

Analysis Soil and Water Conservation Strategies in Ciwidey Sub-Watershed using SWAT Model

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Abstract

The Ciwidey sub-watershed serves as a buffer zone to meet the raw water needs of Bandung Regency. This study aims to assess the hydrological impacts of soil and water conservation techniques and evaluate the combined effects under extreme rainfall on runoff and baseflow dynamics. The Soil and Water Assessment Tool (SWAT) hydrological model was employed to predict flow discharge in the Ciwidey sub-watershed. The methodology included collecting hydrological, climate, and land-use data, delineating watersheds, forming Hydrological Response Units (HRUs), and conducting model calibration, validation, and simulation of a surface runoff. The spatial pattern of the Bandung Regency Regional Spatial Plan (RTRW) for 2016–2036 resulted model simulations predicted a surface runoff of 1,084.36 mm/year under extreme rainfall. The watershed conservation program demonstrates strong implementation of agroforestry and reforestation throughout the watershed region, with 42,313 hectares currently under management with 21 individual conservation projects in 9 districts. The conservation planning program consists of implementation Agroforestry (52.6%), reforestation (39.6%) and 7,8% infiltration well, with Pasir Jambu District and Subbasin 6 emerging as focus area of comprehensive conservation. The study demonstrates that integrating soil and water conservation is crucial for sustainable water resource management and flood risk reduction in rapidly developing regions.

Keywords: *ciwidey sub-watershed, hydrological model, swat, land use, extreme rainfall*

Abstrak

Sub-DAS Ciwidey, bagian dari daerah aliran sungai Citarum Hulu, berfungsi sebagai zona penyangga untuk memenuhi kebutuhan air baku Kabupaten Bandung. Studi ini bertujuan untuk menilai dampak hidrologis dari teknik konservasi tanah dan air serta mengevaluasi efek gabungan dari curah hujan ekstrem terhadap dinamika limpasan dan aliran dasar. Model hidrologis *Soil and Water Assessment Tool* (SWAT) digunakan untuk memprediksi debit aliran. Pengumpulan data DEM, hidrologis, iklim dan penggunaan lahan sebagai input dalam penentuan batas daerah aliran sungai, pembentukan Unit Respons Hidrologis (HRU), dan pelaksanaan kalibrasi, validasi, dan simulasi model. Pola spasial Rencana Tata Ruang Daerah (RTRW) Kabupaten Bandung untuk tahun 2016–2036 memprediksi limpasan permukaan sebesar 1.084,36 mm/tahun dalam kondisi curah hujan ekstrem. Program konservasi DAS menunjukkan rencana focus area konservasi untuk agroforestri dan reboisasi secara menyeluruh di wilayah DAS seluas 42.313 Ha, berupa 21 proyek konservasi pada 9 kabupaten, dengan agroforestri seluas 22.252 Ha (52,6%), reboisasi seluas 16.770 Ha (39,6%), dan sumur resapan seluas 3.291 Ha (7,8%). Kabupaten Pasir Jambu dan Sub-cekungan 6 sebagai daerah terdepan dalam perencanaan implementasi konservasi komprehensif. Studi menunjukkan bahwa integrasi konservasi tanah dan air sangat penting untuk pengelolaan sumber daya air yang berkelanjutan dan pengurangan risiko banjir di wilayah yang berkembang pesat.

Kata Kunci: *sub-das ciwidey, model hidrologi, swat, tata guna lahan, debit puncak*

1. Introduction

Sustainable watershed management requires land-use planning and soil water conservation practices that regulate runoff, enhance infiltration, and maintain baseflow under increasing climate variability. In rapidly developing regions, spatial plans should integrate hydrological evidence to reduce flood risk and secure dry-season water availability. Water management is needed to maintain the quantity and quality of water. One option is to use a watershed system approach to survey and predict flow discharge in the watershed through a hydrological model[1][2]. The hydrological model can also be used for flood control. The model used in water management is a model that can simulate processes in a watershed, which is a distributed model by considering the characteristics of the input model.

Physically based models such as the Soil and Water Assessment Tool (SWAT) enable planners to quantify how land-use configurations and conservation measures alter surface and subsurface flow pathways at the sub-basin scale [3]. SWAT is built based on processes that occur in watersheds by collecting information about climate, soil properties, topography, vegetation, and land management [3]. This comprehensive approach allows for detailed simulation of various watershed processes and their interactions. Under ideal conditions, conservation interventions and spatial planning frameworks work together to attenuate peak flows, increase groundwater recharge, and improve overall watershed resilience. One of the key strengths of SWAT is its ability to assess the long-term impacts on watersheds. It can simulate the long-term effects of best management practices and land use changes on runoff, sediment yield, and water quality [2].

MapWindows Soil and Water Assessment Tool (MWSWAT) are software from the SWAT system and is integrated into the MapWindows Geographic Information System (GIS). It is open-source software and has been developed and widely used in many countries. By using relevant and representative data, SWAT can be used to analyze river flow in water catchment areas. The SWAT model operates on a daily timescale and is designed to predict the long-term impact of land management practices on water, sediment, and pesticide yields in large and complex watersheds in a variety of soil, land and management scenarios [4].

Previous studies show that SWAT can reliably simulate streamflow responses to land-use change and conservation practices when properly calibrated and validated [1][5][6]. Research also demonstrates that reforestation, agroforestry, and infiltration-based measures can reduce surface runoff and enhance baseflow by increasing soil storage and subsurface flow [3]. Forested areas tend to improve water conservation, leading to higher R^2 and NSE values due to more stable hydrological processes. Conversely, converting forests to agricultural land can increase surface runoff and sediment yield, potentially reducing model performance [4][5][6]. However, limited studies have jointly evaluated conservation techniques and statutory spatial plans under extreme rainfall scenarios at the sub-watershed scale.

The Ciwidey sub-watershed is a mountainous area situated at elevations ranging from 500 to 2,000 meters above sea level. As a rural area, Ciwidey Highlands has experienced tourism-driven capitalization that profoundly affects its economic landscape. This transformation has prompted farmers to consider selling their land due to its rising value, resulting in significant changes to local livelihoods and land management practices [7]. The Ciwidey sub-watershed forms part of the upper Citarum watershed, a national priority basin requiring intensive management interventions due to its strategic hydrological importance. Ideally, this watershed should regulate streamflow, reduce flood risk, and sustain dry-season water availability. However, its hydrological function has declined, as reflected in pronounced fluctuations in river discharge and increasing flood vulnerability. Delineating priority sections is essential for the effective and targeted implementation of soil and water conservation measures. The identification of critical areas will not only direct researchers and planners attention to the most problematic zones but also reduce the economic costs [8]. Moreover, previous assessments indicate that 1,005.56 ha of water catchment area in Soreang District and 1,396.65 Ha in Kutawaringin District are categorized as critical [9]. These conditions suggest substantial degradation of infiltration capacity and watershed storage.

Although spatial planning and soil and water conservation measures have been proposed to address these issues, their hydrological effectiveness under extreme rainfall conditions remains insufficiently quantified. Few studies have examined how conservation techniques and the Bandung Regency Spatial Plan 2016-2036 (RTRW 2016-2036) affect runoff and subsurface flow at the sub-watershed scale. This gap underscores the need for a modeling-based assessment to support evidence-based watershed management. This study aims to assess the hydrological impacts of soil and water conservation techniques and evaluate the combined effects of extreme rainfall and the RTRW 2016–2036 spatial configuration on runoff and baseflow dynamics. The findings provide quantitative evidence to support watershed management decisions and spatial planning policies. By integrating conservation strategies with modeling-based scenario analysis, this research contributes practical guidance for improving flood mitigation and hydrological resilience in rapidly developing watersheds.

2. Material and Methods

Study Area

The study was conducted in The Ciwidey sub-watershed is the upstream part of the Citarum watershed, which originates at Mount Patuha and Puncaklawang. Geographically, it is located at 7°2'23.74" South Latitude and 107°29'47.26" East Longitude.

SWAT Model

The Model Soil and Water Assessment Tool (SWAT) is an application developed by the United States Department of Agriculture (USDA) that is used as a tool to identify, assess, and evaluate the level of watershed problems and select management actions to control these problems. The SWAT model works on a daily timescale and is designed to predict the long-term impact of land management practices on water, sediment, and pesticide yields in a watershed in a variety of soil, land, and management scenarios [5].

The stages of the SWAT model begin with secondary data collection. Secondary data inputs for SWAT include DEM maps, river networks, soil types, land use, regional rainfall, river observation discharge, daily rainfall, maximum-minimum temperature, average temperature, average humidity, average wind speed, and solar radiation. The model development stage by SWAT consists of watershed delineation, formation of a Hydrological Response Unit (HRU), climate data input, and SWAT simulation. After that, calibration and model validation were carried out. Then proceed with the application of scenarios in the Ciwidey sub-watershed. SWAT simulates the hydrological cycle based on the calculation of the water balance (Equation 1)[6] as follows:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{\text{day}} - Q_{\text{surf}} - E_a - W_{\text{seep}} - Q_{\text{gw}}) \quad (1)$$

Where SW_t is the final soil water content ($\text{mm H}_2\text{O}$), SW_0 is the initial soil water content on day i ($\text{mm H}_2\text{O}$), t is time (days), and R_{day} is the amount of precipitation on day i ($\text{mm H}_2\text{O}$), Q_{surf} is the amount of surface runoff on day i ($\text{mm H}_2\text{O}$). E_a is the amount of evapotranspiration on day i ($\text{mm H}_2\text{O}$), W_{seep} is the amount of water that enters the vadose zone from the soil profile on day i ($\text{mm H}_2\text{O}$), and Q_{gw} is the amount of water that returns to flow on day i ($\text{mm H}_2\text{O}$). The SWAT model uses the SCS-CN (Soil Conservation Service – curve number) method to predict surface runoff (Q_{surf}). This method was developed to calculate land cover and runoff from various types of soil with the formulas in Equations 2 and 3 [6] as follows:

$$Q_{\text{surf}} = \frac{(R_{\text{day}} - 0.2S)^2}{(R_{\text{day}} + 0.8S)} \quad (2)$$

$$S = 25.4 \left(\frac{1000}{N} - 10 \right) \quad (3)$$

Where R_{day} is rainfall per day (mm), Q_{surf} is surface runoff (mm), S is retention parameter (mm), CN is SCS Curve Number, and Q_{gw} is the amount of water that returns to flow on day i ($\text{mm H}_2\text{O}$).

Input Data

The topographic map used is a Digital Elevation Model (DEM) map from the Shuttle Radar Topography Mission (SRTM) with a scale of 30 m x 30 m in the 2020 Global Database, which was downloaded from the United States Geological Survey (USGS) website (<https://www.usgs.gov/>, 02/25/2022). The DEM-base area is 100 ha and forms 335 HRU units in 6 subbasins in the Ciwidey sub-watershed. Land use according to the Citarum River Basin Center (BBWS) with a scale of 1: 25,000 in 2018, the Ciwidey sub-watershed is categorized into 7 parts, including forest (24.2%), gardens/plantations (22.3%), fields/dry fields (10.1%), rivers/lakes/reservoirs/situ (0.4%), and built (10.9%) (**Figure 1a**). Soil types in the Ciwidey sub-watershed include Dystrandeps; Humitropepts; Hyndrandeps (3.9%), Dystrandeps; Tropaudults; Eutropepts (2.1%), Dystrandeps; Eutropepts; Tropudalfs (43.5%), Dystrandeps; Humitropepts; Troporthents (2.3%), Eutropepts; Euntrandeps; Eutropepts (1.1%) (**Figure 1b**). The slope of the Ciwidey sub-watershed is divided into five classes, namely: flat (0–8%) by 27%; wavy (8–15%) by 1%; wavy (15–25%) by 36%; hilly (25–40%) by 13%; and steep mountains (>40%) by 23% (**Figure 1c**). Cisondari and Cileunca Stations provided daily meteorological data from 2005 to 2021. Because the data is not completely available, for daily river flow data, data from the Ciwidey-Cibeureum River Flow Measurement Station (SPAS) in 2014 and 2018 is used for the calibration and model validation stages (**Figure 1d**).

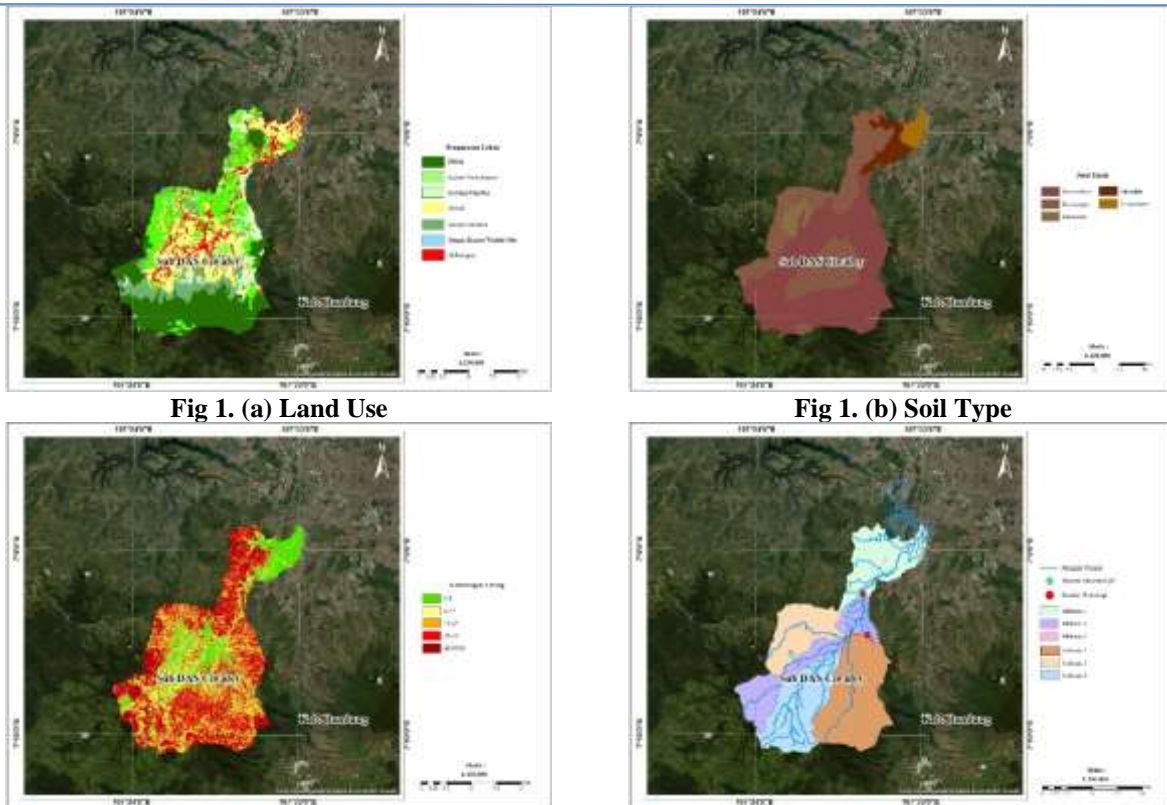


Fig 1. (a) Land Use **Fig 1. (b) Soil Type**
Fig 1. (c) Slope **Fig 1. (d) River Network**
Fig. 1. (a) Land Use, (b) Soil Type, (c) Slope, (d) River Network Ciwidey Sub-watershed

SWAT Model Development

Soil type spatial data is converted to raster, then projected and converted to Universal Transverse Mercator (UTM) or (WGS_1984_UTM_Zone_48S). The first step is to project the coordinates on the ArcGIS 10.1 desktop. The formation of HRU uses a threshold by percentage for each HRU input. The threshold by percentage for land cover, soil type, and slope is 0%, which means that the entire area of the Ciwidey sub-basin area that has been formed is considered in the formation of the HRU. The Ciwidey sub-watershed is formed into 6 subbasins with 335 HRU units. Climate input data was sourced from the Bandung Geophysics Station in 2005–2021. The climate data used includes rainfall data, relative humidity, temperature, wind speed, and solar radiation. The processed data is then entered into the WGEN_USER input folder, which will then be entered into the weather generator data. The initial warm-up period for the model is 3 years (2015–2017).

Model Calibration and Validation

The SWAT model calibration is done manually by the Manual Calibration Helper submenu by setting a combination of parameter values that affect watershed conditions. The calibration uses 2014 water discharge data, and the validation uses 2018 water flow data. The SWAT evaluation parameters use the coefficient of determination (R^2) and the Nash-Sutcliffe Index (NSE) based on equations (4) and (5) below.

$$R^2 = \frac{(X - \bar{X})^2 - (X - Y)^2}{(X - \bar{X})^2} \quad (4)$$

Where R^2 is the coefficient of determination, \bar{X} is the observation data, and Y is the model simulation data. The value of R^2 , which ranges between 0 and 1, indicates how much of the distribution of the observation data can be explained by the simulation data. If the value of R^2 is close to 1, it can be concluded that the error variance is low. If the value of $R^2 = 0$, it indicates that there is no correlation at all, whereas if $R^2 = 1$, it indicates that the distribution of the observation data is the same as the observation data [10] [11] [12]

$$NSE = 1 - \frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - \bar{Y}^{obs})^2} \quad (5)$$

The range of NSE values is $-\infty$ to 1, with $NSE = 1$ being the optimal value. The NSE value between 0.0 and 1.0 is generally considered an acceptable level of model performance, while the NSE value of 0.0 indicates that the average observed data is a better predictor than the simulation data value [10][11][12].

3. Results and Discussion

Streamflow Calibration and Validation

Model calibration and validation were performed using the SWAT model through iterative adjustment of 14 sensitive parameters selected to reflect the physiographic and hydrological characteristics of the Ciwidey Sub-watershed. Monthly calibration yielded an R^2 value of 0.30 and a Nash–Sutcliffe Efficiency (NSE) coefficient of 0.51, indicating satisfactory model performance according to the criteria. Although the coefficient of determination suggests a moderate representation of variance, the NSE value exceeding 0.50 indicates that the model adequately captures the overall dynamics of streamflow at the monthly scale. During validation, model performance declined, with an R^2 value of -0.28 and an NSE value of 0.42. The negative R^2 suggests limited correspondence between observed and simulated variability during the validation period, while the NSE value indicates moderate predictive skill, but reduced robustness compared with the calibration phase.

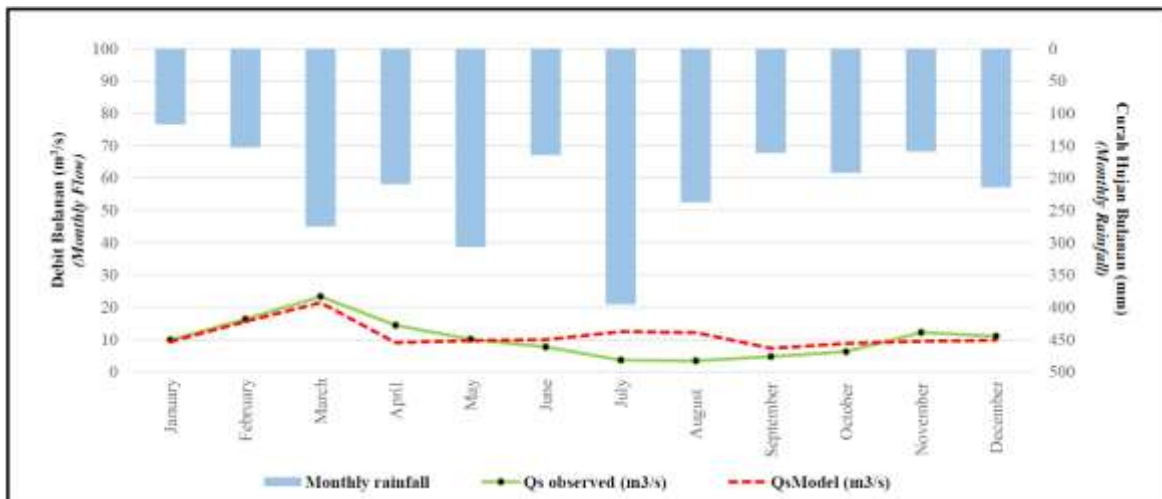


Fig 2. Monthly Period Model Validation,

Although modeled streamflow generally corresponds with observed discharge, the significant discrepancy observed in July and August warrants closer examination. During this period, monthly rainfall and modeled discharge increased, whereas observed discharge remained comparatively low. One possible explanation is measurement uncertainty associated with field discharge data, particularly if high-flow conditions exceeded optimal gauging accuracy. Similar divergences between simulated and observed flows have been reported [4]. Alternatively, localized hydrological processes, such as increased infiltration, temporary floodplain storage, or delayed subsurface flow contributions. It may have attenuated surface discharge despite elevated rainfall[13]. It is also plausible that the model overestimated runoff generation due to simplified parameterization of soil moisture dynamics or rainfall–runoff response functions. This divergence highlights potential limitations in both field measurement and model structure, underscoring the need for calibration refinement and improved representation of catchment-specific processes.

Land Use Change Analysis

The analysis of land use changes in the Ciwidey sub-watershed was carried out using Arcgis 10.1 software by running and then overlaying the land use map and then comparing the area of each land cover for 2014 and 2018. Changes in land use of the Ciwidey Sub-watershed as shown in Table 1 there was an increase around gardens, shrubs, and rivers/lakes/reservoirs/situ by 3,921.36 Ha, 1,814.34 Ha, and 37.84 Ha, or by 18.7%, 8.7%, and 0.2%. While the reduction in land area in the Ciwidey sub-watershed is found

in forest areas, fields/moorlands, rice fields, and built-up areas, respectively, of 336.03 Ha, -3,948.85 Ha, 1,220,17 Ha, and -251.16 Ha, or by -1.6%, -18.9%, -5.8%, and -1.2%.

Table 1. Sub DAS Ciwidey Land Use Change 2014-2018

No.	Land Use	2014	2018	Change	
		Area (Ha)	Area (Ha)	Ha	%
1.	Forest	5,825.31	5,488.29	-337.03	-1.6
2.	Garden/Plantation	673.64	4,595.01	3,921.36	18.7
3.	Field/Moor	6,167.19	2,218.33	-3,948.85	-18.9
4.	Ricefield	5,408.01	4,187.84	-1,220.17	-5.8
5.	Shrubs	588.65	2,402.99	1,814.34	8.7
6.	River/Lake/Reservoir/Situ	7.13	44.97	37.84	0.2
7.	Open land	16.33	0	-16.33	-0.1
8.	Settlement	2,275.92	2,024.75	-251.16	-12
Total		20,962.17	20,962.17		

Source: SWAT Model Simulation Results

Scenario Analysis: Hydrological Response to Soil and Water Conservation Techniques (SWCT) under Extreme Rainfall

Problematic sub-basins within the Ciwidey sub-watershed were identified using the ratio of the Annual Flow Coefficient to Direct Runoff (DRO), defined as the combined surface runoff and lateral flow (mm). This approach identified Sub-basins 2, 3, 4, 5, and 6 as critical hydrological units, with SWCT values ranging from 0.49 to 0.61. This prioritization methodology aligns with established frameworks for watershed management, where sub-basin-scale assessment facilitates targeted allocation of conservation resources [13][14].

Similar multi-criteria approaches have been employed in SWAT-based watershed studies to identify erosion hotspots and runoff-critical zones. The effectiveness of spatial sediment yield mapping and sub-watershed classification (moderate to severe) were demonstrated in the Merguellil watershed, Tunisia [13]. The results successfully identifying six priority sub-watersheds for immediate conservation action. [14] further refined prioritization by ranking soil and water conservation measures (SWCMs) based on unit-area effectiveness quantifying reductions in discharge, surface runoff, and sediment yield per hectare thereby enabling efficiency-based spatial targeting in the Jing River catchment, China.

The implementation of the SWC technique markedly modified the watershed's flow regime, reducing surface runoff by 57.09% (418.03 mm) while increasing lateral flow and base flow by 41.95% (1,073.28 mm) and 64.94% (584.30 mm), respectively. These shifts indicate enhanced infiltration and subsurface water storage, likely resulting from improved vegetation cover and the installation of infiltration wells. The observed reduction in surface runoff indicates enhanced runoff attenuation capacity and may contribute substantially to flood risk mitigation by lowering peak discharge and extending time to peak during storm events. Conversely, the pronounced increases in lateral flow and baseflow reflect enhanced groundwater contributions to streamflow and indicate greater hydrological resilience and sustained dry season flows.

These findings are consistent with SWAT simulation results reported [15] for the Opak Hulu watershed, Indonesia, where generic soil and water conservation scenarios reduced surface runoff by 542.22 mm (-27.09%) and increased baseflow by 797.28 mm (+18.32%) and lateral flow by 321.82 mm (+13.15%). Collectively, these results demonstrate the effectiveness of integrated SWCT in redistributing flow components from rapid surface pathways toward slower subsurface processes, thereby promoting hydrological stability, enhancing aquifer recharge, and supporting sustainable water resource management within the sub-watershed [16] [17].

Collectively, these results demonstrate the effectiveness of the SWC technique in redistributing flow components from rapid surface pathways toward slower subsurface processes, thereby promoting hydrological stability within the sub-watershed.

To evaluate the resilience of the conservation-modified system under climate extremes, an extreme rainfall event that occurred on 30 October 2021, with a recorded intensity of 152 mm/day, was selected for simulation. The hydrological response under this extreme rainfall scenario was evaluated using SWCT technique, which incorporates reforestation, agroforestry, and infiltration wells. Relative to existing conditions, the implementation of the SWC technique reduced surface runoff by 45.02%, while lateral flow and base flow increased by 91.44% and 130.96%, respectively. The 45% reduction in surface runoff under extreme conditions demonstrates enhanced watershed buffering capacity, a critical adaptation strategy for

climate resilience[13]. **Table 2** summarizes the resulting hydrological characteristics under the extreme rainfall scenario.

Table 2. Summarizes the Resulting Hydrological Characteristics Under the Extreme Rainfall Scenario

No.	Hydrological Characteristics	Score (mm/year)	
		Soil and Water Conservation Techniques	The Spatial Pattern of Regional Spatial Planning Kabupaten Bandung 2036
1.	Rainfall	3,935.05	3,937.53
2.	Surface Flow	533.81	1,084.36
3.	Lateral Flow	1,447.47	1,113.68
4.	Basic Flow	818.16	549.73

Source: SWAT Model Simulation Results

Recommendations for Ciwidey Sub-watershed Management Scenarios

Management scenario recommendations are proposed for Subbasins 2, 3, 4, 5, and 6, which have been identified as critical hydrological units within the Ciwidey subwatershed. Soil and Water Conservation Techniques were implemented across nine sub-districts within the Ciwidey Sub-watershed, as summarized in **Table 3**.

Table 3. Distribution of Soil and Water Conservation Techniques Techniques Based on District Administration

No.	Subbasin	Districts	KTA Technique	Area (Ha)	
1	2	Rancabali	Agroforestry	3,723.75	
			Reforestation	2,772.9	
			Infiltration Well	677.16	
2	3	Soreang	Agroforestry	1,441.39	
			Reforestation	146.61	
			Infiltration Well	317.79	
3	4	Banjaran	Agroforestry	467.19	
4.		Cimaung	Agroforestry	595.35	
		Reforestation	2,426.4		
5.	4	Pangalengan	Reforestation	2,669.13	
6.			Cililin	Agroforestry	1,220.22
				Reforestation	488.97
7.	5	Sindangkerta	Agroforestry	939.87	
			Reforestation	823.14	
			Infiltration Well	67.95	
8.	6	Ciwidey	Agroforestry	5,644.08	
			Reforestation	1,683.18	
			Infiltration Well	1,060.74	
9.	6	Pasir Jambu	Agroforestry	8,220.15	
			Reforestation	5,759.91	
			Infiltration Well	1,167.12	
Total				42,313.41	

Source: SWAT Model Simulation Results

The total conservation area spans 42,313.00 hectares, with 21 individual conservation projects in 9 districts. Agroforestry 22,252 Ha (52,6%), reforestation 16,770.24 Ha (39,6%), and 3,290.76 Ha (7,8%). infiltration well. Agroforestry is the dominant technique, covering more than half (52.6%) of the total conservation area. Reforestation accounts for nearly 40% of conservation efforts. Infiltration Wells have the smallest footprint but are strategically important for water management. Subbasin 6, Pasir Jambu leads with 35.8% of total conservation area (15,147 Ha). Subbasin 5 has the most diverse implementation with 8 projects across all three techniques. Subbasin 4 shows heavy focus on Reforestation (83% of its conservation area). Subbasin 3 has the smallest conservation footprint (4.5%). Subbasins (6 and 5) account for 64% of all conservation efforts. Pasir Jambu dominates with over 35% of total conservation area (15,147 Ha)

Top 3 districts (Pasir Jambu, Ciwidey, Rancabali) account for 72.5% of all conservation. Pangalengan focuses exclusively on Reforestation (single-technique district). Banjaran has the smallest conservation area and implements only Agroforestry. Pasir Jambu and Ciwidey are the only districts implementing all three techniques comprehensively.

Recommended Priority Actions:

1. Expand infiltration wells in Cimaung, Pangalengan, Cililin, and Banjaran to improve water infiltration
2. Scale up conservation in Banjaran and Subbasin 3 to reduce regional disparities
3. Replicate Pasir Jambu's success model (comprehensive multi-technique approach) in underperforming districts
4. Introducing technique diversity in Pangalengan and Banjaran
5. Conduct impact assessment of existing projects to optimize future implementations

4. Conclusion

The identification of critical sub-basins using the ratio of the annual flow coefficient to direct runoff (DRO) enabled the targeted assessment of watershed interventions. The results demonstrate that the SWC technique substantially redistributes flow components by reducing surface runoff while enhancing lateral and base flow contributions. This shift indicates an improvement in subsurface infiltration and groundwater recharge capacity, thereby promoting a more stable flow regime. In contrast, the extreme rainfall scenario intensified both surface and subsurface hydrological responses, underscoring the sensitivity of the watershed to high-intensity precipitation events. The watershed conservation program demonstrates strong implementation of agroforestry and reforestation throughout the watershed region, with 42,313 hectares currently under management.

The total conservation area spans 42,313.00 hectares, with 21 individual conservation projects in 9 districts. Agroforestry 22,252 Ha (52,6%), reforestation 16,770.24 Ha (39,6%), and 3,290.76 Ha (7,8%) infiltration well. Pasir Jambu District and Subbasin 6 emerge as focus area for comprehensive conservation, characterized by diversified intervention strategies and extensive land coverage. In contrast, substantial opportunities remain for expanding infiltration wells, particularly in underperforming areas such as Banjaran District and Subbasin 3. The predominance of single-technique interventions in certain districts suggests limited integration of complementary conservation measures. Adopting multi-technique approaches and reallocating strategic investments toward underrepresented interventions may strengthen hydrological regulation, reduce surface runoff, and enhance long-term ecosystem resilience within the watershed.

These findings emphasize that conservation-based land management strategies are essential to mitigate runoff generation and enhance hydrological resilience. Overall, the study demonstrates that integrating soil and water conservation measures within spatial planning frameworks can improve watershed stability under extreme rainfall conditions. Such integration is crucial for sustainable water resource management and flood risk reduction in rapidly developing regions.

5. Abbreviations

DEM	Digital Elevation Model
DRO	Direct runoff
GIS	Geographic Information System
HRU	Hydrological Response Unit
MWSWAT	MapWindows Soil and Water Assessment Tool
NSE	Nash–Sutcliffe Efficiency
SPAS	River Flow Measurement Station
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool
SWCMs	soil and water conservation measures
SWCT	soil and water conservation technique
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
%	Percentage

6. References

- [1] L. B. Moura, T. R. Lopes, S. N. Duarte, and P. Sica, "Hydrological Assessment Using the SWAT Model in the Jundiaí River Basin , Brazil : Calibration , Model Performance , and Land Use Change Impact Analysis," *Resources*, vol. 14, no. 112, pp. 1–24, 2025, doi: <https://doi.org/10.3390/resources14070112>.
- [2] B. Faksomboon, P. Lertkaeo, and B. Phunlao, "Groundwater Recharge and Surface Runoff Modeling Response to Land Use and Land Cover Dynamics in a Mae Wong Watershed of Thailand," *Appl. Environ. Res.*, vol. 46, no. 1, 2024.
- [3] Gassman, Philip W., et al. "The soil and water assessment tool: historical development, applications, and future research directions." *Transactions of the ASABE* 50.4 (2007): 1211-1250.
- [4] A. S. Maulana Ibrahim Rau, Nora Pandjaitan, "Analisis Debit Sungai dengan Menggunakan Model SWAT pada DAS Cipasauran , Banten," *J. Keteknikan Pertan.*, vol. 3, no. 2, pp. 113–120, 2015, doi: 10.19028/jtep.03.2.113-120.
- [5] E. Junaidi and S. D. Tarigan, "Penggunaan Model Hidrologi SWAT (Soil And Water Assessment Tool) Dalam Pengelolaan DAS Cisadane," *J. Penelit. Hutan dan Konserv. Alam*, vol. 9, no. 3, pp. 221–237, 2012.
- [6] M. P. Thavhana, M. J. Savage, and M. E. Moeletsi, "SWAT model uncertainty analysis, calibration and validation for runoff simulation in the Luvuvhu River catchment, South Africa," *Phys. Chem. Earth*, vol. 105, no. April 2017, pp. 115–124, 2018, doi: 10.1016/j.pce.2018.03.012.
- [7] Setiadi, Hafid, et al. "Rural capitalization and agrarian transformation in the Ciwidey highlands, West Java, Indonesia." *Journal of Regional and City Planning* 33.3 (2022): 281-299.
- [8] B. Uniyal, M. K. Jha, A. Kumar, and P. Kasargodu, "Identification of critical areas and evaluation of best management practices using SWAT for sustainable watershed management," *Sci. Total Environ.*, vol. 744, p. 140737, 2020, doi: 10.1016/j.scitotenv.2020.140737.
- [9] Salim, A. G., I. W. S. Dharmawan, and B. H. Narendra. "Pengaruh luas tutupan lahan hutan terhadap karakteristik hidrologi DAS Citarum Hulu." *Jurnal Ilmu Lingkungan* 17.2 (2019): 333-340.
- [10] Kusumawardani, Mawar, Yayat Hidayat, and Kukuh Murti Laksono. "Analisis respon hidrologi dan kualitas air DAS Cisangkuy," *Jurnal Ilmu Tanah dan Lingkungan* 20.2 (2018): 49-56.
- [11] Munggaran, G., et al. "Analysis of hydrology response and simulation of soil and water conservation engineering in upstream Cimanuk Sub Watershed." *J. Ilmu Tanah Dan Lingkungan* 19 (2017): 26-32.
- [12] Rahbeh, Michel, David Chanasyk, and Jim Miller. "Two-way calibration-validation of SWAT model for a small prairie watershed with short observed record." *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques* 36.3 (2011): 247-270.
- [13] Hermassi, Taoufik, et al. "Integrative hydrologic modelling of soil and water conservation strategies: a SWAT-based evaluation of environmental resilience in the Merguellil watershed, Tunisia." *Frontiers in Water* 7 (2025): 1521812.
- [14] X. Li *et al.*, "Response of Runoff Change to Soil and Water Conservation Measures in the Jing River Catchment of," *Land*, no. 2, 2024, doi: <https://doi.org/10.3390/land13040442>.
- [15] Widiatmoko, Nicko, Suria Darma Tarigan, and Enni Dwi Wahjunie. "Analisis Respons Hidrologi untuk Mendukung Perencanaan Pengelolaan Sub-DAS Opak Hulu, Daerah Istimewa Yogyakarta." *Jurnal Ilmu Pertanian Indonesia* 25.4 (2020): 503-514.
- [16] A. Basit *et al.*, "Evaluating the Impact of the Billion Tree Afforestation Project (BTAP) on Surface Water Flow in Tarbela Reservoir Using SWAT Model," in *Environmental Science Proceeding*, MDPI, 2022, pp. 1–6. doi: <https://doi.org/10.3390/environsciproc2022023023>.
- [17] I. W. S. Dharmawan, C. A. Siregar, B. H. Narendra, N. Kadek, and E. Undaharta, "Implementation of Soil and Water Conservation in Indonesia and Its Impacts on Biodiversity, Hydrology, Soil Erosion and Microclimate," *Appl. Sci.*, vol. 13, no. 13, pp. 1–17, 2023, doi: <https://doi.org/10.3390/app13137648>.