Working Paper

Simulating the effect of change in land cover and rainfall in Upper Citarum Watershed: calibration and sensitivity analysis of Genriver model

Lisa Tanika, Betha Lusiana, Adis Hendriatna

World Agroforestry

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Abstract

Land use and climate change are factors that significantly affect the watershed hydrological conditions, and hence influence the effectiveness of the watershed in regulating landscape water balance. Therefore, ensuring that land allocation and utilization are managed sustainably is crucial, and as such watershed management must be supported with integrated watershed planning. This study aims to show the ability of GenRiver model is supporting the watershed planning as a tool to assess the current condition of watershed hydrologcal function, as to what extent the watershed can buffer and filter the impact of changes in land use and climate. We will test the model on an important watershed in West Java, the Upper Citarum watershed which is a part one of the national priority watersheds; Citarum watershed. A process of model calibration and sensitivity analysis were conducted to determine the feasibility of Genriver model in simulating Upper Citarum watershed conditions, in particular to estimate the water balance at landscape level. The results of the GenRiver model simulation in the Upper Citarum Watershed using data from 2012-2016, showed that on average 37% of the rainfall that falls in the Upper Citarum Watershed becomes surface flow (run-off), 7% becomes sub-surface flow and 20% baseflow. Sensitivity analysis was carried out by compiling five land cover scenarios and three rainfall scenarios that were considered to represent various conditions that might include extreme conditions: the entire land became an open area (extremely negative) and the entire land became forest (extremely positive). The results of the extreme negative simulation projection show that the degraded condition of the Upper Citarum watershed with the dominance of open land has the potential to increase surface runoff up to 70% of the rainfall. Meanwhile, improvement of land cover in the upstream Citarum watershed by reforestation (positive extreme scenario) was able to reduce surface runoff by up to 20% of the total rainfall. The model calibration and validation evaluation showed that GenRiver performed satisfactorily and was sensitive enough to capture the range of scenarios. Therefore, GenRiver model can be used for simulating policy-based scenarios to simulate the effect of land-use interventions or restoration programme in Upper Citarum watershed. A soil erosion module needs to be added so that a sound policy recommendation can be developed from Genriver outputs.

Key Word

Citarum watershed, Genriver model, Land and climate change impacts, Hydrological model, Hydrological function of watershed, Sensitivity analysis,

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1. Introduction

A water catchment or watershed has a significant role in sustaining the livelihood of the people living in it. Watershed degradation can trigger various natural disasters such as floods, land slides and droughts. There are many factors that affect watershed conditions, including land cover and climate. Guo et al (2008) stated that changes in land cover affect the total annual discharge in a watershed. Therefore, watershed management, especially land use planning and management, is a pre-requisite to maintain watershed conditions and mitigate problems and issue potential to degrade watershed.

According to Government of Indonesia Regulation No. 37 of 2012 concerning Watershed Management, watershed management is defined as human efforts to regulate the reciprocal relationship between natural resources and humans in the watershed and within all their activities, in order to achieve the sustainability and harmony of ecosystems and increase the benefit of natural resources for humans in sustainable manner. The first stage in watershed management is composed of inventory planning, preparation of watershed management plans and determination of watershed management plans. Inventory activities here can be in the form of setting watershed boundaries and watershed assessments for classifying categories as being maintained and restoring their carrying capacity[1].

With an area of 6.617 km^2, Citarum become one of the major watersheds in Java and Indonesia because of its role as a provider of clean water, energy supply (electricity in Java and Bali) and support for food security as a source of irrigation for rice field (Kurniasih N, 2002 and BBWS, 2016). However, the hydrological condition of the Citarum watershed, both in terms of quality and quantity, is vulnerable to land use change and climate change. In watershed planning and management, the Citarum watershed is divided into 3 parts based on its topography, namely: (a) the Upper Citarum watershed which empties into the Saguling Reservoir, (b) the Middle Citarum Watershed which empties into the Cirata Reservoir and (c) the Lower Citarum Watershed which empties into the Jatiluhur Reservoir. In general, the upstream watershed functions as an important conservation area for protecting the function of the river system. Therefore, any activity in the upstream area ptentialli will have an impact in the downstream area, such as flow rate fluctuations, sediment transport and dissolved materials in the river system. Hence, watershed management is the upstream area often becomes the main focus of attention.

Given the current condition of Citarum watershed it is desirable and pertinent to assess the hydrological function of the Upper Citarum watershed. One approach to assess watershed conditions is to analyze discharge patterns and water balance, which can be done with the help of a hydrological model. A hydrological model is a mathematical representation of a watershed-response system that can be used to simulate the input-output conditions of the watershed. Using a hydrological model, it is possible to predict the magnitude of changes in water discharge that will occur because of potential

[1] Ministry of Forestry Regulation No. 60 of 2014 concerning Criteria for Determination of Watershed Classification.

fiture changes in the watershe. In addition, a hydrological model can also save costs, efforts and time in the research process to assist policy making in designing suitable watershed management plans.

The World Agroforestry (ICRAF) has developed a parsimonious hydrological model, the Generic River Flow or GenRiver model (Van Noordwijk et al, 2011). GenRiver model simulates the impact of land cover changes on hydrological conditions, ie. the landscape water balance partitioned as the amount of evapotranspiration, surface flow, subsurface flow and base flow. GenRiver model also able to simulate the trajectory of changes in water balance components over a period of time.

This study aims to evaluate the suitability of GenRiver model to assess the hydrological function of the Upper Citarum watershed using a model simulation approach. This article specifically discusses:

1. Genriver model calibration process by analyzing the impact of land cover changes in the period 2012-2018 on the condition of the upstream Citarum watershed
2. Sensitivity analysis process by estimating and projecting the impact of various land cover and climate change scenarios on the Citarum watershed in the period 2019-2028.

2. Methodology

2.1. GenRiver Model

Generic Riverflow Model (GenRiver) is a simple model that simulates river flow in a watershed based on the conversion of water balance from plot level to watershed level. The model model was developed by the World Agroforestry Center (ICRAF) to allow the use of a simple, replicable, and rapid approach in assessing the watershed hydrological condition using publicly available hydroclimate data from various sources including government agencies and other research institutions. Specifically, the model was intended to support the development of incentive schemes for ecosystems services in a watershed. The GenRiver model has been applied to various watershed conditions both in Indonesia and outside Indonesia with an area between 6 – 9,800 km^2. Hydrological assessment activities using GenRiver model generally last about 6 months.

The GenRiver model uses the water balance equation shown by equation 1. This equation assumes a closed water system in a landscape where rainfall will be channeled into river discharge (Q), evapotranspiration (E) and groundwater (ΔS).

$$P = Q + E + \Delta S \quad (1)$$

The core concept of the GenRiver model is the daily water balance at the plot level generated by daily rainfall and influenced by land cover changes (Van Noordwijk et al 2011). The output of this plot level water balance is the water yield which is the sum of surface flow, subsurface flow and base flow. Furthermore, the resulting water yield is converted into discharge at the landscape level (watershed) through the river network (distance to the final outlet). Figure 1 is an illustration of the concepts and modules in the GenRiver model. The data required by the GenRiver model consists of spatial, climatic and hydrological data (Table 1).

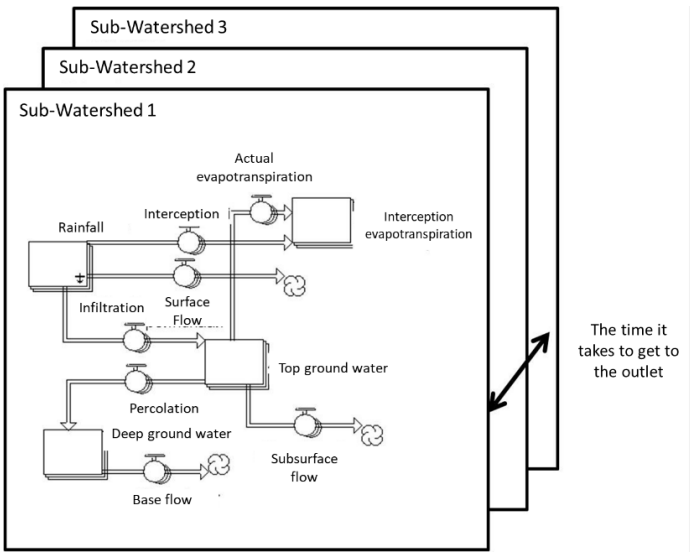


Figure 1. The core of the GenRiver model which is a combination of the water balance at the sub-watershed level to the watershed level

Table 1. Minimum data required to simulate GenRiver Model

No		Input	Period	Minimum data requirement
1	Climate	Rainfall	Daily	10 years data
		Temperature	Daily or monthly	1 year data
		Evaporation from (Pan evaporation)	Daily or monthly	1 year data
2	Hidrology	River discharge	Daily	10 years data
3	Spatial	Land cover map	-	2 transition year
		Soil map	-	-
		DEM map*)	-	
		River map	-	-

2.2. Modeling Stages

There are three stages in carrying out hydrological modeling using the GenRiver model to meet the objectives of this research (Figure 2).

a. **GenRiver model input preparation**. This stage encompasses the preparation of all the inputs needed to simulate the GenRiver model including the data collection and analysis process. The data that has been collected is then analyzed and compiled according to the format required by the GenRiver model. Collecting information on watershed conditions from various stakeholders (community, government, Nand GOs, water use companies and other stakeholders in the watershed area) is also needed to develop plausible land cover change scenarios. Further analysis of climate, hydrological and spatial data can be seen in Khasanah et al (2010).

b. **Hydrological modeling using GenRiver Model.** The hydrological modeling phase with the GenRiver model begins with the calibration and model validation stages. Calibration is a process of adjusting several parameter values (parameterization) in the model with the aim that the simulation results represent the actual watershed conditions (Kumarasamy and Belmont, 2018). Parameter values that require adjustmen are usually paranmeters that require considerable time and cost to measure such as infiltration rate, maximum soil capacity and river roughness. Validation is the process of comparing between the water discharge estimated by the model with the actual measured discharge. When the calibration and validation stages are completed, the next step is to simulate scenarios of land use changes and assess their impact on the landscape water balance.

c. **Model interpretation**. This stage is the final stage, where we compare the simulation results of the different land cover and climate change scenarios. The output of this stage can be used in developing watershed management plans.

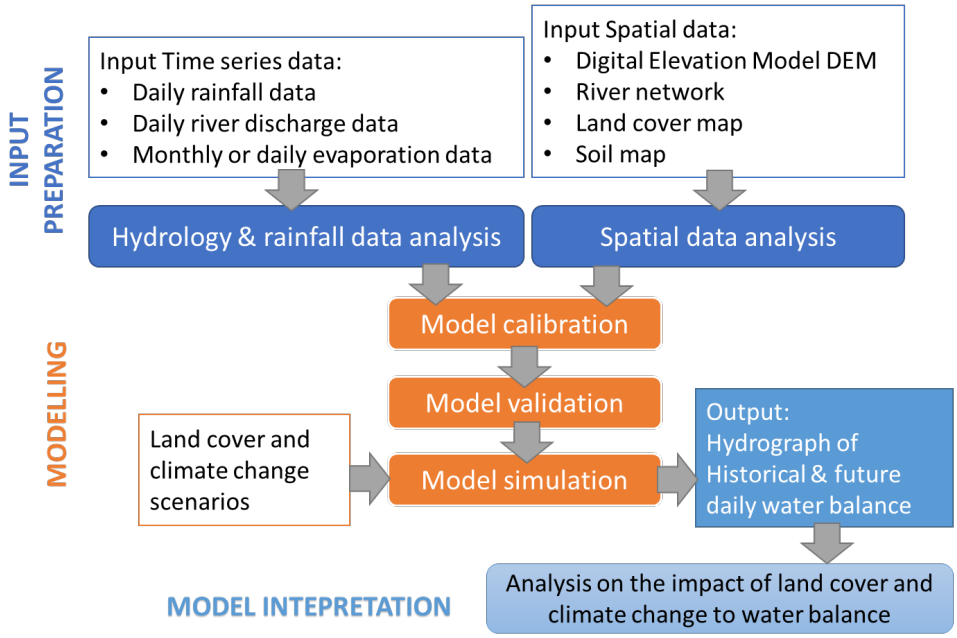


Figure 2. Stages of hydrological modeling using the GenRiver Model

2.3. Calibration, Sensitivity Analysis and Model Evaluation

Calibration, sensitivity analysis and model evaluation are activities conducted in the early stages of modeling, to determine the feasibility of the model and its parameterization.

Calibration is a process of determining parameter values that are not measured and representing watershed characteristics. Generally, calibration of a hydrological model is conducted on a group of parameter values (measured and non-measured) to ensure that the simulated discharge was able to captire the trend of the actual discharge value (Kumarasamy and Belmont, 2018). Although the calibration process cannot correct fundamental errors such as model structure and data quality, the calibration process is an important step and needs to be carried out to improve the reliability of hydrological model applications.

Sensitivity analysis in modeling aims to measure the effect of changes in a parameter on the changes in simulation results. In modeling, especially hydrological modeling, calibration and sensitivity analysis are usually carried out simultaneously to assess the viability of a model application. In this study, the sensitivity analysis is intended to see the sensitivity of the GenRiver model in simulating a range of plausible scenarios and asses if the simulated results are plausible and conceptually sound. Feasibility will be assessed from the ability of Genriver model to simulate changes in the landscape water balance within the range of two extreme scenarios.

Model evaluation is often also referred to as model validation, which is the process of determining whether the model conceptually is a simplification that represents a real system. There are many kinds of validation methods, and in the context of this study, the validation of the GenRiver model is done by comparing the simulation output with field observations/measurements. There are three (3) indicators used to measure how close the simulation results are to the measured discharge: (i) bias, (ii)

correlation coefficient and (iii) Nash-Sutcliffe Efficiency. In this study, each indicator is calculated for one year of daily observations for each year of the 2012-2014 calibration and evaluation period.

Bias (%) measuring the difference between the total daily river discharge observed (y_{obs}) with the total daily river discharge generated by the simulation (y_{sim}), calculated using equation 2 using the performance reference according to Table 2.

$$Bias = \frac{\sum(y_{obs} - y_{sim})}{\sum y_{obs}} x\ 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Table 2. Category of model performance based on the value of bias.

Bias	Model performance
|Bias| < 10	Very good
10 ≤ |Bias| < 15	Good
15 ≤ |Bias| < 25	Enough
|Bias| ≥ 25	Not good

Correlation coefficient (*r*) measuring how similar the trend/pattern is produced by the total daily river discharge observed (x) with the total daily river discharge generated by the simulation (y) with a certain amount of data (n), calculated using equation 3.

$$S_{xx} = \sum x^2 - \frac{(\sum x)^2}{n}$$

$$S_{yy} = \sum y^2 - \frac{(\sum y)^2}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$S_{xy} = \sum xy - \frac{(\sum x)(\sum y)}{n}$$

$$R = \frac{S_{xy}}{\sqrt{S_{xx} S_{yy}}}$$

The value of $r > 0.65$ indicates the model is quite satisfactory in simulating river discharge and conversely the value of $r \leq 0.65$ indicates the model is not satisfactory in simulating river discharge.

Nash-Sutcliffe Efficiency (NSE) measuring the residual variance of the model relative to the diversity of observational data (Moriasi DN, et al, 2007). NSE is between -∞ (infinity) and 1, measured by equation 4 with the reference value in Table 3.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

With Y_i^{obs} as the daily river discharge observed, Y_i^{sim} is the daily river discharge simulation results, Y^{mean} is the average monthly river discharge observed and n is the number of observed data.

Table 3. Category of model performance based on NSE value

NSE	Model performance
0.75 < NSE ≤ 1.00	Very good
0.65 < NSE ≤ 0.75	Good
0.50 < NSE ≤ 0.65	Enough
NSE ≤ 0.5	Not good

2.4. Land Cover and Climate Change Scenarios

There are five scenarios of land cover change and three climate change scenarios in the upstream Citarum watershed that were simulated over the period of ten years: 2019 – 2028 (Table 4). The primary forest scenario (NF) and the open land scenario (CL) are the most extreme scenarios to show the best and worst conditions for the Upper Citarum Watershed. The BAU scenario and the 25 mm/second rainfall intensity scenario are the current condition (2018) which will be used as a baseline for other scenarios. The GenRiver model will be simulated based on a combination of land cover and climate change scenarios (Figure 3). In total, there are 15 scenarios run in this study.

Table 4. Scenarios of land cover and climate change in the Upper Citarum watershed

Scenario		Description
Land change scenario	Primary forest (NF)	All areas, except settlements are converted into primary forest
	Agroforestry (AF)	All areas, except settlements and forests are converted to agroforestry
	Bussiness as Usual (BAU)	There is no change in land cover (land cover in 2028 together with the land cover in 2018)
	Seasonal crop farming (CR)	All areas except the settlements converted to cropland annuals
	Open/degraded land (CL)	All areas, except the settlements converted into open land / degraded
Climate change scenario	I = 20 mm/second	Rainfall intensity 20 mm/second
	I = 25 mm/ second	Rainfall intensity 25 mm/second, Business as Usual conditions
	I = 30 mm/ second	Rainfall intensity 30 mm/second

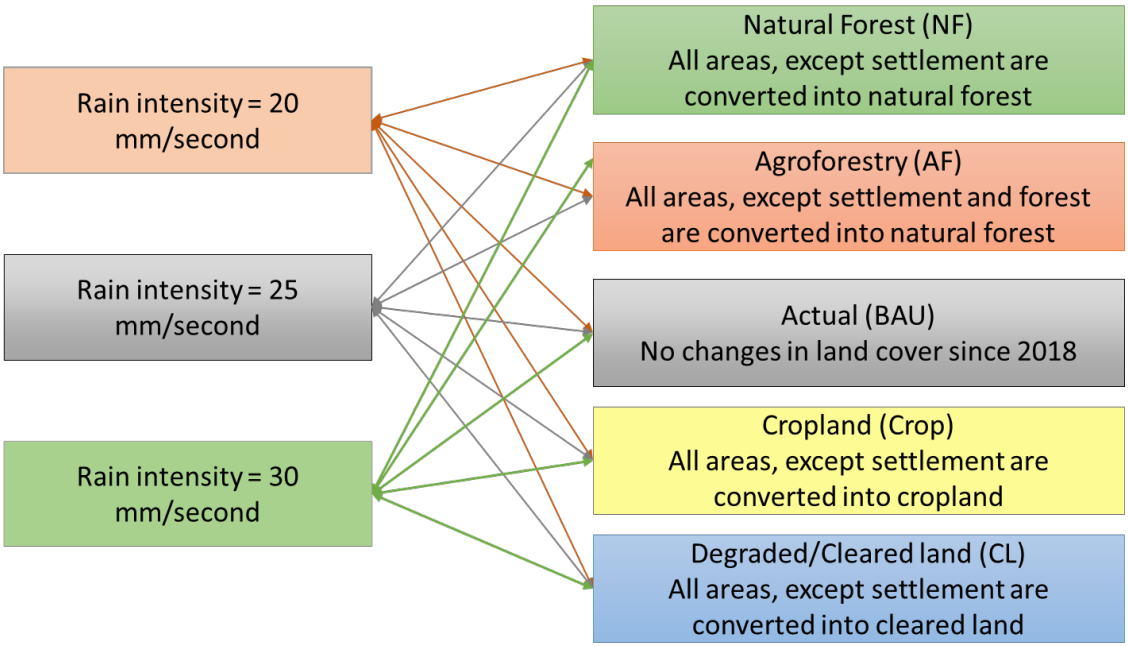


Figure 3. Combination of land cover and climate change scenarios

3. Characteristics of Research Site

3.1. Sub-watershed and Water Flow Distance

The Upper Citarum watershed with a catchment area of 232,050 Ha (based on delineation results) has a final outlet in the Saguling Reservoir. Based on its management, the upstream Citarum watershed can be divided into 7 sub-watersheds: Cirasea, Cisangkui, Citarik, Ciwidey sub-watershed, Cikapundung, Ciminyak and Cimeta. In this study, the Cimeta sub-watershed is not included in the simulation because although its management is categorized under the Upper Citarum watershed, the outlet of its flow is after the Saguling reservoir.

Table 3 shows the results of the spatial analysis for the routing distance from the center point (centroid) of each sub-watershed to the Saguling Reservoir as shown in Table 3. Routing distance is defined as the distance of water flowing and in Genriver, its value is used to estimate the travel time of water from each sub-watershed to reach the Saguling reservoir. The farther the distance, the longer it takes for the water to flow until it reaches the Saguling reservoir.

Table 5. The area and routing distance of each sub-watershed in the Upper Citarum Watershed

SUB-WATERSHED	Area (ha)	Distance from the center of the Sub-watershed to the Saguling Reservoir
Cisarea	37,5	88.5
Citarik	45,9	78,0
Cisangkuy	30,5	78.3
Cikapundung	40,0	72.3
Ciwidey	27,0	59.8
Ciminyak	32,2	5,0
Saguling Reservoir	3,3	0.0
TOTAL	**216,4**	**-**

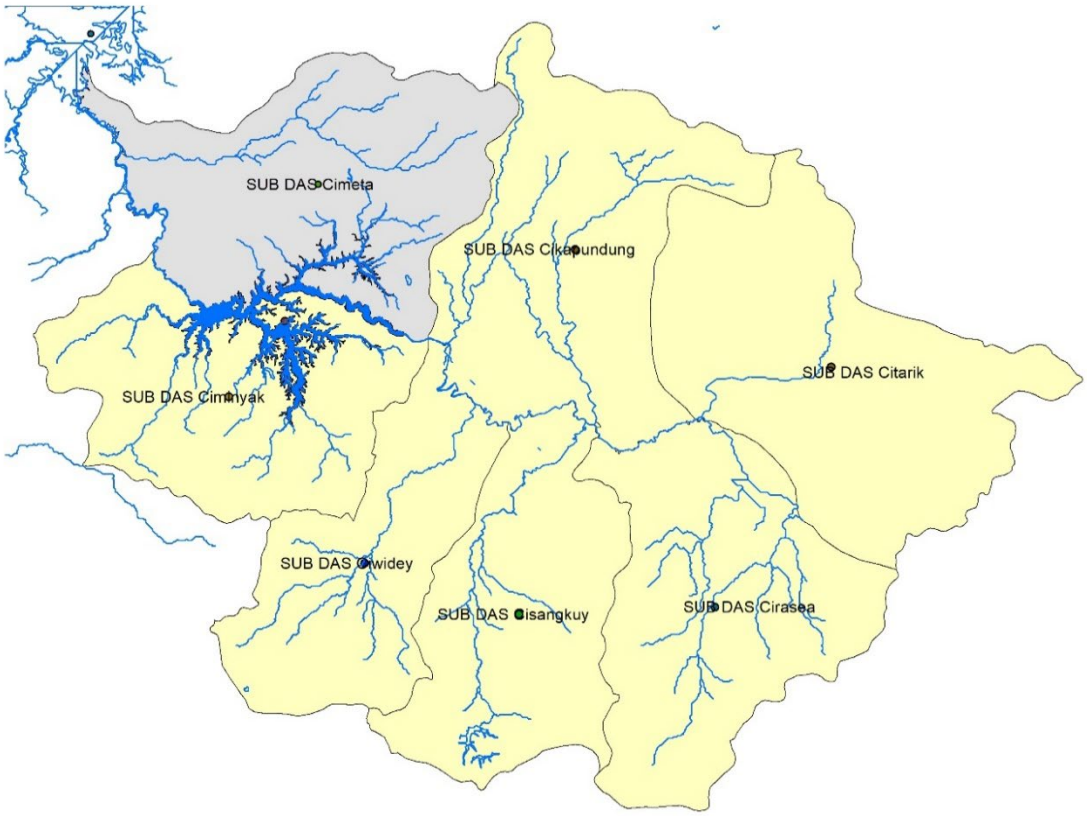


Figure 4. Sub-watershed of the Upper Citarum Watershed

3.2. Climatic and Hydrological Data

Rainfall and hydrological data used in this study are secondary data obtained from the Center for Research and Development of Water Resources, the Center for Water Resources Management (PSDA) for the Citarum River Watershed and the Citarum River Watershed Center (BBWS). Figure 5 shows the distribution of rainfall stations in the Citarum watershed. There are several stations that have rainfall data starting in 1980, 1990, 2000 and 2010. The availability of rainfall and hydrological data for each station varies depending on the year the station started operating. This study used rainfall and hydrological data from 2012-2018 in line with the existing land cover maps.

Of the many hydrological stations in the Upper Citarum watershed, Nanjung Station was chosen because it is located on the Citarum river and is the closest station to the Saguling Reservoir, thus supporting the model calibration results to represent actual conditions. Rainfall data used came from three different stations because all stations near Nanjung station do not have a complete rainfall data (2012-2017). Therefore, we used the rainfall data from Bojong Soang Station (2016-2017), Cicalengka Station (2012-2014) and Hantap Station (2015). The three stations are the closest rainfall stations to Nanjung Station.

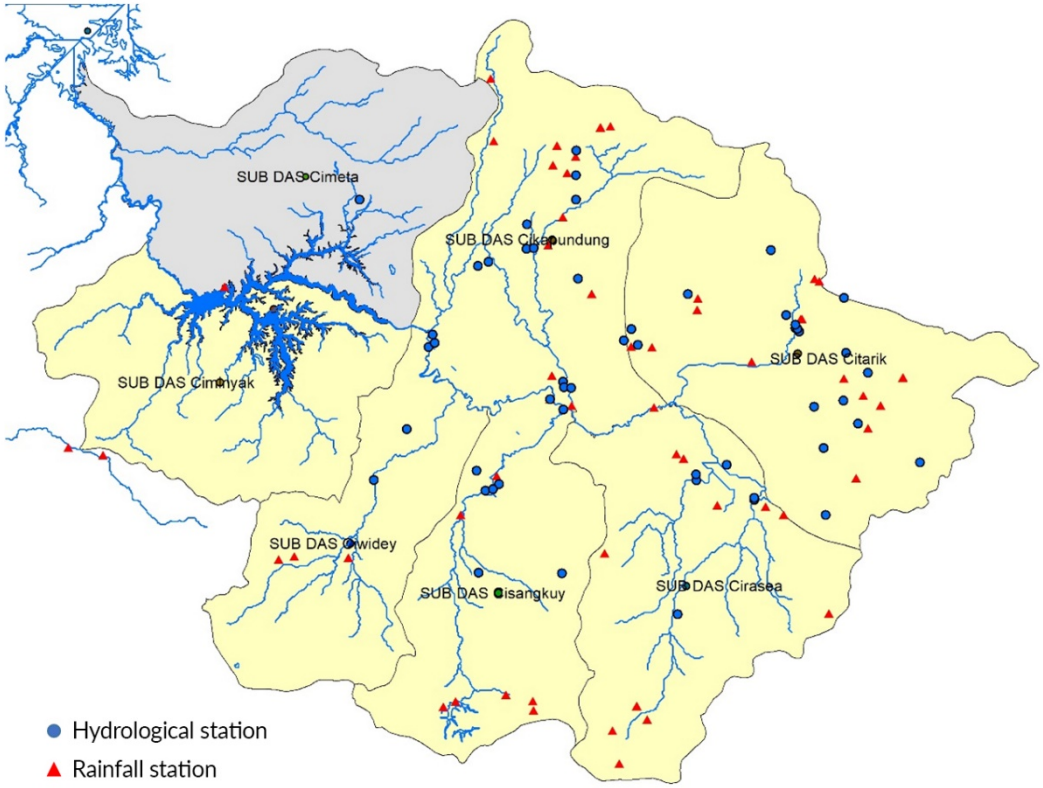


Figure 5. Distribution of rainfall and hydrological stations in the Upper Citarum watershed

3.3. Land Cover

Land cover data used in this study is the result of Landsat images classification by the World Agroforestry (ICRAF) based on groudtruthing survey. Land cover in the Upper Citarum watershed from 2012-2018 was dominated by seasonal crops (23.7%), settlements (16.7%), rice fields (15.5%) and agroforestry (12.2%). The remaining forest area is in the upstream part of the watershed, which is a state-owned forest area. Figure 7 and Table 6 show land cover changes in the upstream Citarum watershed from 2012-2018. During the period of 6 years, the biggest changes occurred in the reduction in the area of high-density secondary forest (4.32% or 9.341 ha), the decrease in the area of seasonal crops (4.12% or 8925 ha), the increase in mixed agroforestry areas (4.27% or 9.239 ha), settlements (2.93% or 6,344 ha) and rice fields (2.89% or 6,258 ha).

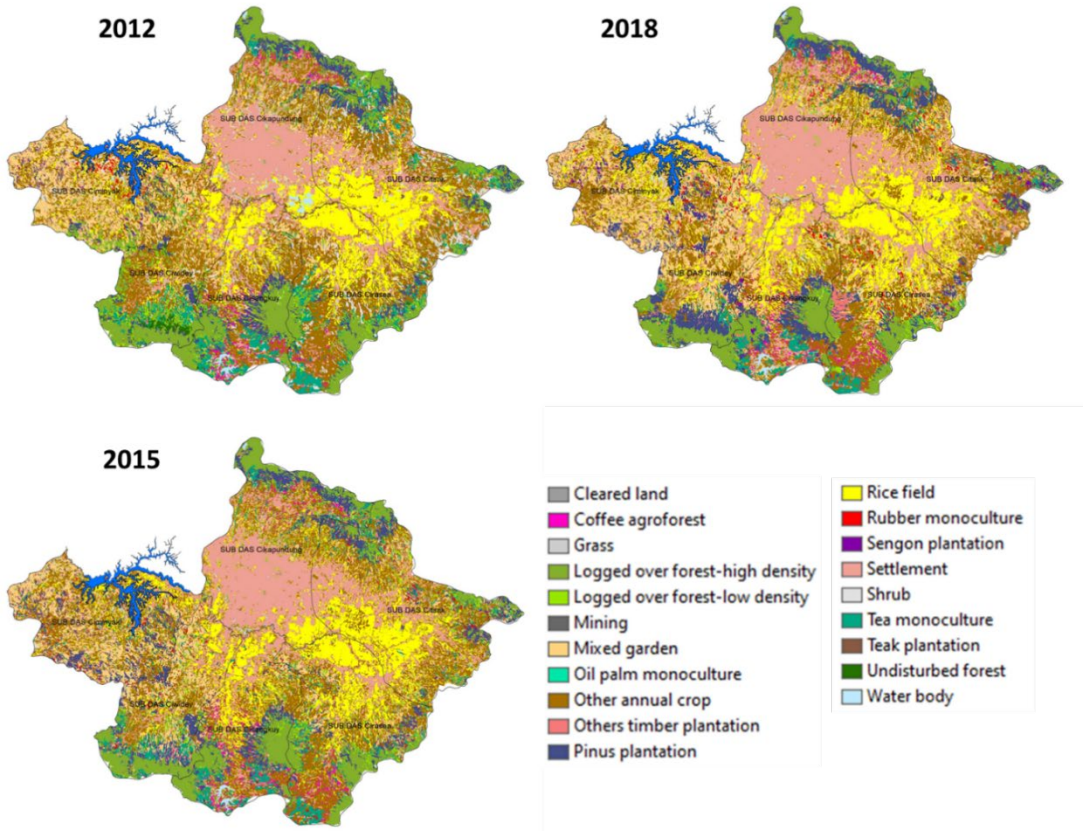


Figure 6. Upper Citarum watershed land cover map

Table 6. The area of each type of land cover in the Upper Citarum Watershed

TYPES OF LAND COVER	2012		2015		2018	
	Ha	%	Ha	%	Ha	%
Primary forest	1,380	0.64	25	0.01	25	0.01
High density secondary forest	27,291	12.61	22,230	10.27	17,945	8.29
Low density secondary forest	5,248	2.42	4,798	2.22	2,224	1.03
Mixed agroforestry	22,037	10.18	25,806	11.93	31,273	14.45
Coffee agroforestry	1,888	0.87	2,910	1.34	2,591	1.20
Rubber plantation	679	0.31	2,333	1.08	2,272	1.05
Oil palm plantation	41	0.02	41	0.02	41	0.02
Teak plantation	559	0.26	2,458	1.14	1,869	0.86
Sengon plantation	910	0.42	984	0.45	1,613	0.75
Pine plantation	10,458	4.83	15,032	6.95	16,233	7.50
Other plantations	690	0.32	1,796	0.83	2,944	1.36
Tea plantation	9,620	4.45	10,049	4.64	6,412	2.96
Rice field	30,292	14.00	33,984	15.70	36,544	16.89
Annual plants	55,543	25.67	51,736	23.91	46,609	21.54
Settlement	33,018	15.26	35,778	16.53	39,356	18.19
Open field	11,820	5.46	2,225	1.03	4,054	1.87
Mine	30	0.01	26	0.01	172	0.08
Water body	4,900	2.26	4,192	1.94	4,190	1.94
TOTAL	216,404	100	216,405	100	216,366	100

3.4. Soil Type

Based on the soil map (source: Repprot), the soil type in the Upper Citarum watershed is dominated by Inseptisols (80%) while the rest is Ultisols (20%) (Figure 8).

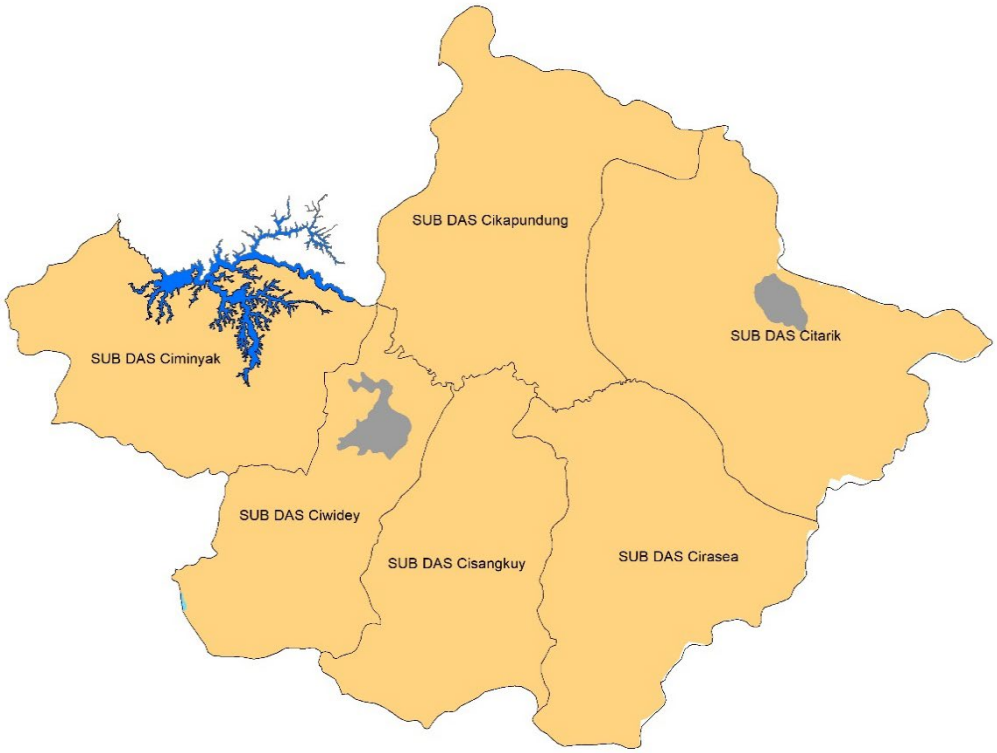


Figure 7. Map of soil types in the Upper Citarum watershed

4. Suitability test on hydrometeorological data

The hydrometeorological data intended to be used in this study must pass quality check. A reasonably good rainfall and water discharge that will be used is tested for suitability first. The corresponding data will temporally have similar pattern, ie. high rainfall will be associated with an increase or stable the water discharge. If a pattern difference occurs, eg. high rainfall associated with a decrease in river discharge or no river discharge at all, it is necessary to review why this occurs and review the use of rainfall and river discharge data for simulation.

Based on our analysis on 2012-2017 data, the following cautionary result were found (Figure 8):

i. Data in 2017 resulted in small evaporation value (less than 500 mm/year) compared to other years

ii. Data in 2015 showed a pattern where an increase in the Citarum river discharge was not associated with rainfall occurrence.

As the rest of data were categorized as plausible, we will use the hydrometeorological data and the results of this analysis will be used to explain the results of calibration and model validation in the later stage.

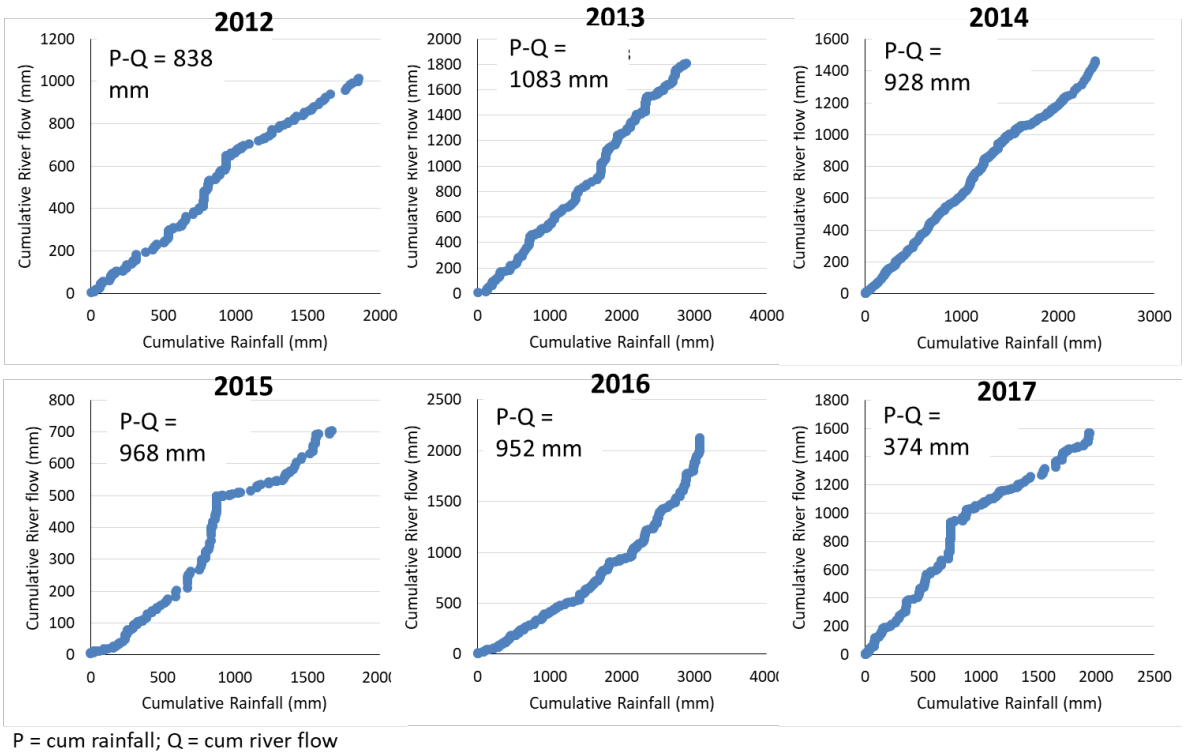


Figure 8. Analysis of rainfall and discharge of Citarum river in 2012-2017

5. Results and Discussion

5.1. GenRiver Model Calibration and Evaluation

The GenRiver model calibration were calibrated using the rainfall data from Bojong Soang Station (2016-2017), Cicalengka Station (2012-2014) and Hantap Station (2015), with river discharge data at Nanjung Station (2012-2017), shown in Table 7. For year 2015 and 2016, the NSE value are less than 0.5 (Table 8), most likely due to the mismatch between river discharge and rainfall data as discussed in the pervious section (Figure 7). The complete results of the simulation and descriptive comparison between the measured river discharge and simulated ones using the GenRiver model are depicted in Figure 9 and 10.

Based on the results of the evaluation of the model's performance in simulating the Citarum river discharge in 2012-2018 (Table8), we concluded that the model was suitable to simulate the landscape water balance in the Upper Citarum Watershed. Thus, the calibrated GenRiver model can be used to simulate land use and change scenarios in the Upper Citarum Watershed.

Table 7. The parameters used in the GenRiver Model for simulating the Upper Citarum Watershed

Parameter Name	Explanation	Value
RainInterceptDripRt	Rainfall interception rate	10
RainMaxIntDripDur	Raindrop interception duration	0.5
InterceptEffectontrans	Effect of rainfall interception on transpiration	0.4
RainIntensMean	Average rainfall intensity	25
RainIntensCoefVar	Coefficient of variation of rainfall intensity	0.3
MaxInfRate	Maximum infiltration capacity per day	900
MaxInfSubsoil	Maximum infiltration capacity into sub-soil per day	200
PerFracMultiplier	Groundwater release fraction per day	0.15
MaxDynGrWatStore	Maximum capacity of groundwater storage	100
GWReleaseFracConst	Baseflow release fraction	0.05
Tortuosity	Watershed form factor	0.7
Dispersal Factor	Flow density	0.5
River Velocity	Flow speed	0.6

Table 8. GenRiver Model Calibration and Validation Resulting from simulating the Upper Citarum Watershed

Year	n	Biased (%)	NSE	r	Biased (%)	NSE
2012	12	9.14	0.84	0.94	Very good	very good
2013	12	17.52	0.56	0.91	satisfactory	satisfactory
2014	12	-11.46	0.82	0.96	good	very good
2015	12	51.59	-0.34	0.67	unsatisfactory	unsatisfactory
2016	12	0.42	-0.65	0.25	Very good	unsatisfactory
2017	12	-21.40	0.62	0.81	satisfactory	satisfactory

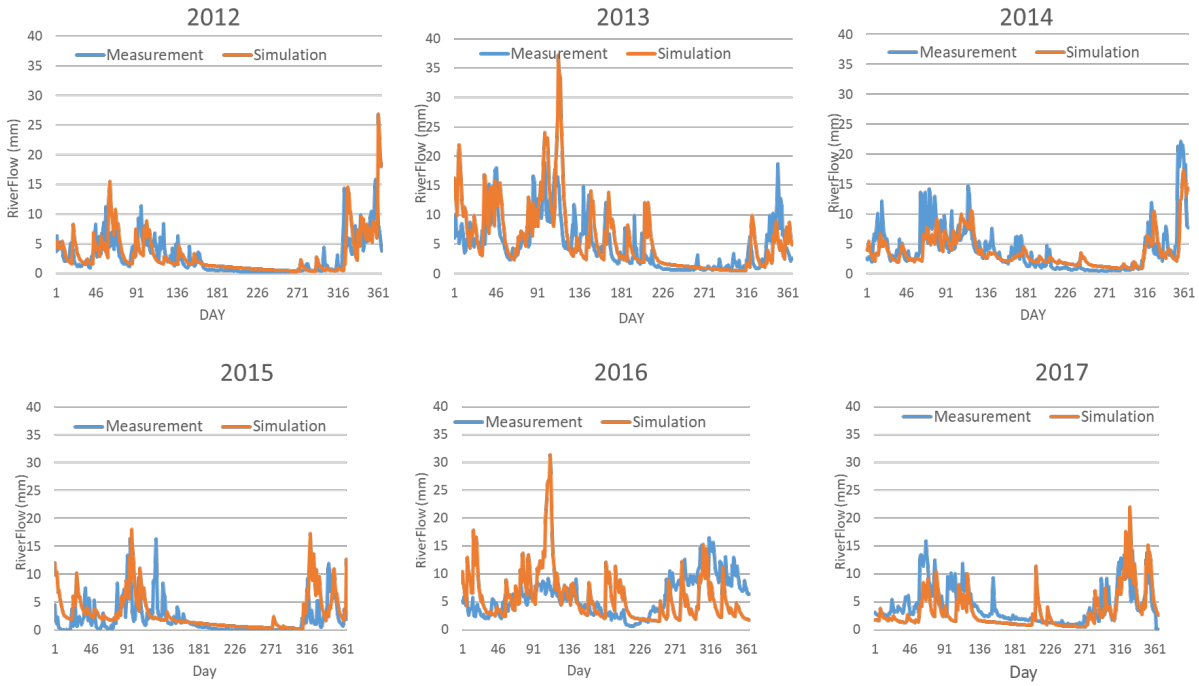


Figure 9. Comparison of hydrographs between measured data in Nanjung Station and the simulated GenRiver model results.



Figure 10. Comparison of cumulative rainfall and cumulative discharge between measured data in Nanjung Station and the simulated GenRiver model results.

5.2. Simulating the Impact of Land Cover Change on the hydrological watershed function of the Upper Citarum Watershed in 2012-2018

Based on the simulation results of the calibrated model, the water balance of the upstream Citarum watershed for 6 years (2012-2018) has an average annual evapotranspiration of 787 mm or 35% of the total landscape water balance in that period, run-off of 824 mm (37 %), subsurface flow amounted to 154 mm (7%) and the base flow of 415 mm (20%) with the total rainfall varies between 1670-3076 mm with an average of 2230 mm (Table 9). In general, it is challenging to validate the results of the water balance, particularly the components of stream flow (base flow, sub-surface flow and run-off) due to difficulties to measure at landscape level and therefore inavailability of data. Instead, what can be done is to compare the existing theories/concepts regarding the water balance in a wet tropical climate. For example, the evapotranspiration value never exceeds the total rainfall (Peters T, 2014).

Table 9. The condition of the water balance of the Upper Citarum Watershed for 6 years (2012-2018) from the simulation results of the GenRiver model

Water balance components	Lowest		Average		Highest	
	mm	%	mm	%	mm	%
Rainfall	1670		2230		3076	
Evapotranspiration	645	39	787	35	1055	34
River discharge	989	59	1424	64	2101	68
Surface flow	548	33	824	37	1204	39
Subsurface flow	28	2	154	7	315	10
Base flow	355	21	451	20	644	21

The landscape dynamics during the period of simulation was derived from changes in the land cover maps (Table 6, Figure 6). At the start of the simulation, in 2012, land cover consisted of 39.7% of annual crops including rice fields, 20.7% of settlements and open land, 16.9% of tree systems such as tree plantations and agroforestry, 15% secondary forest and less than 0.7% primary forest. During the period 2012-2018, there was a decline in primary forest by almost 100% and secondary forest by 38%, equivalent to about 1350 ha and 12,370 ha. Seasonal crops increased by 53%, equivalent to 19,320 ha. The impact of the landcover changes on landscape water balance are shown in Figure 11A. Figure 11B depicted the relationship between total rainfall with surface runoff, subsurface flow and base flow. The higher the annual rainfall, the higher the surface runoff, subsurface flow and base flow will. In the Upper Citarum watershed, every 100 mm increase in rainfall will increase surface runoff by 40 mm, subsurface flow by 19 mm and base flow by 20 mm.

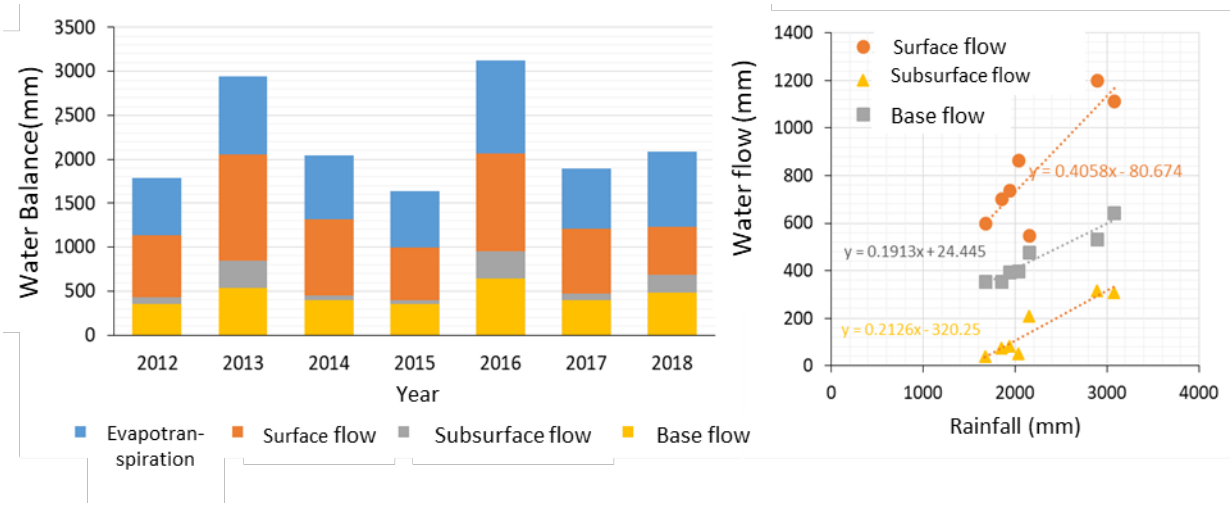


Figure 11. The simulated water balance of the Upper Citarum watershed in 2012-2018 (left) and the relationship between simulated stream flow and rainfall dynamics (right)

Reducing the total rainfall from 3076 mm to 1851 mm, while keeping the landcover dynamics similar led to similar results of stable surface runoff, subsurface runoff and baseflow over the period of simulation (Figure 12). Hence, suggesting land use changes over the period of simulation does not provide significant changes the water balance in the Upper Citarum Watershed, due to the proportion of forest area is stable of less than 1%, and also the area of seasonal crops is stable at 20-25% during 2012-2016.

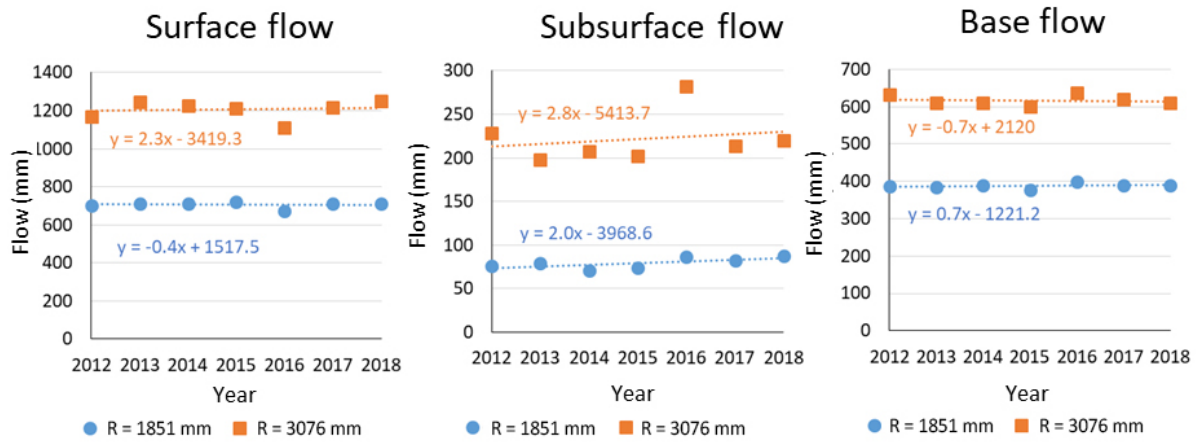


Figure 12. Effect of land cover change and rainfall on surface runoff, subsurface flow in the Upper Citarum Watershed

5.3. Simulating the Impact of Land Cover and Climate Change Scenarios in the Upstream Citarum Watershed (2019-2028)

The model simulations intend to explore the changes in hydrological conditions in the upstream Citarum watershed due extreme changes in land use and climatic changes . There are five land cover change scenarios and three simulated climate change scenarios for 2019 – 2028 (Table 4). The five

land change scenarios are (1) increase in primary forest hutan (**NF**), (2) increasing agroforestry farming (**AF**), (3) business as usual, where the land use/cover stable over 2018- 2028 period (**BAU**), (4) increasing of annuall crop farming (**Crop**) and (5) increase in open/degraded land (**CL**). The three climate change scenarios consist of: (i) decrease in rainfall intensity (**I = 20 mm/second**), (2) rainfall intensity is the same as current conditions (**I = 25 mm/second**), (iii) increase in rainfall intensity (**I = 30 mm/second**).

The simulation results showed that an increase in tree or woody vegetation (NF and AF) will reduce the surface runoff and increase subsurface flow and base flow. On the other hand, the reduction of woody vegetation (Crop and CL) will increase surface runoff and decrease subsurface flow and base flow. In addition, the increase in rainfall intensity also causes an increase in surface runoff and a decrease in subsurface and base flow. Furthermore, surface runoff is the component of the water balance that is most vulnerable to changes in land cover and climate, while base flow is the component that is least vulnerable to these changes (Table 8, Figure 13).

When compared to the BAU scenario, the NF and AF scenarios have a significant impact on changes in surface runoff and subsurface flow (Figure 14). On the other hand, the scenario of massive land clearing (CL) will cause evapotranspiration to decrease drastically and turn into runoff, which will increase the potential for flash floods.

Table 10. The simulated landscape water balance at the end of model run under different land and climate change scenarios in the Upper Citarum Watershed

Climate Change Scenarios	Water balance components (%)	Land change scenario				
		NF	AF	BAU	Crop	CL
I = 20 mm/second	Base flow	24.6	23.5	19.4	20.9	21.1
	Subsurface flow	23.3	15.7	3.5	5.3	4.5
	Surface flow	13.2	26.4	46.1	41.7	52.0
	Evapotranspiration	38.8	34.3	31.3	32.1	22.6
I = 25 mm/second	Base flow	23.7	22.3	20.7	19.1	19.4
	Subsurface flow	19.9	10.7	5.5	3.0	2.2
	Surface flow	18.1	33.6	41.4	47.9	57.2
	Evapotranspiration	38.2	33.5	32.6	30.2	21.5
I = 30 mm/second	Base flow	22.9	21.2	19.4	17.7	17.9
	Subsurface flow	17.0	7 .5	3.5	2.1	1.3
	Surface flow	22.4	38.8	46.1	52.0	60.8
	Evapotranspiration	37.6	32.7	31.3	28.6	20.5

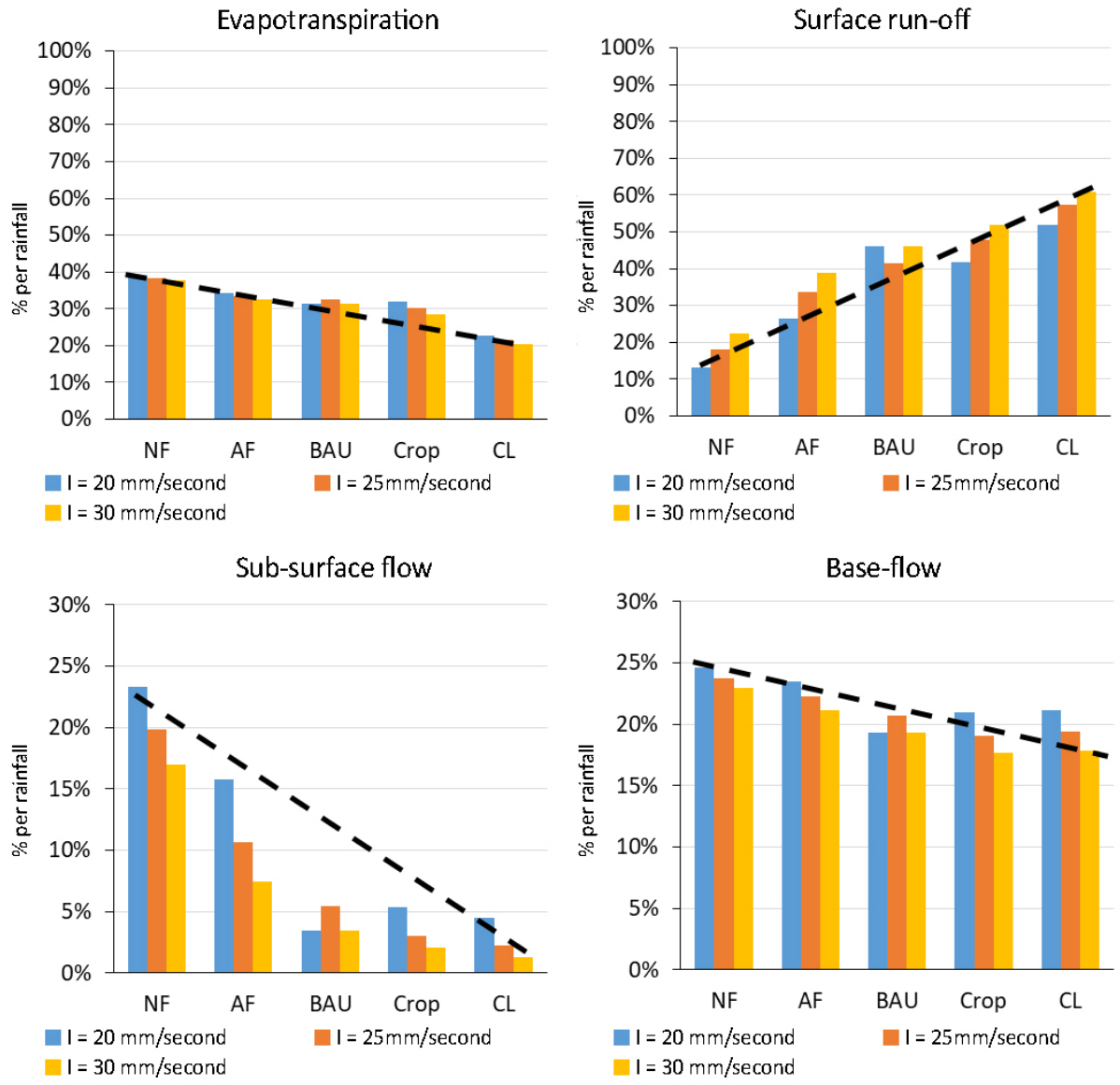


Figure 13. Simulation results of the 2028 upstream Citarum watershed water balance based on various scenarios of land cover and climate change

Figure 15 provides further analysis of surface run-off changes in the NF and CL scenarios. Further analysis showed that the conversion of 82% (174,723 ha) of land in the upper Citarum watershed into natural forest areas would reduce runoff by 22% of the total rainfall. On the other hand, clearing the same area as open land will cause 70% of the rain to become surface runoff at the end of the simulation (2028). Thus, the model simulated that 5 mm/s of rainfall will cause an increase in runoff of about 5% of rainfall.

NF and CL scenarios are extreme conditions which in reality is almos impossible to occur. However, the results of these extreme conditions can provide an overview of the range of recovery and degradation of the Upper Citarum Watershed that could occur and intervention schemes at the plot level through soil and land conservation as well as interventions at the landscape level through regional planning policies will result in a water balance at the landscape level within the range of NF and CL scenarios.

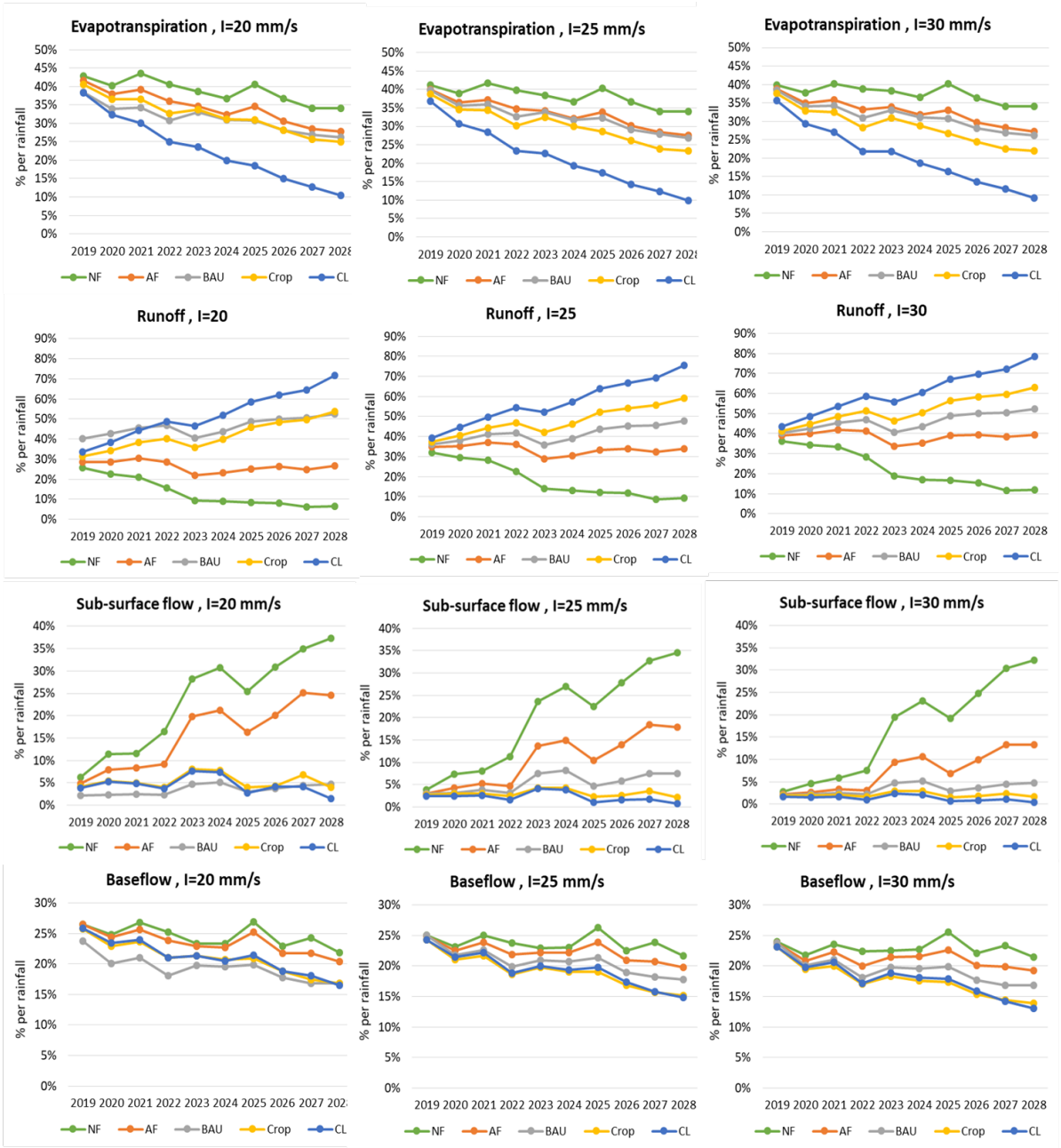


Figure 14. Trends in changes in water balance components in 2019-2028 for various scenarios of land cover and climate change.

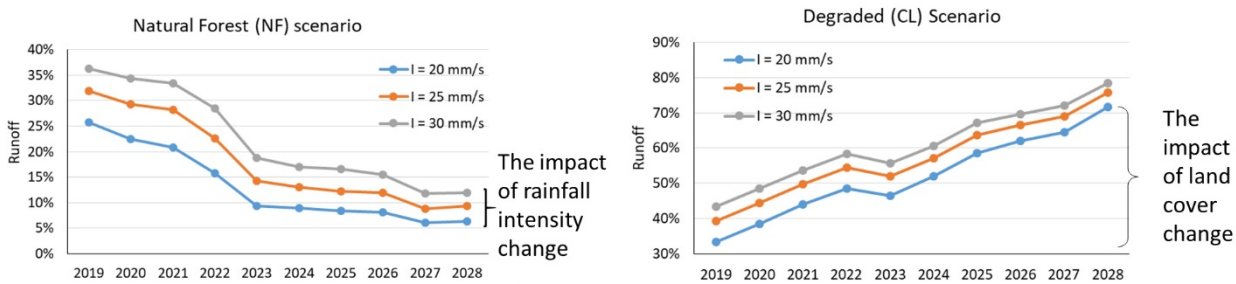


Figure 15. Simulation of the impact of land cover and climate change in the Upper Citarum Watershed 2019-2028

6. Conclusions and Recommendations

The results of calibration and evaluation showed that the parameterization of the GenRiver model using observation data of rainfall and water discharge in the Upper Citarum Watershed in the period 2012-2018 performed well and hence, GenRiver is suitable to be used to simulate the effect of land cover change and climate change on the hydrological function of the Upper Citarum Watershed. Sensitivity analysis by simulating the range of extreme positive and extreme negative land use and climatic changes depicted that the model is quite sensitive in simulating the impact on the water balance at the landscape level and has provided the range of changes (degradation and improvement) that occur of the hydrological watershed functions.

Under the current condition of land use management (2012-2018), 35% of the rainfall that falls in the upstream Citarum watershed is used by vegetation and evaporated, 37% flows as surface runoff, 7% becomes subsurface flow and 20% base flow.

Based on the simulation results of the GenRiver model (2019-2028), every 4700 ha of land clearing will contribute to a 1% increase in runoff (from rainfall). In contrast to reduce runoff of 1% is is necessary to increase 7900 ha of land area into woody vegetation.

The increase in rainfall intensity is positively correlated with an increase in surface runoff. The higher the intensity of rainfall, the higher the runoff. Therefore, increasing woody vegetation in the landscape is recommended to buffer against the possible occurrence of changes in rainfall intensity.

This study was prepared using conceptual scenarios that were not based on realistic intervention schemes at either the plot or landscape level. Also, the current version of GenRiver does not have Soil Erosion module, and therefore unable to estimate the impact of land use change on soil erosion, an important issue in the Upper Citarum Watershed. The next steps that can be taken are (i) to add erosion module to GenRiver model, (ii) developing plausible and realistic intervention scenarios, ie. land restoration programme, that can be implemented in the Citarum watershed based on the Focus Group Discussions and Key Informant Interviews conducted in the Upper Citarum watershed, and (iii) simulating the scenarios using the GenRiver model, to develop policy recommendations on suitable land use interventions in the Upper Citarum watershed.

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