correlation at all, whereas if $R^2 = 1$ means the distribution of predictive data is the same as
observation data. The use of the equation from the Nash-Sutcliffe Efficiency (NSE) efficiency model was recommended by The American Society of Civil Engineers in testing the accuracy of model output. The equation is as follows:

\[
NSE = 1 - \left[ \frac{\sum_{i=1}^{n} (Y_{i}^{obs} - Y_{i}^{sim})^2}{\sum_{i=1}^{n} (Y_{i}^{obs} - Y_{i}^{\bar{obs}})^2} \right]^{2}
\]

Where
- \(Y_{i}^{obs}\) = Observation data \(-i\),
- \(Y_{i}^{sim}\) = Simulation data \(-i\),
- \(Y_{i}^{\bar{obs}}\) = Observation data Average,
- \(n\) = Observation total.

Table 2 showed the range of NSE values is between \(-\infty\) to 1, with NSE = 1 being the optimal value. NSE values between 0.0 to 1.0 are generally seen as acceptable levels of model performance, while NSE values \(\leq 0.36\) indicate that the average value of observation data is a predictor that is close to the value of simulation data, then the range of values shows acceptable performance level [3].

| No | NSE Value | Catagories |
|----|-----------|------------|
| 1  | NSE > 0.75 | Good       |
| 2  | 0.75 > NSE > 0.36 | Satisfy |
| 3  | 0.36 < NSE | Not Satisfy |

Source: Motovilov et al. 1999

2.4. Design of the land management simulation for the Cibeet Sub-Watershed

The simulation of the Cibeet watershed management activities was carried out to produce the best scenario in reducing surface flow and discharge fluctuations (Watershed hydrological response indicators). The simulation applied is landuse application on 2011 and 2014 Landsat imagery, Landuse on 2017 from LISAT imagery and application of West Java Spatial Pattern Map on 2025, and Application of KTA (Soil and Water Conservation) Techniques with SRA (Water Infiltration Wells) on LISAT Landuse on 2017 in the Cibeet Sub-watershed.

3. Result and discussion

3.1 Accuracy model (calibration and validation)

The calibration process is carried out to test the accuracy of the model in describing the condition of the watershed in the field being tested. Calibration used in this study with manual calibration. Manual calibration is done by finding sensitive parameter values in the SWAT model. The SWAT model has several sensitive parameters that affect the output of the model. According to Arnold et al. [2], sensitive parameters used in the calibration process related to surface runoff include CN2 (Initial SCS runoff curve number for moisture condition II), SOL_AWC (Available water capacity of first soil layer (mm/mm)), ESCO (Soil evaporation compensation factor), EPCO (Plant uptake compensation factor), SURLAG (Surface runoff lag time (day)), and OV_N (Manning’s “n: value for overland flow). Sensitive parameters related to base flow include ALPHA_BF (Baseflow alpha factor (days)), GW_REVAP (Groundwater “revap” coefficient), GW_DELAY (Groundwater delay (days)), GW_QMIN(Threshold depth of water in the shallow aquifer for return flow to occur), REVAPMN (Treshold depth of water in the shallow aquifer for “revap” to occur), and RCHARG_DP (Deep aquifer percolation fraction). The sensitive parameters used in the calibration process in the Cibeet Sub-watershed include CN (surface flow curve number), ALPHA_BF (base flow alpha factor), GW_DELAY (long 'delay' underground water), GWQMN (minimum base flow height), ESCO (soil evaporation factor), EPCO (plant uptake factor), CH_N2 (Manning value for main channel), CH_N1 (Manning value for tributary channel), CH_K1 (tributary hydraulic channel), CH_K2 (hydraulic conductivity on alluvium main channel),
ALPHA_BNK (base flow alpha factor for 'bank storage') and SURLAG (surface flow lag coefficient) (table 3). The input model parameters are used in the calibration and validation process.

The hydrological model, especially SWAT, is expected to describe the hydrological response of the Cibeet Sub-watershed according to conditions in the field. With this model calibration process, the input parameters of the model can be adjusted to the field conditions in the watershed area studied. In addition, a validation process was carried out to see the consistency of the SWAT model in simulating the hydrological process in the watershed being studied.

Figure 2 shows the initial value before calibration has an NSE of -0.40 and a $R^2$ value of 0.49. Based on the graphic image and scatter plot, it can be indicated that the trend of the flow of the Cibeet Sub-watershed resulting from the model with the observation debit does not have a similar flow pattern. Therefore, it is necessary to adjust the input parameters of the model with conditions in the field, so that the discharge of the model with observation discharge has similarities.

Table 3. Parameters used in the calibration process of the Cibeet Sub-watershed.

| No | SWAT Parameters | Max Value | Min Value | Value Used |
|----|-----------------|-----------|-----------|------------|
| 1  | CN2             | 25        | 92        | 25-92*     |
| 2  | CH_K1           | 0         | 300       | 5          |
| 3  | CH_N1           | 0.01      | 30        | 0.01       |
| 4  | ESCO            | 0         | 1         | 0.65       |
| 5  | EPCO            | 0         | 1         | 0.85       |
| 6  | CH_K2           | 0.01      | 500       | 12.70      |
| 7  | CH_N2           | 0.01      | 0.3       | 0.025      |
| 8  | SHALLST         | 0         | 5000      | 2500       |
| 9  | DEEPST          | 0         | 10000     | 4000       |
| 10 | GW_DELAY        | 0         | 500       | 29         |
| 11 | ALFA_BF         | 0         | 1         | 0.8        |
| 12 | GWQMIN          | 0         | 5000      | 2000       |
| 13 | ALFA_BNK        | 0         | 1         | 0.75       |
| 14 | REVAPMN         | 0         | 10000     | 150        |

Description: * value used based on landuse characteristics

NSE before calibration = -0.4

Figure 2. Value of debit simulation and debit observation before calibration on 1st January until 31st December 2013; (a) Flow hydrograph and (b) Scatter plot.

The result of the calibration process of the output of the SWAT model in the Cibeet Sub-watershed shows the values of $R^2$ and NSE of 0.62 and 0.53, respectively (satisfactory categories). This shows that the SWAT model is quite good at simulating flow discharge in the Cibeet Sub-watershed. According to Motovilov et al. [4], the value of $0.4 < \text{NSE} < 0.5$ in the SWAT model can be accepted and used to simulate flow discharge in a watershed, so that the model built can simulate the desired scenario. Figures
3 and 4 illustrate the comparison of the output flow discharge of the simulation model and observation flow discharge after calibration.

![NS after calibration = 0.53](image)

**Figure 3.** Value of debit simulation and debit observation after calibration on 1st January until 31st December 2013; (a) Flow hydrograph and (b) Scatter plot

The process after calibration is continued with validation. Validation is the step to test the consistency of the SWAT model parameters used in the simulation. Validation is done by comparing the observation discharge (1st January–31st December, 2014) Cibeet–Shipon outlet with the model flow using a calibration parameter. The values of R² and NSE after validation were 0.7 and 0.4 (satisfactory categories) (figure 4).

![NSE after validation = 0.4](image)

**Figure 4.** Value of debit simulation and debit observation after validation on 1st January until 31st December 2013; (a) Flow hydrograph and (b) Scatter plot.

3.2 Hydrological response of Cibeet Sub-watershed

Hydrological characteristics of the watershed in the SWAT model are described in the form of direct runoff (direct surface flow), lateral flow and base flow. Direct runoff is the result of surface flow (SURQ) with lateral flow (LATQ). The simulations of the SWAT model were carried out on several land use changes from the LISAT IPB image, the West Java RTRW on 2025 and the application of the KTA technique in LISAT 2017 land use.

The results of running the SWAT model from land use LISAT imagery on 2017 have surface flow of 1,284.52 mm, lateral flow 628.6 mm and KAT 0.54 including very high categories. In 2017 there was a decrease in dry land forest area of 100.13 Ha compared to the use of Landsat interpretation land use on 2011 having a secondary dry land forest area of 5,279.66 Ha and plantation forest of 7,746.47 Ha. Forest areas play an important role in the hydrological cycle of watersheds. The function of the forest as a water catchment area and storing water as a base stream that fills the ground water table in the ground. The
wider the area of forest land use, the rainwater that falls on the surface of the tree canopy will be intercepted and above ground level infiltrated into the soil profile. In addition, there was an increase in the area of settlements in 2017 was 8,500.18 Ha, an increase compared to 2011 with a settlement area of 2,950.94 Ha. The addition of residential area indicates that as the year increases, the higher the population growth in the Cibeet Sub-watershed area. In the land use, the West Java RTRW spatial pattern has a surface flow value of 1054.08 mm, lateral flow 697.76 and KAT 0.49 including the high category. Allocation of residential land on the RTRW map of the space pattern in West Java Province is 4,349.28 Ha. Land allotment in the Cibeet Sub-watershed according to the map RTRW recommends 54,889.13 Ha as paddy fields because of the focus on agricultural development in the Cibeet Sub-watershed area as a rice granary area.

Based on the results of running the SWAT model on LISAT on 2017 land use and the RTRW Regional land use allocation planning of West Java Province on 2025 having KAT 0.54 and 0.49, it is necessary to recommend land management techniques KTA (Soil and Water Conservation) and SRA (Water Infiltration Wells) (table 4 and figure 5). The KTA technique with SRA is used to reduce the potential for surface runoff, flooding and landslides, so that more water is infiltrated into the ground and fills the ground water table. The application of the KTA technique in dry land use and mixed agricultural land was able to significantly reduce surface flow because the extent of the application of KTA reached 47.71% of the total area of the Cibeet Sub-watershed. In addition, the application of terracing KTA techniques in the use of rice fields amounted to 21.69% of the total area of the Cibeet sub-watershed. The application of SRA (Infiltration Wells) in Settlement Areas is 9.33% of the total area of the Cibeet Sub-watershed. Application of KTA (Soil and Water Conservation) Techniques to LISAT Land Use on 2017 in the Cibeet Sub-watershed has a significant influence on changes in hydrological characteristics. The application of the KTA technique in the Cibeet Sub-watershed produces surface flow of 468.93 mm (13.22% of total rainfall), lateral flow of 962.5 mm, and base flow of 1005.37 mm (figure 6). Therefore the KAT (Annual Flow Coefficient) value of 0.4 is included in the moderate category according to the Regulation of the Minister of Forestry of the Republic of Indonesia No. P.61 / MENHUT-II / 2014.

| No | Hydrology Character          | LISAT Imagery on 2017 | RTRW on 2025 | KTA Technique in LISAT Imagery on 2017 |
|----|-------------------------------|-----------------------|--------------|---------------------------------------|
| 1  | Rainfall (mm)                 | 3545.21               | 3545.21      | 3545.21                               |
| 2  | Runoff/SURQ (mm)              | 1284.52               | 1054.08      | 468.93                                |
| 3  | Lateral Flow /LATQ (mm)       | 628.6                 | 697.76       | 962.5                                 |
| 4  | Annual Flow Coefficient (KAT) | 0.54                  | 0.49         | 0.40                                  |

Figure 5. Distribution of annual flow coefficient (KAT) values as result of applying the regional planning land cover map (RTRW) in Cibeet Sub-watershed.
4. Conclusion

Simulation running the SWAT model on 2017 land use LISAT imagery in the Cibeet Sub-watershed has a surface flow of 1284.52 mm with a KAT value of 0.54 very high category, while the land use spatial pattern of the West Java RTRW has a surface flow value of 1054.08 mm and KAT 0.49 including the high category. The use of LISAT 2017 land and Spatial Pattern RTRW shows that the hydrological conditions of the Cibeet Sub-watershed are being degraded, so it needs to be supplemented by the application of KTA (Soil and Water Conservation) techniques with SRA (Water Infiltration Wells). The application of the KTA technique with the SRA on the LISAT 2017 land use in the Cibeet Sub-watershed was able to reduce surface flow by 63.49% and the KAT value (Year Flow Coefficient) decreased to 0.4 including the moderate category according to the Regulation of the Minister of Forestry of the Republic of Indonesia No. P.61 / MENHUT-II / 2014.

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