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Hydrological Response to Land Use/Land Cover Projection in Cisadane Watershed, Indonesia

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ABSTRACT

The Cisadane Watershed is in a critical state, which has resulted in the expansion of residential areas upstream of Cisadane. Changes in land use and cover can impact a region's hydrological characteristics. The Soil and Water Assessment Tool (SWAT) is a hydrological model that can simulate the hydrological characteristics of the watershed affected by land use. This study aims to evaluate the impact of land use change on hydrological characteristics and variations in inflow and outflow to develop optimal recommendations for land use in the Cisadane sub-watershed using different scenarios. The models were calibrated and validated, and the results showed satisfactory agreement between observed and simulated streamflow. The main river channel is based on the results of the watershed delineation process, with the watershed boundary consisting of 85 sub-watersheds. The hydrological characteristics showed that the maximum flow rate (Q max) was 12.30 m^3/s, and the minimum flow rate (Q min) was 5.50 m^3/s. The study area's distribution of future land use scenarios includes business as usual (BAU), protecting paddy fields (PPF), and protecting forest areas (PFA). The BAU scenario had the worst effect on hydrological responses due to the decreasing forests and paddy fields. The PFA scenario provided the best hydrological response with a significant reduction in surface flow, lateral flow, and groundwater due to increased water infiltration, as well as increased water yield and evapotranspiration. Therefore, it is vital to maintain green vegetation and conserve land to support sustainable water availability.

Keywords: Hydrological Characteristics, LULC, Sustainable Development, SWAT Model

1. INTRODUCTION

A watershed is a geographical unit of combined terrestrial and aquatic ecosystems [1], which provides several benefits, such as providing and regulating water resources [2]. There are complex interactions between water, soil, climate, and vegetation within watersheds to support the capture and distribution of water [3]. One of the significant important watersheds in Indonesia because of its location in the densely populated Greater Jakarta Area is The Cisadane watershed. It is home to approximately 1.7 million people and serves as a source of clean water for agriculture, animal husbandry, industries, and raw water supply for PDAM, a regional water utility company [4].

However, the Cisadane watershed faces numerous challenges primarily due to land use conversion activities, which disturbs the natural balance of ecosystems. This activity escalates alongside population growth, urbanization, and industrialization [5]. Uncontrolled and unsustainable land use in the upstream areas of this watershed, which are protected areas, has caused serious ecological damage and has harmed the middle and downstream areas [6]. These problems result in significant degradation of watershed quality. According to a report from the Ministry of Environment and Forestry 2015 [7], the Cisadane watershed is one of 15 priority watersheds that require immediate restoration.

Land use and land cover change (LULC) is a crucial factor that determines changes in catchment hydrological processes, as it affects the water cycle in several ways [8]. Numerous studies have been conducted to evaluate the impacts of land use on water resources [9], [10],[11]. These studies have shown that land use conversion can result in significant alterations to hydrological processes, such as evapotranspiration, interception, and infiltration, which can lead to spatial and temporal changes in surface and subsurface flow patterns. The shift from vegetation to non-vegetation areas in the river basin due to rapid development activities led to significant changes, such as an increase in flow discharge, extreme discharge fluctuations between seasons, fluctuations in surface flow coefficients, river overflows during the rainy season, and drought during the dry season [12]. It is essential to represent land-use dynamics in agro-hydrological models because land-use change can affect water supplies.

Modeling tools are currently being developed and implemented to integrate various components that constitute natural and human-modified landscapes to assess hydrological processes as a provider of ecosystem services in watersheds [13]. The integrated assembly characteristic of hydrological models combining vegetation, soil, water, management, and weather components of landscapes, serves as a comprehensive approach to estimating several variables that can be interpreted as ES [14]. Several researchers have focused on watershed hydrological characteristics and models, such as creating a hydrological simulation model for rural watersheds in China [15] and hydrological modeling in the Thamirabarani sub-watershed in India [16]. Many models have been developed to model hydrology, including the ParFlow Hydrological model [17], the Hydrologic Engineering Center's Hydraulic model [18], and the Large-Scale Distributed Hydrological model [19]. The SWAT model provides advantages compared to other models, including that the results of the hydrological model are depicted graphically, and can project changes in hydrological characteristics [20].

Various strategies can be implemented to minimize the negative effects of land use change on hydrological responses in watersheds. These include ecosystem conservation and restoration, adopting sustainable land use practices, and implementing integrated water resource management. Land use planning can effectively mitigate future risks associated with changes in land use cover [21]. Coupled models are typically used to provide good insight into land use change impacts on hydrological processes. A Markov Chain model and a Dynamic Conversion of Land Use are used to simulate future land uses, and the SWAT model is used to simulate hydrological processes to quantify the hydrological impacts of land use changes. The study aims to assess the effects of changes in land use on hydrological characteristics and variations in inflow and outflow to develop the ideal recommendations for land use in the Cisadane watershed using different scenarios.

2. MATERIALS AND METHODS

2.1. Study area

The research was conducted in the Cisadane watershed in West Java and Banten Province, Indonesia at 106º20’50”–106º28’20” E and 6º0’59”–6º47’02” S (Fig. 1). Cisadane River is the main river in this watershed, subbed from Mount Gede and flowing 126 km into the Java Sea, passing several regencies and municipalities specifically Bogor Regency, Bogor Municipality, Tangerang Regency, South Tangerang Municipality, and Tangerang Municipality. The Cisadane watershed spans an area of 151.126 ha and experiences a mean annual rainfall ranging from 2000 to 5000 mm. As located in a tropical climate zone, the Cisadane watershed has a temperature range of 20°C-34°C. This watershed has diverse landscapes and topography, the upper part is dominated by mountains with a slope of up to >40%, the middle is undulating, and 0–8% overlooks the lower flat area. Some soil types that make up the watershed are Andosols, Cambisols, Fluvisols, Lithosols, Nitosols, and Regosols.

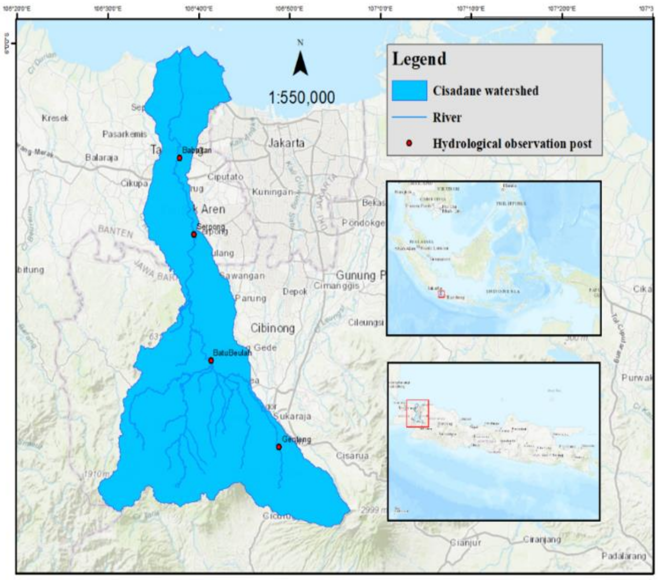

Figure 1. Study area, Cisadane watershed, Indonesia.

2.2. Methods

The study used spatial DEM data with a resolution of 30 x 30 m for the Cisadane area from USGS, land cover and use projection in 2030 and 2050 [22], Climatological data from NASA POWER, soil type from the Center for Research and Development of Agricultural Land Resources (BBSDLP), as well as rainfall and river discharge data from BBWS Ciliwung Cisadane (Big Agency for River Basin) (Table 1).

Table 1. Matrix of research methods

No.		Data type	Sources and methods of data collection	Data analysis method	Output
1.	a	DEM data	USGS, BBWS Ciliwung-Cisadane, NASA POWER, BBSDLP	ArcGIS, SWAT	Hydrological Characteristics
	b	River discharge and rainfall data			
	c	LULC map			
	d	Climate data			
	e	Soil type data			
2.	a	LULC map	The analysis results of hydrological characteristics		Scenario of changes in hydrological characteristics
	b	Hydrological characteristic data			

The soil and water assessment tool (SWAT) is a comprehensive, continuous, and physically grounded model designed to simulate various water management scenarios [23]. This study utilized the SWAT model, which is a physically based semi-distributed model, to project hydrological responses for 2030 and 2050 across three scenarios. The model divides a catchment into sub-catchments and then further into hydrological response units

(HRUs) for which a land-phase water balance is calculated. SWAT defines the hydrological water balance using Equation (1) [24].

$$SWt = SWo + \sum_{t=1}^{t}(R - Qsurf - ET - Wseep - Qgw) \quad (1)$$

where SWt is the last water amount in the soil (mm), SWo is the early soil water amount (mm), t is time (days), R is the precipitation amount (mm), Qsur is the surface runoff (mm), ET is evapotranspiration (mm), Wseep is the deep infiltration (mm), and Qgw is the amount of flow return (mm).

The methodology of the SWAT model comprises four distinct phases: watershed delineation, HRU development, climatic data input, and execution of the SWAT model. The SWAT model utilizes the digital elevation model (DEM) to represent the topography of the study watershed. LULC, soil, and weather data are used to imitate and simulate hydrological processes [25].

To begin, the Cisadane watershed was delineated using a DEM, enabling an examination of the drainage patterns of the land surfaces. The HRUs of the study watershed were created by spatially overlaying a land-use map with seven classes, a slope map with five classes, and a soil map with six classes through a threshold of 0%. Daily climate data, including rainfall, maximum and minimum temperature, humidity, wind, and sunshine hours, for 2021 from two stations were input into the model.

The SWAT simulation process can be divided into two stages: preparation and processing. During the pre paration stage, the flow and direction of water through the landscape were calculated to delineate the watershed. HRU overlays were used to classify land cover and soil types according to SWAT standards. Weather data from gauges were collected and inputted into the model. In the processing stage, the SWAT model was used to calculate various outputs such as streamflow, groundwater flow, direct runoff, water yield, sedimentation, and contaminants. This study primarily focuses on surface runoff, lateral flow, groundwater recharge, water yield, and the evapotranspiration of the watershed (Figure 2). These outputs were then analyzed to understand the overall water cycle and potential impacts on the environment.

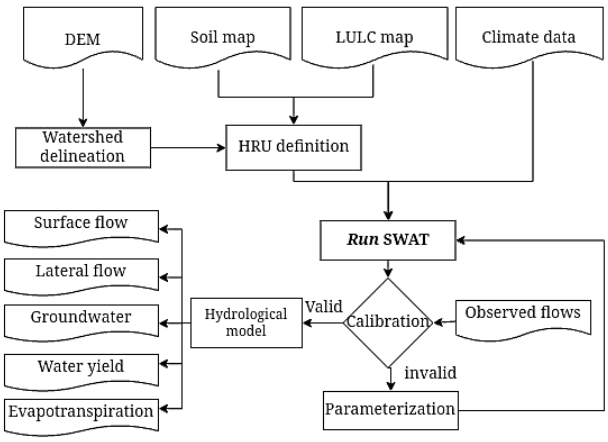

Figure 2. Stages of SWAT analysis in the Cisadane watershed

Model calibration involves adjusting the model parameters within the recommended ranges to optimize the simulated output so that it matches the observed data. The model contains a series of calibration parameters that can modify these components to represent site-specific watershed conditions [24]. Model validation is conducted to determine the level of accuracy of the model output. This is done by performing discharge estimation simulations using a model that has been calibrated. The model's validity is based on the appearance of the relationship between the debits model with actual discharge graphically, and statistical test results with different objective functions. Statistical parameters including the Nash–Sutcliffe efficiency (NSE) and determination coefficient (R^2) were used for the study, as outlined in Equations (2) and (3), respectively [26]. Test benchmarks are used to assess the accuracy of the model output.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - Q_{mobs})^2} \quad (2)$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{obs,i} - Q_{mobs}) \times (Q_{sim,i} - Q_{msim})\right]^2}{\sum_{i=1}^{n}(Q_{obs,i} - Q_{mobs})^2 \times \sum_{i=1}^{n}(Q_{sim,i} - Q_{msim})^2} \quad (3)$$

where $Q_{obs,i}$ is the measured value, $Q_{sim,i}$ is the simulated value, Q_{mobs} is the mean observed value, and Q_{msim} is the mean simulated value.

Simulations are run by including different scenarios of LULC in the years analyzed (2030 and 2050). The three scenarios are business as usual (BAU), protecting paddy fields (PPF), and protecting forest areas (PFA). Integration of a Markov chain and a cellular automata model (CA–Markov) with multiple-criteria evaluation (MCE) was used to project land-use changes in the watershed for the future period [22]. The output results are then used to evaluate the impact of changes in land cover on the response hydrology so that the ideal scenario can be obtained.

3. RESULT

3.1. Hydrological model

The land units in the Cisadane watershed consist of six groups. The land unit with the most significant area is Cambisol, with an area of 51693,40 ha (34,1%), while the lowest area in Regosols was 12209,63 ha (8%). Cambisols are a soil group without a layer of accumulated clay, humus, or iron and aluminum oxides. They are usually suitable for agriculture due to their favorable structure and high mineral content that are limited by terrain and climate [27]. Regosol soil has low soil fertility and water availability because of low water-holding ability or water retention.

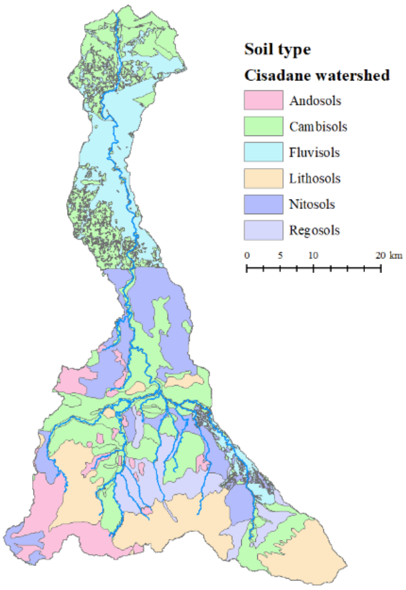

Figure 3. Soil type map of the Cisadane watershed

In the SWAT model the hydrologic soil group (HSG) is a vital factor that impacts the rainfall-runoff process. The HSG classification system is used to categorize land based on its hydrological characteristics. It ranges from well-drained soils (HSG type A) to poorly drained soils (HSG type D) [28]. Most of the soils in this watershed belong to the Group C category, which has soil attributes with moderately high runoff potential, less than 50% sand, 20-40% clay, and a variety of loamy textures. The soil structure is dense and less permeable, and the soil particles are closely packed together [29]. Only a small fraction of the watershed is designated as type D soils, which have high runoff potential and more than 40% clay.

The Cisadane watershed area has diverse topography, ranging from flat to mountainous terrain, with an altitude range of 0 to 2590 meters above sea level. DEM data processing with a 30-meter resolution has classified the land slope into five classes based on [30], with the dominant slope being 0-8%, covering an area of 60980,4 ha (40,5%).

The watershed's topography is characterized by a gentle slope in the north and steeper slope in the south. Areas with gentle slopes are generally suitable for economic growth, such as industry, settlements, and other community practices. On the other hand, steeper slopes over 40% dominant in the north, including Mount Gede, play a crucial role as conservation areas. The slope is a factor that affects the flow characteristics of water because it can de termine the size and run-off volume velocity [31][32]. On gentle slopes, the flow pattern is spread more evenly over the ground surface, forming a broader and more fragmented flow. The steeper the slope, the faster the flow.

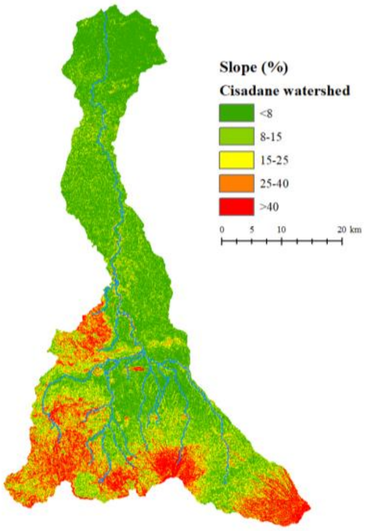

Figure 4. Map of the slope of Cisadane watershed

The Cisadane watershed covers an extensive area of land measuring 151,126 hectares. To better manage this large region, the delineation process has divided the catchment area into various sub-basins or catchment areas [33]. It has been divided into 85 sub-basins based on surface elevation to better manage this large area. These sub-basins have further been divided into 3,453 HRUs based on factors such as soil type, land use, and slope length. Each HRU is responsible for generating specific hydrological features consistent with its unique characteristics. By breaking down the watershed into smaller units like sub-basins and HRUs, it becomes easier to monitor and manage the area's water resources.

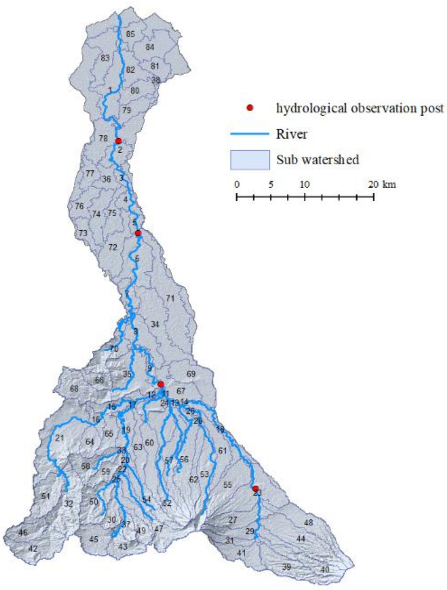

Figure 5. Cisadane watershed delineation map

Water balance knowledge is crucial in understanding the water cycle, particularly in determining how much water enters (inflow) and leaves (outflow) a particular structure, such as a watershed. Precipitation is a significant factor in water accumulation in watersheds, and it plays a vital role in water balance [34], especially as an inflow component. The Cisadane watershed area has a tropical climate that is influenced by the monsoon winds and has two seasons, namely the rainy season and the dry season. The rainy season in the Cisadane watershed lasts from November to April, while the dry season lasts from June to October [35]. The peak rainy season happens in January or February, and it affects the discharge in the watershed, with the maximum discharge (Qmax) measuring 12,30 m3/s. On the other hand, the dry season, which occurs in June, experiences a decrease in precipitation, with the minimum discharge (Qmin) measuring 5,50 m3/s. This shows that precipitation significantly affects the river's flow in terms of increase and decrease.

The water balance in the Cisadane Watershed is crucial in meeting the area's water needs. If the regional rainfall and surface water runoff in rivers remain high while water usage levels remain normal, the Cisadane Watershed will have a surplus water balance and meet the area's water needs. However, the hydrological conditions of inflow and outflow can be significantly impacted by the increased intensity of land-use change. Therefore, it is essential to maintain a balance between land-use activities and water resources to ensure that the water balance in the watershed remains stable.

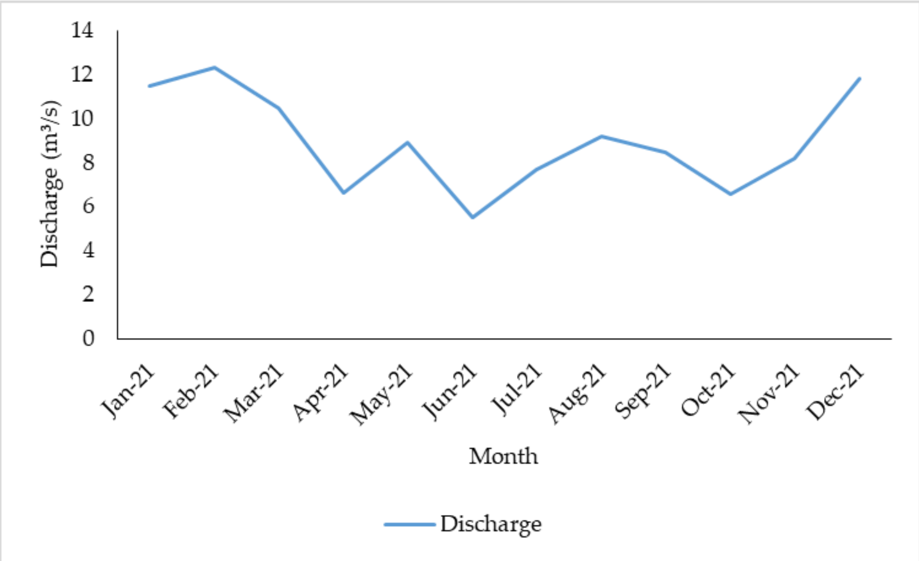

Figure 6. Discharge fluctuation of the Cisadane watershed in 2021

3.2 SWAT calibration and validation

The SWAT is evaluated by calibration and validation performance by comparing observed and simulated streamflow discharge (Fig 7). The calibration process involves adjusting the parameters of the hydrological model to match the observation data. After calibration, the validation process follows, which involves testing the performance of the calibrated hydrological model using independent data not used during calibration.

Statistical approaches such as the coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) are utilized to assess the model's performance. The R^2 represents the degree to which the model explains changes in the measured data. The size of the linear relationship between the simulated and experimental standard was the determining factor. The coefficient of determination (R^2) ranges from 0 to 1. If the value is closer to 1, the inde pendent variable provides almost all the necessary information to forecast the dependent variable [36]. In contrast to the variance in observed data, the NSE evaluates the normalized relative amount of remaining variation. The NSE ranges from 1.0 to − ∞, with 1.0 representing the best fit [37].

The model's performance is considered satisfactory if the NS value is greater than 0,75, satisfactory between 0,36 and 0,75, and inadequate if below 0,36. Based on the calibrated simulation results, the R^2 value is 0,52, and the NS is 0,51, indicating satisfactory model performance. The calibration improved model performance with a previously lower R^2 of 0,39 and NS of 0,27. Validation results showed satisfactory model performance with an R^2 value of 0,51 and an NS value of 0,49. Hence, this model can predict future hydrological responses in the Cisadane watershed.

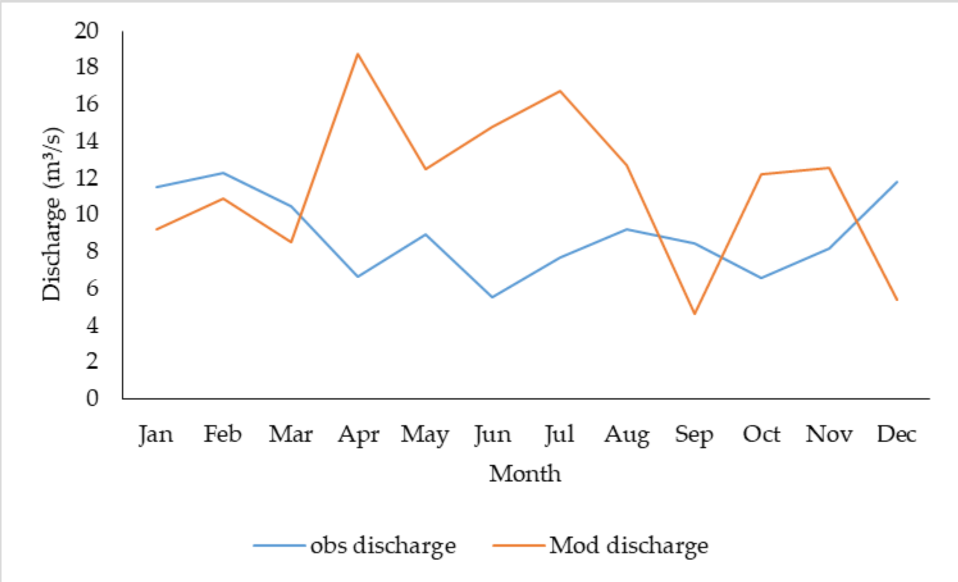

Figure 7. Modeled and observed hydrographs after calibration (m³/sec) in 2021

3.3 Scenario of land use/cover change on hydrological characteristics

The three scenarios were simulated using the same rainfall input, 2,764.2 mm/year. Rainfall will be partitioned into several hydrological processes, including evapotranspiration, runoff, and changes in land flow due to changes in land cover. The BAU scenario is a projection of a future situation where no measures are taken to control land-use change in a specific catchment area. Under this scenario in 2050, the watershed will predominantly built up, followed by dryland farms, forests, paddy fields, plantations, and waterbodies [22]. Compared to the year 2030, there has been a decrease in the forest area, paddy fields, and dryland farms, while built-up areas have increased. The increase in built-up areas is particularly significant in the downstream and midstream areas. Previously existing paddy fields and dryland farms are expected to be converted into impervious areas. Meanwhile, in the upstream area, the forest area is expected to be mainly converted into plantation. These changes are expected to significantly impact the environment and ecosystem of the study catchment area.

Table 2. Values and changes in annual hydrological components in BAU scenario

Parameter	Year LULC		
	2030 (mm)	2050 (mm)	Difference (mm)
Surface flow	486,5	642,5	156,0

Lateral flow	140,5	220,6	80,1
Groundwater	680,8	610,6	-70,2
Water yileld	1870,5	1620,4	-250,1
Evapotranspiration	650,4	430,6	-219,8

Implementing the BAU scenario in 2030-2050 increases surface flow by 156 mm due to the increasingly limited catchment areas. Another increase in hydrological response occurred in lateral flow, namely 80,1 mm (Table 2). This scenario reduces groundwater flow, water yield, and evapotranspiration by 70,2 mm, 250,1 mm, and 219,8 mm. A massive land-use conversion from the vegetated areas into built-up areas, as suggested by the BAU scenario, will significantly reduce canopy interception and soil infiltration capacity, resulting in a significant fraction of rainfall being transformed into surface run-off [38].

Under scenario PPF in 2050, the watershed is predominantly built up, followed by dryland farms, paddy fields, forests, plantations, and waterbodies. Compared to 2030, built-up, paddy fields and plantations increased while dryland farms and forests decreased. This scenario comes from the fact that it supports the food security function for each region in Indonesia [22]. Apart from supporting food security, rice fields will contribute significantly to a country's economy. The increase in the coverage of paddy fields in the PPF scenario is a positive sign, but it also highlights the need for sustainable farming practices.

Table 3. Values and changes in annual hydrological components in PPF scenario

Parameter	Year LULC		
	2030 (mm)	**2050 (mm)**	**Difference (mm)**
Surface flow	485,5	633,5	148,0
Lateral flow	138,5	215,0	76,5
Groundwater	670,8	602,8	-68,0
Water yileld	1820,5	1600,5	-220,0
Evapotranspiration	652,3	466,8	-185,5

The current condition of the watershed ecosystem based on the PPF scenario is similar to the results of the BAU scenario. In this scenario, there is a slight increase in surface and lateral flow of 148 mm and 76,5 mm, less than that observed in the BAU scenario. However, there is a decrease in groundwater, water yield, and evapotranspiration of 68 mm, 220 mm, and 185,5 mm (Table 3). The difference between 2030 and 2050 is insignificant, indicating a slight improvement in the condition of the watershed ecosystem This improvement can be attributed to implementing sustainable agricultural practices that help maintain the integrity of rice field ecosystems, manage water efficiently, reduce soil erosion, face the risk of flooding or drought, and maintain soil fertility.

Based on the PFA scenario projection for the year 2050, the majority of the watershed is expected to be predominantly occupied by built-up areas, followed by forests, dryland farms, plantations, paddy fields, and water bodies. However, compared to 2030, a few noteworthy changes have been observed in the land-use pattern. There has been an increase in the area covered by forests, built-up areas, and plantations, while the area occupied by dryland farms and paddy fields has decreased. The PFA scenario prioritizes the conservation and expansion of forest areas, which has increased forest cover. The expansion of built-up areas and plantations can be attributed to the growth in population and the need for resources. At the same time, the decrease in dryland farms and paddy fields may be due to changes in agricultural practices and land-use policies. The PFA scenario aims to balance development and conservation, focusing on sustainable land use to benefit present and future generations.

Table 4. Values and changes in annual hydrological components in PFA scenario

Parameter	Year LULC		
	2030 (mm)	**2050 (mm)**	**Difference (mm)**
Surface flow	484,5	623,5	139,0
Lateral flow	128,5	203,1	74,6
Groundwater	658,8	592,8	-66,0
Water yileld	1880,5	1672,0	-208,5
Evapotranspiration	666,4	495,9	-170,5

From 2030 to 2050, according to the PFA scenario, there will be changes in the hydrological response. Surface and lateral flow will increase by 139 mm and 74.6 mm, respectively, and then groundwater, water yield, and evapotranspiration will decrease by 66 mm, 208.5 mm, and 170.5 mm (Table 4). The figure for this scenario is smaller than the two previous scenarios. This is due to an increase in the number of green areas, such as forests, as a result of protected forest conservation, sustainable forest management, and controlling deforestation and forest degradation.

Figure 8. Values and changes of annual hydrological components in the scenarios

An analysis and comparison of the hydrological response in the Cisadane watershed under different scenarios has been conducted, with Figure 8 showcasing the changes in annual hydrological components between 2030 and 2050. The comparison showed that the PFA scenario had the lowest surface flow in both study years, with values of 484.5 mm and 623.5 mm, respectively. Conversely, the BAU scenario had the highest surface flow, with figures of 486.5 mm and 642.5 mm in 2030 and 2050. Similar patterns were observed for lateral flow components, with the BAU scenario having the highest values with values of 140.5 mm and 220.6 mm, while the lowest values were recorded in the PFA scenario at 128.5 mm and 203.1 mm. Groundwater levels were highest in the BAU scenario, at 680.8 mm and 610.6 mm, and lowest in the PFA scenario, with values of 658.8 mm and 592.8 mm. The PPF scenario showed the lowest water yield conditions, with values of 1820.5 mm and 1600.5 mm, whereas the PFA scenario exhibited the highest water yield, with values of 1880.5 mm and 1672.0 mm. These findings provide valuable insights into the impacts of different scenarios on hydrological components, which can be useful for water resource management and planning in the Cisadane watershed.

4. DISCUSSION

Changes in land use and cover, such as deforestation, urbanization, and agricultural expansion can significantly alter the hydrological response in a watershed. Also, this happened in the Cisadane watershed. Previous research in this watershed has indicated that the conversion of forested areas to urban developments or agricultural fields reduces vegetation cover, thereby affecting processes like evapotranspiration and interception. This leads to increased surface runoff and a decrease in water absorption capacity [39].

Several studies have compared scenarios such as urban expansion, agricultural intensification, or forest conservation have provided insights into their effectiveness in influencing hydrological parameters [40], [41], [42], [43]. Under the BAU scenario, the Cisadane watershed experiences the highest increase in the mean annual surface flow and lateral flow. Land conversion in the upstream areas of the Cisadane watershed will significantly reduce canopy interception and soil infiltration capacity and diminish the watershed’s capacity to retain or absorb rainwater. As a result, most of the rainwater transforms into surface runoff [44] and flows rapidly to the downstream part of the watershed [45]. This scenario also witnesses a significant decrease in evapotranspiration, leading to reduced water yield due to increased surface runoff and diminished infiltration. Groundwater flow increased due to urbanization as well as similar to the previous study [46]. The directions of change in the water balance components by land-use change in this study are in line with other studies[47] [48].

The PPF scenario shows intermediate surface runoff, lateral flow, groundwater, water yield, and evapotranspiration changes during the years 2030-2050. The agricultural areas tend to produce more runoff due to compaction of lower soil horizons during land tilling [49]. It depends on the extent of land conversion and vegetation cover. However, the scenario demonstrates a better quantity of hydrological responses compared to BAU, as it promotes higher vegetation cover and transpiration rate, and water retention capacity.

The PFA scenario significantly improves hydrological responses in this watershed. This finding is supported by the fact that the lowest amount of surface and lateral flow during 2030-2050 was found in the PFA scenario. Forests can absorb more water through the roots, slow down water flow, and reduce horizontal water flow below the surface. Previous studies have also confirmed that forest expansion enhances infiltration rates, and decreases surface runoff [50], [51], [52]. The PFA scenario achieves the highest water yield by enhancing soil moisture retention, groundwater recharge, and overall water availability within the watershed. However, it also results in the lowest groundwater value due to higher evapotranspiration rates of forest vegetation [53], [54], [55]. Due to the large leaf area index and long growth season, forests tend to have higher ET than other land cover types [56]. It exhibits the highest evapotranspiration rates, which promotes transpiration, interception, and soil evaporation thereby maintaining ecological balance and hydrological integrity.

Vegetation, particularly forests, plays a crucial role in regulating hydrological processes by intercepting rainfall, reducing surface runoff [57], and enhancing infiltration by improving soil structure and increasing soil moisture retention [58]. Conversely, urbanization disrupts natural landscapes, replacing permeable surfaces with impervious ones, which can disrupt the water cycle [28], and increase flood risk and drought. Those risks can potentially be reduced by introducing and enforcing land-use planning regulation. Integrated watershed management approaches recognize the interconnectedness of land use planning, water resource management, and environmental conservation. Considering between socio-economic, ecological, and hydrological factors holistically are crucial for promoting sustainable development and resilience in watersheds.

In order to effectively understand and mitigate the effects of changes in land use and land cover on hydrological responses in watersheds, it is essential for future research and management efforts to address some key challenges and opportunities. This can be achieved through the integration of advanced modelling techniques, remote sensing data, and stakeholder engagement strategies. It will improve predictive capabilities, inform decision-making, and enhance the sustainability of water resources and ecosystems in the face of ongoing environmental change.

5. CONCLUSIONS

This study uses the SWAT model to simulate the hydrological responses to land cover change scenarios in The Cisadane watershed. An analysis of the variation in discharge in the Cisadane watershed in 2021 reveals significant differences. The results of the study indicated significant differences in discharge variations, with maximum and minimum discharge values of 12.30 m³/s and 5.50 m³/s. The calibration of the model achieved satisfactory performance, with R^2 and NSE values of 0.52 and 0.51, respectively, and validation against the observed streamflow data yielded acceptable statistical results of $R^2 = 0.51$ and NSE = 0.49. The study revealed that intensified land-use changes had a significant impact on hydrological conditions, affecting various factors such as surface runoff, lateral flow, groundwater flow, water yield, and evapotranspiration. The business as usual (BAU) scenario showed rapid land conversion to built-up areas, which increased surface runoff, lateral flow, and groundwater flow while reducing evapotranspiration and water yield due to decreased infiltration rates on impervious surfaces. On the other hand, the Protecting Paddy Field (PFA) scenario, which involved expanding forest areas, emerged as the most favorable for watershed management, positively affecting the ecosystem. The expansion of green vegetation in the PFA scenario potentially enhanced water absorption. These findings underscored the importance of land-use planning in mitigating water-related risks and maintaining ecological balance in the Cisadane watershed. By providing science-based information, local decision-makers and stakeholders can implement site-specific control measures and strategies for achieving water balance and sustainable development within watersheds.

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