Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.14.2.415

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Water Balance Prediction by Simulating Land Use Planning and Water Retention Infrastructure in Upper Cisadane Sub-Watershed, West Java, Indonesia

Yayat Hidayat[a], Latief Mahir Rachman[a], Enni Dwi Wahjunie[a], Dwi Putro Tejo Baskoro[a], Wahyu Purwakusuma[a], Sri Malahayati Yusuf[a], Fulki Dwiyandi Araswati[b]

[a] Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, IPB Darmaga Campus, Darmaga, Bogor, 16680, Indonesia

[b] Study Program of Watershed Management, Graduate School of IPB University, IPB University, IPB Darmaga Campus, Darmaga, Bogor, 16680, Indonesia

Article History
Received 02 April 2024
Revised 26 June 2024
Accepted 27 June 2024

Keywords
reforestation, reservoir, spatial plan, SWAT model, water scarcity

ABSTRACT

Currently, water resources management is still focused on on-site water resources infrastructure to achieve optimal water utilization, with almost never considered land management in which water resources are produced naturally. The research aim is to study the water balance in the Upper Cisadane Sub-Watershed, and to simulate a land use plan and development of water resource infrastructure to fulfill the need for water in the Upper Cisadane Sub-Watershed using the SWAT (Soil and Water Assessment Tool) model. Existing water availability was calculated using stream discharge data from River Flow Measurement Station Empang, whereas water demand has been analyzed for domestic, industries, agriculture, fisheries, and animal husbandry. Totally, water availability in the Upper Cisadane Sub-Watershed was ± 222.9 MCM (Million Cubic Meters) year^{-1}, which was higher than the demand for water of as much as ± 209.8 MCM year^{-1} and resulted in a water surplus of ± 13.1 MCM year^{-1}. However, water availability was not evenly distributed throughout the year, and there was always a water deficit in the dry season. To overcome drought during the dry season, five simulations of land use management and construction of water retention infrastructure were carried out using the SWAT model. The water deficit in the Upper Cisadane Sub-Watershed will be overcome by the consistent application of the spatial plan of West Java Province, reforestation of converted forest areas, applied agroforestry in agricultural land, and development of a reservoir with a storage capacity of 30 MCM.

Introduction

Most Indonesian regions have water scarcity problems during the dry season, whereas there is excessive water availability during the rainy season, which often causes floods in the surrounding areas. For example, the flow discharge of the upper Citarum Watershed (West Java) during the rainy season was very high (578 m^3 sec^{-1}), which caused floods in several areas, such as Majalaya, Banjaran, and Dayeuhkolot Sub-district. In contrast, in the dry season, the flow was very low, approximately 2.7 m^3 sec^{-1}, causing drought, failure of the rice harvest, and reduced water supply to the hydropower plant in Saguling [1]. Rainfall water in the rainy season did not infiltrate the soil and was not retained in terrestrial areas; it was lost to rivers and seas because of the reduced forest land and increase in agricultural land and settlements. Compared with the forest area, the constant infiltration rate in the agricultural area (corn) drastically decreased by ± 71.8% [2]. Water retention in terrestrial areas was lower, in line with the increase in human settlement and agricultural areas [3], and smaller area sizes of permanent vegetation cover, such as forests [4].

Land use planning is basically a human intervention that is carried out in order to realize a comfortable and productive living environment so that humans and other living creatures and their environment can live in harmony and balance to achieve human welfare and environmental sustainability to support sustainable

Corresponding Author: Yayat Hidayat yahida@apps.ipb.ac.id Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, IPB Darmaga Campus, Darmaga, Bogor, Indonesia.

development. A hot issue that has been widely discussed lately is that spatial planning is not yet optimal in harmonizing, synchronizing, and integrating various sector plans and programs so that various disaster phenomena related to water, such as floods, landslides, and droughts, occur almost evenly in various regions of Indonesia. The spatial plan in various regions of Indonesia is more oriented towards regional economic growth, such as the development of monoculture oil palm plantations that are not accompanied by the application of adequate soil conservation measures, which will further increase the incidence of flooding in the Deli, Barumun, Belumai, Padang, and Silau watersheds [5].

The Upper Cisadane Sub-Watershed is located in the Regency and City of Bogor and is classified as a priority watershed that must be restored [6]. Critical land covers an area of 12,732 ha and is caused by land utilization, which is more intense than the land capabilities, which greatly affects the water storage capacity of the watershed and reduces the function of the Upper Cisadane Sub-Watershed as a water supplier for the downstream area [7]. The availability of water in the Upper Cisadane Sub-Watershed as much as 1,718.92 × 106 m^3 $year^{-1}$ has yet to meet the need for water for 1,596,690 people, which is 2,554.70 × 106 m^3 $year^{-1}$. Therefore, there is a water deficit of 1,718 × 106 m^3 $year^{-1}$ in the Upper Cisadane watershed [8]. To ensure the availability of sufficient water in the dry season and reduce peak flow in the rainy season, the integration of the water resource plan into the land use plan/spatial plan is the key that must be carried out immediately. The integration of land use and water resource management plans is necessary to create sustainable development in the future [9].

The allocation of spatial patterns, as well as the consistent utilization and control of spatial patterns, is an important key to the protection of water resources. Land use zoning, including the development of land management standards in various predefined zoning, minimizes undesired impacts and is the best approach for reducing spatial land use conflicts [10]. Research by Marhaento et al. [11] in the Samin sub-watershed in Central Java showed that the implementation of the spatial plan of Central Java Province reduced the surface runoff discharge by 16% and increased the baseflow discharge by 6%. River flow discharge in watersheds dominated by conifer forests was 11.9% lower than that in watersheds dominated by grasslands [12]. Landuse simulation in the Zayandehrood watershed (central Iran) with a composition of forests (36%), grazing fields (42%), and irrigated agriculture (22%) resulted in a lower volume flow of 9.3% compared to the existing conditions [13]. However, simulations of land use in the Jhelum River Basin (Mangla Dam Watershed) showed that surface runoff decreased by 17.1% if all grassland and agricultural land were converted to forests [14].

The conversion of grassland to forest at a slope of > 3% in the semi-arid watershed in the Central African region also reduced the monthly average surface runoff by 30% and increased the lateral flow and base flow by 110% and 254%, respectively [15]. The influence of land use on hydrological processes, particularly surface runoff discharge, is well known. However, how to arrange the land use of an area and manage river flow discharge to ensure the availability of water throughout the year still needs to be studied. Land use arrangements that have been carried out in various areas, both as stated in the spatial plan and other plans (such as an integrated watershed management plan), still result in very high fluctuations in river flow discharge between the rainy and dry seasons. This research aims to study the water balance in the Upper Cisadane Sub-Watershed and simulate a land use plan and development of water resource infrastructure to fulfill the need for water in the Upper Cisadane Sub-Watershed using the SWAT (Soil and Water Assessment Tool) Model.

Materials and Methods

Study Area

The research was carried out in the Upper Cisadane Sub-Watershed with an outlet at the Empang River Flow Measurement Station (SPAS/*Stasiun Pengamatan Air Sungai*), which covers an area of 23,692 ha and is administratively located within the Regency and City of Bogor, West Java, Indonesia (Figure 1). The study began in April 2019 and ended in July 2020. Characterization of the biophysical conditions of the Upper Cisadane Sub-Watershed and field data collection were carried out in 2019. In 2020, we focused on simulation of the SWAT Model and water balance analysis. Typic Hapludans and Typic Tropopsamments are the dominant soil types in the Upper Cisadane Sub-Watershed [16], which covers an area of 7,735 ha (32.6%), followed by Andic Humitropepts covering an area of 4,575 ha (19.3%), Typic Tropopsamments-Andic Humitropepts covering an area of 3,794 ha (16.0%), and Typic Humitropepts covering an area of 2,424 ha (10.2%) (Figure 2). Based on the 2018 land use map, the main land use of the Upper Cisadane Sub-Watershed was 5,705 ha (24.3%) settlement, 4,806 ha (20.5%) forest, 3,581 ha (15.2%) rice fields, 3,631 ha (15.5%) mixed gardens, 3,376 ha (14.3%) upland agriculture/annual crop upland agriculture, and 2,161 ha (9.2%) shrubs (Figure 3). The rainfall in the Upper Cisadane Sub-Watershed is quite high, with an average rainfall of 3,215.3 mm year^{-1}. The highest monthly rainfall of 401.4 mm occurs in February and the lowest was 142.3 mm in August (Figure 4).

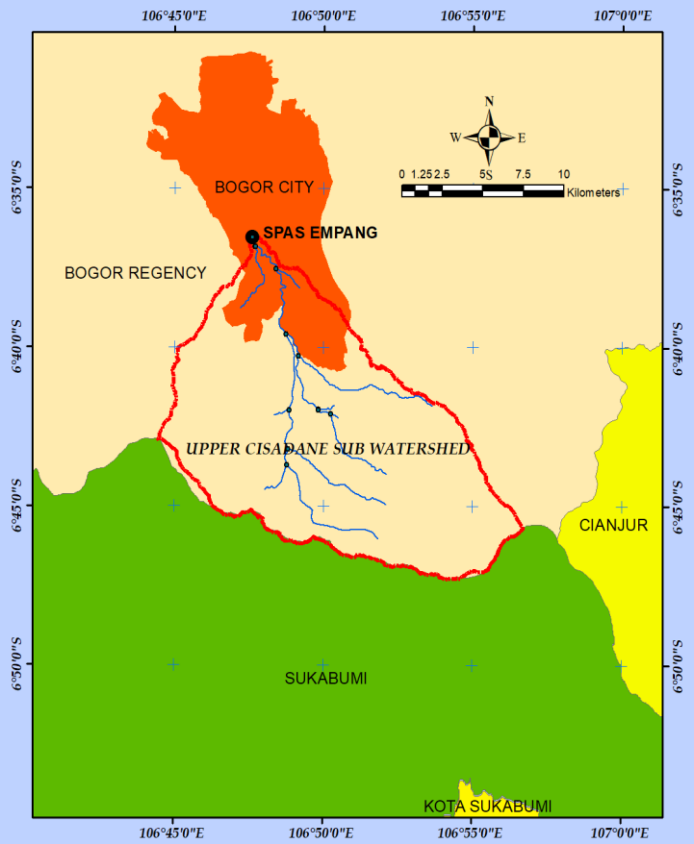

Figure 1. Study area.

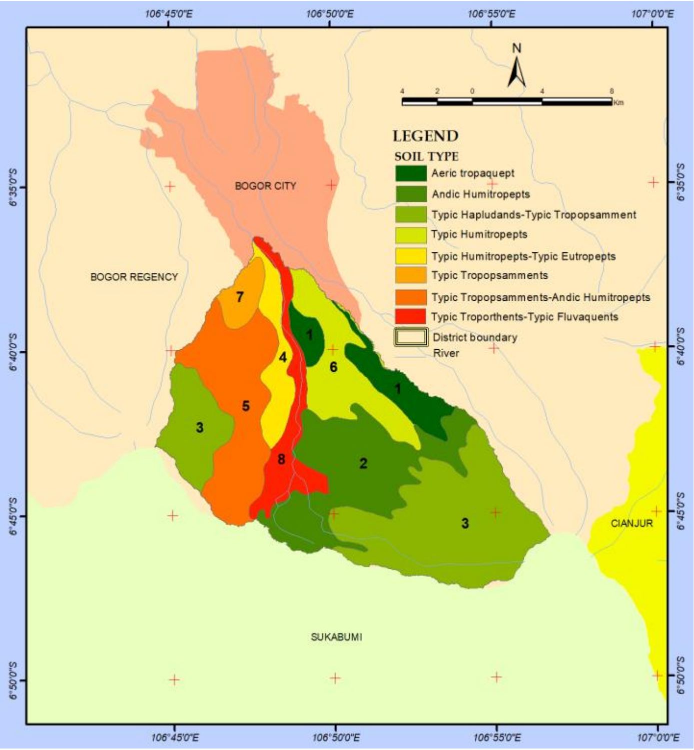

Figure 2. Soil map of Upper Cisadane Sub-Watershed.

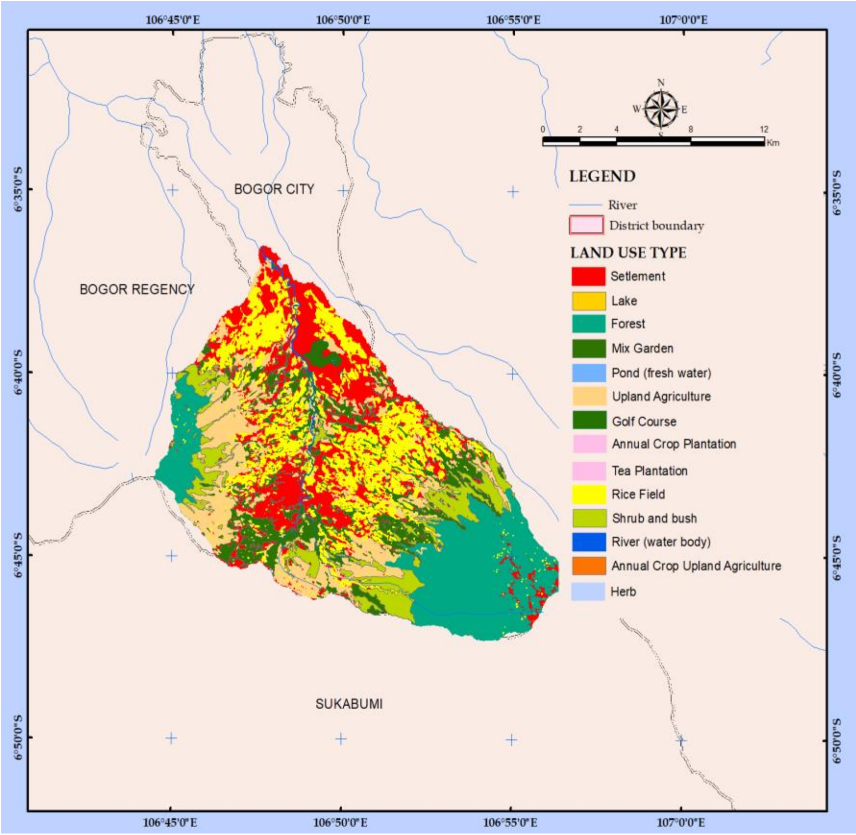

Figure 3. Land use map of Upper Cisadane Sub-Watershed 2018.

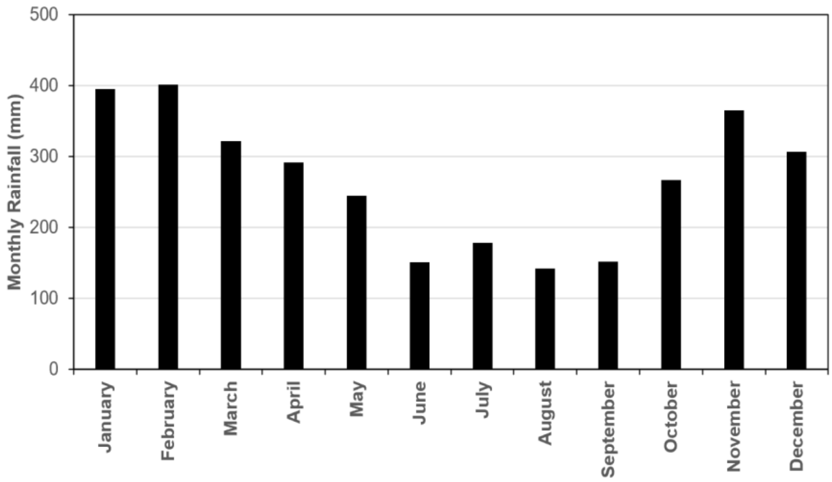

Figure 4. Montly rainfall of Upper Cisadane Sub-Watershed 2009–2018.

Water Balance

The water balance is defined as the balance between the amount of water available and the amount of water needed to meet various needs in a watershed. If the balance is positive, it is known as a surplus; if it is negative, it is called a deficit. Water balance is given by the following equation:

$$Q_{Availability} - Q_{demand} = \Delta S \quad (1)$$

Where:

$Q_{Availability}$ = Total water availability (m^3)

Q_{Demand} = Total water demand (m^3)

ΔS = Change in water quantity (m^3)

The calculated demand for water consisted of domestic water needs (SNI 6728.1 2015), which was predicted based on the amount of water consumed per person per day for household use [17], industrial water needs (SNI 6728.1 2015) used in industrial processes and industrial workers' needs [18], irrigation water needs (SNI 6728.1 2015) to irrigate paddy fields through irrigation networks, fishery water needs (SNI 19-6728.1 2002), especially for freshwater aquaculture, and livestock water needs (SNI 19-6728.1 2002). The total water demand was calculated as follows:

$$Qtotal = QDM + QID + QIR + QFP + QL \quad (2)$$

Where:

QTotal = Total water demand (m^3 $year^{-1}$)

QDM = Domestic water demand (m^3 $year^{-1}$)

QID = Industrial water demand (m^3 $year^{-1}$)

QIR = Irrigation water demand (m^3 $year^{-1}$)

QFP = Fishery water demand (m^3 $year^{-1}$)

QL = Livestock water demand (m^3 $year^{-1}$)

Existing water availability was analyzed using data from the Upper Cisadane River flow at SPAS Empang, which was obtained from Sari et al. [19]. The monthly available water volume is calculated as follows:

$$Volmonth = Qave \times \Sigma Dmonth \times 24 \times 3{,}600 \quad (3)$$

Where:

Volmonth = Monthly water volume (m^3)

Qave = Average flow discharge in one month (m^3 s^{-1})

Dmonth = Number of days in one month

Water availability, which was used to calculate water balance in various land use plans and water retention infrastructure simulations, was predicted using the SWAT Model. The SWAT model was developed by USDA-ARS [20] and has been proven valid for predicting river flow discharge in Indonesia [21–24]. The input parameters of the SWAT Model include climatic characteristics (rainfall, maximum and minimum temperatures, relative humidity, wind speed, and solar radiation), soil characteristics (solum depth and soil layer thickness, bulk density, texture, soil hydraulic conductivity, organic carbon, available soil moisture content, rock in surface soil, and soil erodibility), vegetation characteristics (vegetation type, tree height, root depth, leaf area index, optimum temperature for plant growth, crop management factors, manning coefficient for land surface, and surface runoff curve number), topographic characteristics (length, slope, and direction), sub-basin characteristics (manning coefficient for channel, soil evaporation compensation factor (ESCO), plant uptake compensation factor (EPCO), depth of impermeable layer in soil, Surlag, channel hydraulic conductivity, groundwater depth, groundwater delay, and groundwater recession coefficient), and watershed characteristics (evapotranspiration and surface runoff prediction methods).

Daily climate characteristics were obtained from the BMKG Dramaga and Citeko stations (2016–2018) [25] and daily rainfall data from the Empang rain station. Soil characteristics were obtained by field ground check (based on soil map 1:250,000), and soil samples were taken for laboratory analysis. The land-use map was interpreted from *Satellites Pour l'Observation de la Terre* (SPOT) 6 imagery by on-screen digitation using ArcGIS 10.5, which was then carried out by a field ground check to identify the accuracy of the interpretation results (Kappa Accuracy 90.6%) and to identify the characteristics of vegetation for several inputs of the SWAT model. The topographic characteristics were extracted from the National DEM (8 × 8 m). The characteristics of the sub-basin and other watersheds were obtained from various secondary data and other literature studies [26].

The SWAT Model was run in daily time steps, with the main output being stream discharge, which was then converted to daily and monthly water availability. Surface runoff was predicted using the daily rain and runoff curve number of the rainfall-runoff method, which was combined with the Penman/Monteith (potential evapotranspiration model) and variable storage for the channel routing method. Calibration and validation of the model were carried out manually with indicators of NSE (Nash Sutcliffe Efficiency) and R^2 (determination coefficient) using 365 paired data for both calibration (2017) and validation (2018). The types and sources of data used in this study are presented in Table 1.

Table 1. The type, source, and objective data utilization.

No	Data type	Data source	Objective utilizatian
1.	Total population (2018)	BPS of City and Regency of Bogor	Domestic water demand
2.	Number of industrial workers (2018)	BPS and industry office City and Regency of Bogor	Industries water demand
3.	Paddy field area (2018)	BPS and Agriculture office of City and Regency of Bogor	Agriculture water demand
4.	Fish pond area (2018)	BPS and Fishery office of City and Regency of Bogor	Fishery water demand
5.	Number of cattle (2018)	BPS and Animal husbandry office of City and Regency of Bogor	Animal husbandry water demand
7.	Stream discharge of Upper Cisadane (2009–2018)	BBWS Ciliwung-Cisadane	Water availability and calibration /validation of SWAT model
8	Daily climate datas (2009–2018)	BMKG Bogor	Parameter inputs of SWAT Model
9.	Soil characteristics	Field study and laboratory analysis	Parameter inputs of SWAT Model
10.	Digital Elevation Model 8 m	Geospatial Information Agency	Parameter inputs of SWAT Model
11.	SPOT 6 imagery (2018)	National Space and Aviation Agency	Landuse map, parameter input of SWAT model and simulation of SWAT model
12.	Map of Spatial Plan	Bappeda West Java Province	Simulation of SWAT model
13.	Map of RTkRHL of Cisadane Watershed	BPDAS Citarum-Ciliwung	Simulation of SWAT model
14.	Map of forest area	Ministry of Environment and Forestry	Simulation of SWAT model

BPS (*Badan Pusat Statistik*): Central Bureau of Statistics; BBWS (*Balai Besar Wilayah Sungai*): River Region Hall; BMKG (*Badan Meteorologi, Klimatologi, dan Geofisika*): Agency for Meteorological, Climatological and Geophysics; Bappeda (*Badan Pembangunan Daerah*): Development Planning Agency at Sub-National Level, RTkRHL (*Rencana Teknik Rehabilitasi Hutan dan Lahan*): Forest and Watershed Land Rehabilitation, BPDAS (*Balai Pengelolaan Daerah Aliran Sungai*): Central Management of Regional River Flow.

Scenario of Land Use Planning and Water Retention Infrastructure Simulations

Conversion of the forest into agricultural land and subsequent conversion to other uses is very common in Indonesia, so the forest area is decreasing annually, especially on Java Island. The allocation of space use has been regulated in local government policy as outlined in the Provincial/Regency Spatial Plans, although, in practice, control over the use of space still needs to be stronger. To ensure the availability of water distributed throughout the year to meet various needs, several scenarios for land use planning and water retention infrastructure are as follows: (a) Scenario 1, Reforestation of forest that has been converted to other uses; (b) Scenario 2, Applied spatial plan of West Java Province (especially space allocation for protection function areas and resettlement developments); (c) Scenario 3, Agroforestry implementation of agriculture and shrub areas; (d) Scenario 4, Development of reservoir; (e) Scenario 5, A combination of scenarios 1, 2, 3, and 4.

Results and Discussion

Water Balance

Water demand was calculated using a sector approach by considering the size of the administrative area (Bogor Regency and City) covered in the Upper Cisadane Sub-Watershed. The population of the Cisadane Sub-watershed is 1,389,139 [27,28], with domestic water needs of as much as 50.46 MCM year^{-1}, with the highest water needs in West Bogor Sub-District of 8.89 MCM year^{-1} and Ciomas Sub-District of 8.09 MCM year^{-1}. The total water demand of the Upper Cisadane Sub-Watershed is 209.76 MCM year^{-1}, and the monthly demand is presented in Figure 5. The development of industry (especially small industries) in the sub-districts of West Bogor, South Bogor, and East Bogor, employing ± 10,559 workers, shows that industrial water demand is the dominant water requirement in the Upper Cisadane Sub-Watershed at ± 105.99 MCM year^{-1}. Other water needs are irrigation water (52.08 MCM year^{-1}), fishery water needs (0.34 MCM year^{-1}), and livestock water needs (0.90 MCM year^{-1}).

Table 2 shows the total water availability of the Upper Cisadane Sub-Watershed is ± 222.87 MCM year^{-1}, which is greater than the demand for ± 209.76 MCM year^{-1}, resulting in a surplus of 13.11 MCM year^{-1}. Water availability is strongly influenced by climate and human activity [29]. The availability of water in the Upper Cisadane Sub-Watershed was generally very high during the rainy season and relatively low during the dry season. The abundant availability of water during the rainy season cannot be used optimally, because there is no water retention infrastructure available as a water reserve during the dry season. Because water availability is strongly influenced by rainfall and evapotranspiration [30], water availability in the Upper Cisadane Sub-Watershed is not evenly distributed throughout the year, and water deficits occur during the dry season, that is, in June, July, August, September, and October. The total water availability cannot be used as an absolute indicator of water availability in an area.

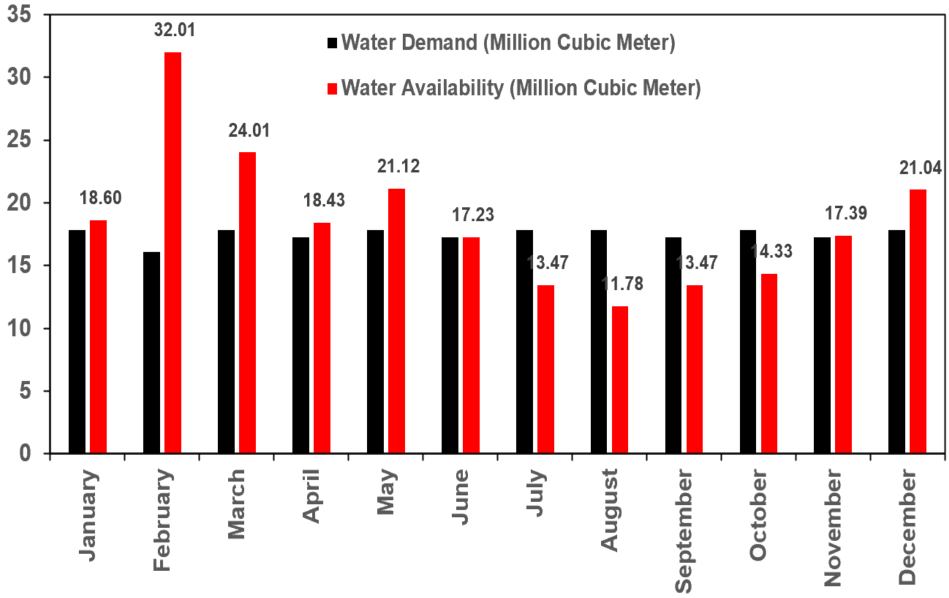

Figure 5. Water demand and water availability of Upper Cisadane Sub-Watershed 2018.

Table 2. Water balance of Upper Cisadane Sub-Watershed (2018).

Months	Water demand (MCM)	Water availability (MCM)	Surplus/deficit (MCM)
January	17.82	18.60	0.79 (S)
February	16.09	32.02	15.92 (S)
March	17.81	24.01	6.19 (S)
April	17.24	18.43	1.19 (S)
May	17.82	21.12	3.30 (S)
June	17.24	17.23	–10.86 (D)
July	17.82	13.47	–4.35 (D)
August	17.82	11.78	–6.04 (D)
September	17.24	13.47	–3.78 (D)
October	17.82	14.33	–3.49 (D)
November	17.24	17.40	0.15 (S)
December	17.82	21.04	3.23 (S)
Total	209.76	222.87	13.11 (S)

MCM: Million Cubic Meter, S: Surplus, D: Defisit.

SWAT Model Calibration and Validation

The input parameters of the SWAT Model were obtained based on primary data from field observations and secondary data from previous studies; therefore, some of these parameters need to be calibrated. The calibration process was intended to obtain a representative model for the input parameter value representing the field. Using 365 paired stream discharge data from 2017 (ranging between 2.05 to 66.14 m^3 s^{-1}), the calibration of the model is quite good with an R^2 value of 0.71 (very strong relationship) and an NSE value of 0.73 (qualified). The manual calibration process begins with the most sensitive parameter, that is, the surface runoff curve number (CN2), followed by other parameters, such as alpha base flow (ALPHA_BF) and groundwater delay (GW_delay). The next calibration process was carried out automatically using the SWAT Cup for all parameters that affect the output of the model, especially CN2, ALPHA_BF, GW_delay, ESCO, EPCO, GWQMIN, GW_Revap, CH_N2, and CH-K2. Model validation was intended to identify the consistency of the SWAT Model output from time to time. Figure 6 shows the result of model validation with an R^2 value of 0.61 (strong), NSE value of 0.79 (good), RMSE of 3.32, and MAPE of –13.09.

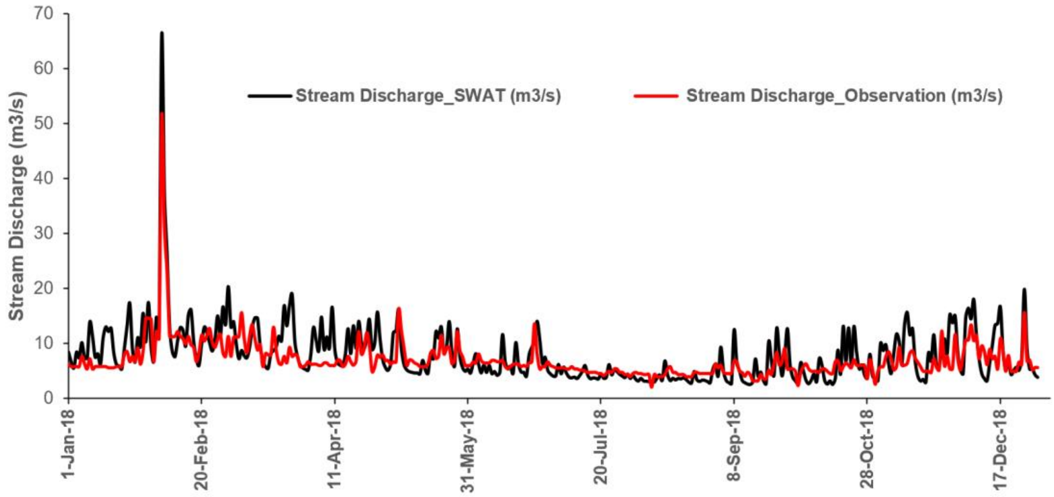

Figure 6. Validation of SWAT Model on Upper Cisadane Sub-Watershed (2018).

Water Balance Prediction by Simulating Land Use Planning and Water Retention Infrastructure

Scenario 1: Reforestation of Converted Forest

Based on the forest area map published by the Ministry of Forestry and Environment (KLHK/*Kementerian Lingkungan Hidup dan Kehutanan*) [31], the forest area in the Upper Cisadane Sub-Watershed was 6,603 ha. The existing forest in 2018 was 4,806 ha, so some forest land (1,797 ha) had been converted to other uses such as 151.2 ha of gardens/plantations, 254.4 ha of fields/dry land farm, 24.7 ha of rice fields, 1,086.5 ha of shrubs, and a built-up area of 280.2 ha (Table 3). The simulation of reforestation of converted forest areas (except paddy fields and built-up land) was carried out in the form of agroforestry using woody plants (20%), multi-purpose tree species (20%), and annual crops (60%). Table 4 and Figure 7 show that reforestation of converted forest areas shortened the time of water deficit from 5 months to 4 months, with an intensity reduction of water deficit by 46%.

Table 3. Space allocation for protection function areas (Spatial Pattern of West Java Province 2009–2029) and existing land use in 2018.

No	Space allocation for protection function areas (Spatial Pattern of West Java Province 2009–2029)		Existing land use 2018	
	Land use type	Area (ha)	Land use type	Area size (ha)
1.	Conservation Forest (CF)	6,741.3	CF_Forest	4,649.6
			CF_Mix garden	339.0
			CF_Upland agriculture/dry land farm	325.4
			CF_Rice field	54.0
			CF_Shrub/bush	1,064.7
			CF_Settlement	308.6
2	Prone to Soil Movement (PSM)	5,497.8	PSM_Mix garden	1,225.1
			PSM_Upland agriculture/dry land farm	1,553.9
			PSM_Rice field	821.2
			PSM_Shrub/bush	399.0
			PSM_Settlement	1,462.1
3	Water Absorption Zone (WAZ)	1,233.2	WAZ_Forest	59.2
			WAZ_Mix garden	197.9
			WAZ_Upland agriculture/dry land farm	344.2
			WAZ_Rice field	138.8
			WAZ_Shrub/bush	389.8
			WAZ_Settlement	103.3
		13,435.8		13,435.8

Table 4. The impact of the application of vegetative and civil engineering soil and water conservation measures on water availability in the Upper Cisadane Sub-Watershed.

Months	Water demand (MCM)	Existing		Scenario 1		Scenario 2	
		W. Availability (MCM)	Status	W. Availability (MCM)	Status	W. Availability (MCM)	Status
January	17.82	18.60	0.79 (S)	20.97	3.15 (S)	21.53	3.71 (S)
February	16.09	32.01	15.92 (S)	28.55	12.46 (S)	28.84	12.75 (S)
March	17.82	24.01	6.19 (S)	24.22	6.41 (S)	24.93	7.11 (S)
April	17.24	18.43	1.19 (S)	21.64	4.40 (S)	22.35	5.11 (S)
May	17.82	21.12	3.30 (S)	19.29	1.48 (S)	20.14	2.32 (S)
June	17.24	17.23	–0.01 (D)	17.43	0.19 (S)	17.83	0.58 (S)
July	17.82	13.47	–4.35 (D)	15.24	–2.57 (D)	16.38	–1.43 (D)
August	17.82	11.78	–6.04 (D)	13.93	–3.89 (D)	15.23	–2.59 (D)
September	17.24	13.47	–3.78 (D)	14.52	–2.72 (D)	16.00	–1.24 (D)
Oktober	17.82	14.33	–3.49 (D)	15.24	–2.58 (D)	16.73	–1.08 (D)
November	17.24	17.39	0.15 (S)	17.77	0.53 (S)	19.38	2.14 (S)
December	17.82	21.04	3.23 (S)	20.99	3.18 (S)	22.58	4.77 (S)
Total	209.76	222.87	13.11 (S)	229.79	20.02 (S)	241.90	32.14 (S)
January	17.82	20.07	2.25 (S)	26.16	8.34 (S)	28.07	10.25 (S)
February	16.09	28.69	12.60 (S)	38.22	22.13 (S)	38.10	22.01 (S)
March	17.82	23.22	5.40 (S)	29.86	12.05 (S)	31.31	13.50 (S)
April	17.24	20.26	3.02 (S)	27.55	10.31 (S)	28.75	11.50 (S)
May	17.82	18.59	0.78 (S)	22.66	4.84 (S)	24.22	6.41 (S)
June	17.24	17.58	0.34 (S)	19.77	2.54 (S)	21.51	4.27 (S)
July	17.82	15.58	–2.24 (D)	17.45	–0.37 (D)	19.73	1.92 (S)
August	17.82	14.90	–2.92 (D)	17.19	–0.63 (D)	19.20	1.39 (S)
September	17.24	15.37	–1.87 (D)	18.33	1.09 (S)	20.84	3.59 (S)
Oktober	17.82	15.90	–1.91 (D)	20.46	2.65 (S)	21.03	3.21 (S)
November	17.24	19.75	2.51 (S)	24.80	7.55 (S)	26.80	9.56 (S)
December	17.82	24.26	6.45 (S)	26.21	8.40 (S)	28.95	11.14 (S)
Total	209.76	234.17	24.41 (S)	253.15	78.90 (S)	308.52	98.75 (S)

W. Availability: Water Availability, MCM: Million Cubic Meter, S: Surplus, D: Deficit.

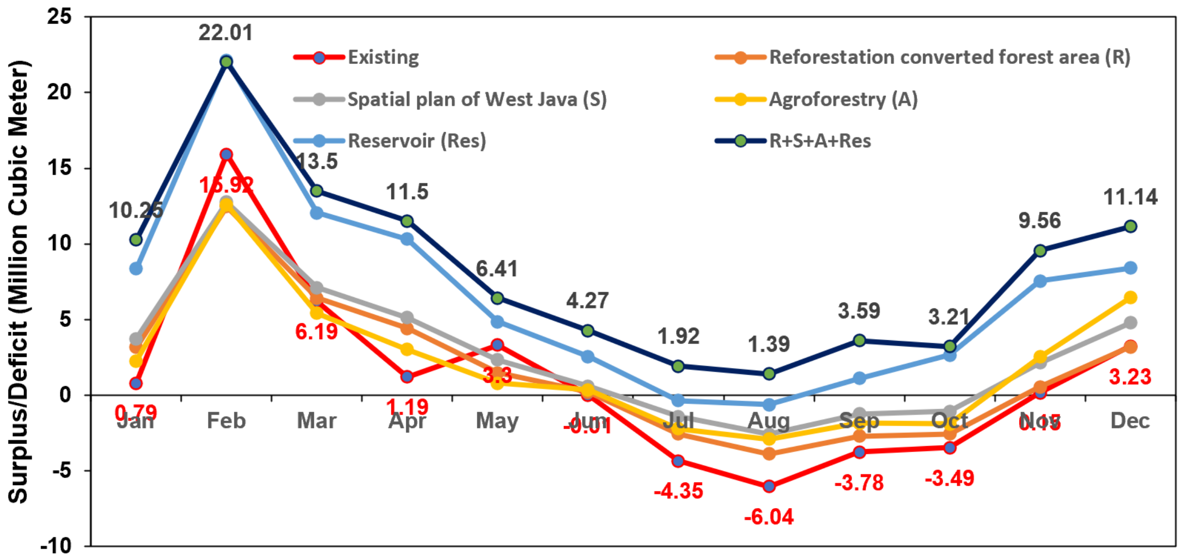

Figure 7. Status of water balance in various land use management and reservoir development scenarios in Cisadane Sub-Watershed.

Scenario 2: Applied Spatial Plan of West Java Province 2009–2029

In an effort to harmonize development and protect environmental sustainability in the Upper Cisadane Sub-Watershed, the West Java Provincial Spatial Plan [32] allocates a protected function area of 13,435.8 ha (57.2% of sub-watersheds) in the form of conservation forest (6,741.3 ha), areas prone to soil movement

(5,461.3 ha), and water absorption areas (1,233.2 ha). Table 3 shows that the protected area on the land use map for 2018 was converted to other uses. Table 4 and Figure 7 show the allocation of the spatial pattern of the West Java Province (Provincial Spatial Planning Plan (RTRWP/*Rencana Tata Ruang Wilayah Provinsi*) 2009–2029), which shortens the time of water deficit from 5 months to 4 months with an intensity reduction of 72% in water deficit.

Scenario 3: Agroforestry on Agriculture Land and Shrub and Bush Land

The simulation of agroforestry on agricultural and shrublands was aimed at increasing interception storage due to an increase in vegetation canopy cover and increased water infiltration into the soil due to the improvement of the physical and biological properties of the soil. Table 4 and Figure 7 show that agroforestry simulation of agriculture and shrubland has shortened the time of water deficit from 5 months to 4 months (similar to simulations 1 and 2) with a 59% reduction in water deficit intensity.

Scenario 4: Development of Water Retention Reservoir

The development of a water retention reservoir was simulated with a storage volume of 15 MCM, which was placed in the tributary basin (it requires a more detailed study) with an annual average discharge coming out of the principal spillway of 2.5 $m^3 s^{-1}$. The development of 1 water retention reservoir would shorten the duration of the water deficit from five months to three months with the intensity of reducing the water deficit by 69%, while the construction of two reservoirs was able to shorten the duration of the water deficit up to two months (July and August) with a reduction in water deficit intensity of 84% (Table 4 and Figure 7).

Scenario 5: Combination of Scenarios 1, 2, 3 and 4

Simulations of applying vegetative soil and water conservation measures (scenarios 1, 2, and 3) and technical civil engineering measures (scenario 4) have yet to overcome the water deficit of the Upper Cisadane Sub-Watershed. Scenarios 1, 2, and 3 were carried out by increasing rainwater interception by vegetation and increasing water infiltration into the soil, which increased baseflow in the dry season. On the other hand, scenario four is carried out by collecting rainwater and surface runoff into a reservoir, which then drains it slowly through the principal spillway. Table 4 and Figure 7 show that a combination of scenarios 1, 2, 3, and 4 could overcome the water deficit in the Upper Cisadane Sub-Watershed.

Land-based water resource management includes: 1) reforestation of converted forests to increase the amount of rainwater intercepted by the vegetation canopy and improve soil hydraulic conductivity, which in turn will increase the amount of water infiltrated into the soil as a reserve of groundwater to be released as baseflow into the river flow during the dry season; 2) utilization and control of space in accordance with its designation in the spatial pattern of West Java Province to suppress forest encroachment both in forest areas and in water absorption zones and zones prone to ground movement disasters, as well as controlling settlement development; and 3) agroforestry of agricultural and shrub lands to increase and stabilize plant canopy cover on agricultural land so that agricultural land also contributes positively to increasing water availability during the dry season. River-based water resource management through the construction of reservoirs is intended to store surface runoff during the rainy season as a water reserve that can be utilized during the dry season. Thus, water resource management in the Upper Cisadane Sub-Watershed cannot be carried out by only repairing/restoring the catchment area or constructing infrastructure buildings but must be carried out in an integrated manner by improving the catchment area and constructing water retention infrastructure.

The water deficit in June, July, August, September, and October occurred because the rainfall in those months was lower than that in other months, indirectly indicating that the Upper Cisadane Sub-Watershed in its existing condition was unable to store water as reserve water during the dry season. To increase water reserves in watersheds, efforts have been made to absorb water into the soil through land cover improvement. The impact of land cover improvement on river flow is well known. Table 4 shows a simulation of reforestation of forest land that has been converted to other uses (scenario 1), reduced river flow rates during the rainy season, and increased water availability in the dry season by shortening the duration of the water deficit from 5 months to 4 months with a reduction intensity of 46%. This is in line with the results of a study by Schleich and Hillenbrand [17] on semi-arid watersheds in Central Africa, which showed that the conversion of grasslands to forests on a slope of > 3% reduced the average monthly surface runoff in the rainy season by 30% and increased lateral flow and base flow by 110% and 254%, respectively. The river flow discharge during the rainy season in watersheds with good forest conditions was lower than that in watersheds where the forest had been degraded [33]. Saddique et al. [14] simulated land use in the Jhelum River Basin (Mangla Dam Watershed) and found that the surface runoff decreased by 17.1% if all grassland

and agricultural land were converted to forests. Reforestation of forest land that had been encroached on agricultural land in the Upper Nan River reduced river flow rates during the rainy season and increased base flow in the dry season [34].

Table 4 and Figure 7 show a simulation of the spatial pattern of West Java Province (RTRWP 2009–2029) (as a scenario 2) is quite effective in reducing river flow discharge during the rainy season and shortening the duration of water deficit from 5 months to 4 months with an intensity reduction of water deficit of 72%. Research by Marhaento et al. [11] on the Samin sub-watershed in Central Java showed that the implementation of the spatial pattern of Central Java Province reduced the surface runoff discharge in the rainy season by 16% and increased the baseflow discharge in the dry season by 6%. In contrast, a study in the Wakung Watershed (Pemalang Regency, Central Java) showed that the application of the spatial pattern of the Pemalang District slightly increased river flow discharge during the rainy season [35]. This is because there are several plans for the development of urban areas and horticultural land on steep slopes (> 25%).

Upland agriculture occupies a fairly large area in the Upper Cisadane Sub-Watershed, approximately 7,007 ha (29.8%), consisting of 3,631 ha of mixed gardens (15.5%) and 3,376 ha of field/dry land farms (14.3%). Most of the current agricultural management has not applied adequate soil and water conservation measures; therefore, agricultural land is one of the contributors to fluctuations in river flow discharge. Agroforestry simulation on agricultural land and shrubs (scenario 3) has a similar effect in increasing water availability during the dry season by reducing the duration of the water deficit from five months to four months with an intensity of 59% reduction in water deficit. Another study in the Mara River Basin (East Africa) showed that river flow discharge during the rainy season decreased by 4% in agroforestry intercropping sparsely distributed trees with different crops, 7% in agroforestry trees along hedges and borders, and 12.5% in agroforestry woodlots [36]. Agroforestry simulations on agricultural land and shrubs can reduce river flow discharge in the rainy season by 13.9% and increase the minimum discharge in the dry season by 157% [37].

The simulation development of two water retention infrastructures (reservoirs) with a total storage volume of 30 million cubic meter (scenario 4) in the Upper Cisadane Sub-Watershed was able to shorten the duration of the water deficit by up to two months (July and August) with a reduction in water deficit intensity of 84%. Most rainwater and surface runoff are stored in reservoirs and can be used as water reserves during the dry season. Using the HEC-GeoHMS, Simulation of dry dam in the Upper Ciliwung watershed was effective in reducing peak discharge by 77.7%, from 123.2 $m^3 s^{-1}$ to 27.4 $m^3 s^{-1}$ [38]. Scenario 4 is quite effective in overcoming the water deficit in the Upper Cisadane Sub-Watershed; however, the development of the reservoir, which is not disserted with adequate land rehabilitation, causes the reservoir to dry during the dry season. Therefore, the combination of scenarios 1, 2, 3, and 4 is a realistic mitigation strategy to overcome the water deficit while simultaneously maintaining the environmental dynamic stability and disaster mitigation related to hydrometeorology in the Upper Cisadane Sub-Watershed. The combination of these scenarios must be applied to watersheds, some of which have developed into urban/suburban areas.

Conclusion

Based on the total volume of water available, the water balance of the Upper Cisadane Sub-Watershed is a surplus of 13.11 MCM $year^{-1}$. Conversely, based on the temporal availability (monthly), the water balance is deficient in the dry season, namely in June, July, August, September, and October. Sectoral water management to control water deficit that only involves partial stakeholders, such as the Ministry of Forestry (scenario 1), Regional Development Planning Boards (scenario 2), the Ministry of Agriculture (scenario 3), and the Ministry of Public Works and Public Housing (scenario 4), has not been able to overcome the water deficit as a whole. The availability of water in the Upper Cisadane Sub-Watershed, which is distributed throughout the year, is guaranteed, and the water deficit can be overcome through cooperation between parties, as shown in combined scenarios 1, 2, 3, and 4.

The water scarcity and water deficit in the Upper Cisadane Sub-Watershed in the dry season is difficult to deal with partially through an approach such as restoration of the catchment area or development of water retention infrastructure. However, this must be carried out in an integrated manner through the improvement of the catchment area and the development of water retention infrastructure. To increase water availability in the Upper Cisadane Sub-Watershed, it is necessary to apply a spatial plan (especially protection of conservation forests and control of settlement development), develop an agroforestry system for converted forest and agricultural areas, apply soil and water conservation measures in critical lands, and develop water retention infrastructure such as a reservoir.

Author Contributions

YH: Conceptualization, Methodology, SWAT Analysis & Writing; **LMR**: Methodology, Formal Analysis, Review & Editing; **EDW**: Data Curation & Investigation; **DPTB**: Formal Analysis, Review & Editing; **WP**: Data Curation, Review - Editing & Visualization; **SMY**: Data Curation & Visualization; **FDA**: Data Curation, Formal Analysis & Visualization.

Conflicts of Interest

The are no conflicts to declare.

References

1. Hidayat, Y.; Murtilaksono, K.; Wahjunie, E.D.; Panuju, D.R. The characteristics of river discharge of Citarum Hulu. *Jurnal Ilmu Pertanian Indonesia* **2013**, *18*, 109–114.
2. Hidayat, Y.; Purwakusuma, W.; Wahjunie, E.D.; Baskoro, D.P.T.; Rachman, L.M.; Yusuf, S.M.; Adawiyah, R.M.; Syaefudin, I.; Siregar, M.R.; Isnaini, D.A. Characteristics of soil hydraulic conductivity in natural forest, agricultural land, and green open space area. *Journal of Natural Resources and Environmental Management* **2020**, *9*, 100–103, doi:10.29244/jpsl.9.1.%15p.
3. Oktanthya, P.S.; Sinukaban, N.; Hidayat, Y. Pengaruh penggunaan lahan terhadap debit aliran sungai di sub das Batang Arau Hulu Kota Padang. Undergraduate Thesis, IPB University, Bogor, ID, 2011.
4. Muchtar, A.; Abdullah, N. Analysis of factors influencing the river discharge of Mamasa. *Jurnal Hutan dan Masyarakat* **2007**, *2*, 174–187.
5. Hidayat, Y. *Spatial Plan Based on Water Resources: Lecture Material of Ecohydrology and Sustainable Water Resources Management*; IPB University: Bogor, ID, 2021;
6. BPDAS (Balai Pengelolaan Daerah Aliran Sungai) Citarum-Ciliwung. *The Report on the Preparation of Sequence of Watershed Priority*; BPDAS: Bogor, ID, 2009;
7. Ahsoni, M.A. Perencanaan Penggunaan Lahan Berkelanjutan Di Sub Das Cisadane Hulu. Thesis, IPB University, Bogor, ID, 2008.
8. Maulana, A. Analisis Perubahan Kapasitas Simpan Air pada DAS Cisadane Hulu, Jawa Barat. Thesis, IPB University, Bogor, ID, 2016.
9. Rodríguez, M.I.; Grindlay, A.L.; Cuevas, M.M.; Zamorano, M. Integrating land use planning and water resource management: threshold scenarios – a tool to reach sustainability. *Ecosystems and Sustainable Development X* **2015**, *192*, 231–242.
10. Pantic, M.; Milijic, S.; Miljkovic, Z.J. Spatial Planning as a Land-use and Building Regulation Tool for Protected Natural Areas in Serbia. In Proceedings of 2nd International Conference on Urban Planning - ICUP2018, Serbia, Niš, 14–17 November 2018, pp. 331–338.
11. Marhaento, H.; Booij, M.J.; Hoekstra, A.Y. Hydrological response to future land-use change and climate change in a tropical catchment. *Hydrological Sciences Journal* **2018**, *63*, 1368–1385.
12. Bultot, F.; Dupriez, G.L.; Gellens, D. Simulation of land use changes and impacts on the water balance – A case study for Belgium. *Journal of Hydrology* **1990**, *114*, 327–348, doi:10.1016/0022.1694(90)90064-5.
13. Jou, H.H.H.; Khojasteh, D.M., Besalatpour, A.A. Land use planning based on soil and water assessment tool model in a mountainous watershed to reduce runoff and sediment load. *Canadian Journal of Soil Science* **2019**, *99*, 305–320, doi:10.1139/cjss-2018-0109.
14. Saddique, N.; Mahmood, T.; Bernhofer, C. Quantifying the impacts of land use/land cover change on the water balance in the afforested River Basin, Pakistan. *Environmental Earth Science* **2020**, *79*, 1–13.
15. Woyessa, Y.E.; Welderufael, W.A. Impact of land-use change on catchment water balance: A case study in the central region of South Africa. *Geoscience Letters* **2021**, *8*, 1–10, doi:10.1186/s40562-021-00204-9.
16. Center for Soil and Agroclimate Research. *Semi detailed of soil map of Bogor Regency*; Center for Soil and Agroclimate Research: Bogor, ID, 1990;

17. Schleich, J.; Hillenbrand, T. Determinants of residential water demand in Germany. *Ecological Economics* **2009**, *68*, 1756–1769.
18. Sari, I.K.; Limantara, L.M.; Priyantoro, D. Analysis of water availability and demand in the Sampean Watershed. *Jurnal Teknik Pengairan* **2012**, *2*, 29–41.
19. Department of Highways and Water Resources of Bogor City. *Daily Discharge of Cross and Non-Cross Weirs, Water Resources Management Center for the Ciliwung Cisadane River Region 2013-2018*; Department of Highways and Water Resources of Bogor City: Bogor, ID, 2018;
20. Arnold, J.G.; Kiniry, J.R.; Srinivasan, R.; Williams, J.R.; Haney, E.B.; Neitsch, S.L. *Soil and Water Assessment Tool: Input-Output Documentation Version 2012*; Texas Water Research Institute: College Station, USA, 2012;
21. Ridwansyah, I.; Pawitan, H.; Sinukaban, N.; Hidayat, Y. Watershed modeling with ArcSWAT and SUFI2 in Cisadane Catchment Area: Calibration and validation of river flow prediction. *International Journal of Science and Engineering* **2014**, *6*, 12–21, doi:10.12777/ijse.6.2.92-101.
22. Sulaeman, D.; Hidayat, Y.; Rachman, L.M.; Tarigan, S.D. Best management practice untuk menurunkan debit aliran dan hasil sedimen das ciujung menggunakan model SWAT. *Jurnal Ilmu Tanah dan Lingkungan* **2016**, *18*, 8–14.
23. Nugroho, S.P.; Tarigan, S.D.; Hidayat, Y. Analisis perubahan penggunaan lahan dan debit aliran di Sub DAS Cicatih. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan* **2018**, *8*, 258–263, doi:10.29244 /jpsl.8.2.258-263.
24. Munggaran, G.; Hidayat, Y.; Tarigan, S.D.; Baskoro, D.P.T. Analisis respon hidrologi dan simulasi teknik konservasi tanah dan air Sub DAS Cimanuk Hulu. *Jurnal Tanah dan Lingkungan* **2017**, *19*, 26–32.
25. BMKG (Badan Meteorologi, Klimatologi, Geofisika). Data online Pusat Data Base-BMKG. 2020. Available online: https://data online.bmkg.go.id (accessed 10 January 2020).
26. BPDAS (Balai Pengelolaan Daerah Aliran Sungai) Citarum-Ciliwung. *Perencanaan Pengelolaan DAS Terpadu DAS Cisadane*; BPDAS Citarum-Ciliwung: Bogor, ID, 2016;
27. BPS (Badan Pusat Statistik) Kota Bogor. *Kota Bogor Dalam Angka Tahun 2018*; BPS: Bogor, ID, 2018;
28. BPS (Badan Pusat Statistik) Kabupaten Bogor. *Kabupaten Bogor Dalam Angka Tahun 2018*; BPS: Bogor, ID, 2018;
29. Zhang, W.; Shou-sheng, M.; Zhang, Y.Z.; Chen, K.M. Seasonal and interannual variations of flow discharge from Pearl River into the sea. *Water Science and Engineering* **2012**, *5*, 399–409.
30. Konapala, G.; Mishra, A.K.; Wada, Y.; Mann, M.E. Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *Nature Communications* **2020**, *11*, 1–10.
31. KLHK (Kementrian Lingkungan Hidup dan Kehutanan). Peta Kawasan Hutan berdasarkan SK Men LHK No 278 Tahun 2017. 2017. Available online: https://tanahair.indonesia.go.id/sdi/dataset/peta-kawasan-hutan-berdasarkan-sk-men-lhk-no-278-2017 (accessed 15 July 2017).
32. Pemerintah Daerah Jawa Barat. Peraturan Daerah Nomor 22 tahun 2010: Rencana Tata Ruang Wilayah Provinsi Jawa Barat tahun 2009-2029. 2020. Available online: https://jdih.dprd.jabarprov.go.id/dokumen/peraturan-daerah/2010/22 (accessed 10 January 2020).
33. Qazi, N.Q.; Bruijnzeel, L.A.; Rai, S.P.; Ghimire, C.P. Impact of forest degradation on streamflow regime and runoff response to rainfall in the Garhwal Himalaya, Northwest India. *Hydrological Sciences Journal* **2017**, *62*, 1114–1130, doi:10.1080/02626667.2017.1308637.
34. Wangpimool, W.; Pongput, K.; Sukvibool, C.; Sombatpanit, S.; Gassman, P.W. The effect of reforestation on stream flow in the Upper Nan River Basin using Soil and Water Assessment Tool (SWAT) model. *International Soil and Water Conservation Research* **2013**, *2*, 53–63.
35. Anwar, Y.; Setyasih, I.; Setiawan, M.A.; Christanto, N. Evaluation of spatial plan in controlling stream flow rate in Wakung Watershed, Pemalang, Central Java, Indonesia. *IOP Conf. Series: Earth and Environmental Science* **2018**, *148*, 012030, doi:10.1088/1755-1315/148/1/012030.
36. Mwangi, H.; Julich, S.; Patil, S.D.; McDonald, M.A.; Feger, K.H. Modelling the impact of agroforestry on hydrology of Mara River Basin in East Africa. *Hydrological Processes* **2016**, *30*, 3139–3155, doi:10.1002/hyp.10852.
37. Rachman, L.M.; Hidayat, Y.; Baskoro, D.P.T.; Noywuli, N. Simulation of water discharge control using SWAT Model. In Proceedings of National Seminar on Integrated Watershed Management; Pekanbaru, 2017.
38. Inayah, A. Simulasi Retensi Air Permukaan menggunakan Model HEC-GeoHMS. Thesis, Institut Pertanian Bogor, Bogor, ID, 2017.