

Hydrological Condition Analysis Using the SWAT Model and Statistical Analysis Based on Streamflow and Sediment Yield in the Bajing Sub-Watershed, Jember, Indonesia

ABSTRACT

This study aimed to assess the hydrological conditions of the Bajing Sub-watershed, Jember, Indonesia, using the Soil and Water Assessment Tool (SWAT) and statistical analysis of streamflow and sediment yield. A quantitative approach integrating GIS-based spatial analysis, SWAT hydrological modeling, and statistical analysis was applied. The study was conducted in the Bajing Sub-watershed, Jember Regency, East Java, Indonesia, using climate and hydrological input data for the 2016–2024 period. Spatial data on land cover, soil type, slope, and climate were integrated into the SWAT model to simulate streamflow and sediment yield at the sub-watershed outlet. Descriptive statistics, coefficient of variation (CV), trend analysis, boxplot analysis, and linear regression were used to evaluate hydrological variability and the relationship between streamflow and sediment yield. The results showed that the Bajing Sub-watershed was dominated by forest cover (67.90%), Andisols (54.60%), and flat to gentle slopes (51.35%). Simulated streamflow ranged from 2.24 to 430.00 m³/s, with a mean of 132.93 m³/s and a CV of 73.17%, while sediment yield ranged from 0 to 1.60 tons, with a mean of 0.30 tons and a CV of 113.90%. A strong positive relationship was observed between streamflow and sediment yield ($r = 0.90$; $R^2 = 0.81$), indicating that streamflow statistically explained approximately 81% of the variation in sediment yield. The Bajing Sub-watershed generally maintains favorable hydrological conditions due to its dominant forest cover and relatively stable biophysical characteristics; however, substantial variability in streamflow and sediment yield indicates potential runoff and erosion risks, particularly during high-flow periods. Maintaining forest cover, implementing conservation measures on steep slopes, and controlling land-use changes are therefore essential for sustainable watershed management.

Keywords: SWAT Model, Streamflow, Sediment Yield.

1. INTRODUCTION

Watersheds are fundamental hydrological units that regulate the movement, storage, and distribution of water through the interaction of climate, topography, soil properties, and land

use. The hydrological condition of a watershed is commonly evaluated through streamflow and sediment yield, which serve as key indicators of watershed health, water resource sustainability, and land degradation. Well-maintained vegetation cover enhances infiltration, reduces surface runoff, sustains baseflow, and minimizes soil erosion, thereby contributing to stable hydrological processes. Conversely, land degradation and land-use changes can significantly alter watershed hydrological responses by increasing runoff, peak discharge, and sediment transport. In Jember Regency, East Java, Indonesia, the Mayang Watershed is one of the most important river basins, covering approximately 33% of the regency's total area and supplying water for agriculture, domestic consumption, and industrial activities. Consequently, understanding its hydrological condition is essential for sustainable watershed management.

During the past decades, the Mayang Watershed has experienced considerable land-use changes, particularly the conversion of forested areas into intensive agricultural land and the expansion of built-up areas. These changes have been reported to increase hydrological hazards, especially flooding in downstream regions (Hakim et al., 2023; Indarto et al., 2023). The reduction in natural vegetation decreases infiltration capacity while increasing surface runoff and peak streamflow. Furthermore, land degradation in the upstream area has accelerated soil erosion, generating substantial sediment loads transported through the river network (Rafif et al., 2024). Excessive sediment transport not only reduces river conveyance capacity through sediment deposition but also increases flood susceptibility and degrades aquatic ecosystems. Therefore, streamflow and sediment yield are essential hydrological variables for assessing watershed conditions and identifying potential environmental degradation

Accurate assessment of watershed hydrological processes requires a physically based hydrological model capable of representing spatial heterogeneity. The Soil and Water Assessment Tool (SWAT) has been widely applied worldwide to simulate watershed hydrology, including surface runoff, streamflow, soil erosion, and sediment yield under various land-use and climatic conditions. The model has demonstrated reliable performance in tropical watersheds, including those in Indonesia (Kardhana et al., 2024). The accuracy of SWAT simulations largely depends on the quality of climatic, land-use, topographic, and soil datasets, as demonstrated by previous studies on SWAT parameter sensitivity. Although SWAT effectively simulates hydrological processes, model outputs require statistical evaluation to better characterize watershed behavior. Statistical indicators such as maximum, minimum, mean, standard deviation, coefficient of variation, temporal trends, and the relationship between streamflow and sediment yield provide additional insights into watershed hydrological dynamics and variability (Liu et al., 2024; Tumsa, 2023).

The Bajing Sub-Watershed, one of the upstream catchments within the Mayang Watershed, is characterized by predominantly forested land cover and hilly to mountainous terrain. Although no major flood events have been recorded in this sub-watershed, ongoing land-use changes may alter its hydrological response in the future. Despite its strategic role in maintaining downstream hydrological stability, comprehensive studies investigating streamflow and sediment yield characteristics in the Bajing Sub-Watershed remain limited, particularly those integrating physically based hydrological modeling with statistical analysis. Such information is crucial for understanding flow variability, sediment production, and the interaction between hydrological processes within the watershed.

Therefore, this study aims to analyze the hydrological condition of the Bajing Sub-Watershed using the SWAT model integrated with statistical analysis of simulated streamflow and sediment yield. Specifically, the study (i) evaluates the temporal characteristics of streamflow and sediment yield, (ii) quantifies hydrological variability using descriptive and trend statistics, and (iii) examines the relationship between streamflow and sediment yield as indicators of

watershed condition. The findings are expected to provide scientific evidence supporting sustainable watershed management and conservation planning in the Mayang Watershed and other tropical watersheds with similar environmental characteristics. Provide a factual background, clearly defined problem, proposed solution, a brief literature survey and the scope and justification of the work done.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The study was conducted in the Bajing Sub-Watershed, which is part of the Mayang Watershed located in Jember Regency, East Java, Indonesia. The study area covers portions of Tempurejo and Mumbulsari Districts and is geographically located between 8°18'02.2"–8°21'09.5" S and 113°40'41.8"–113°45'51.8" E (Figure 1).

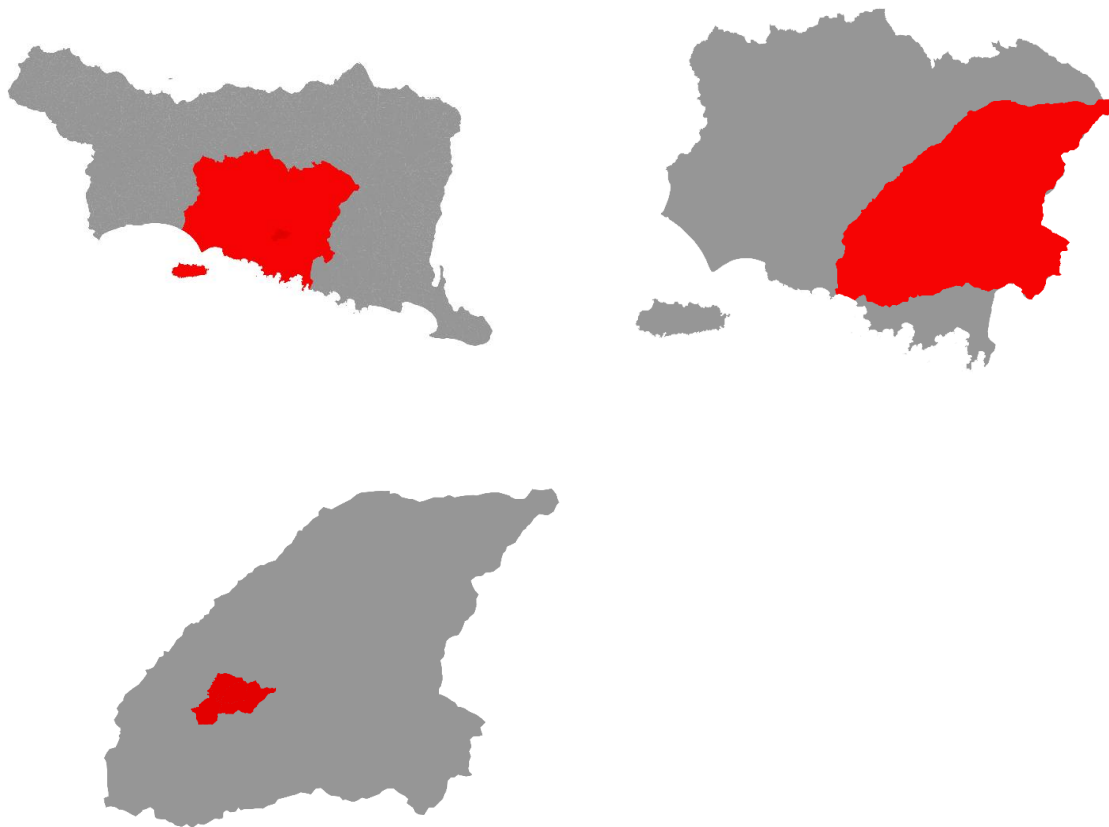


Fig. 1. Location of the Bajing Sub-Watershed, Jember Regency, East Java, Indonesia

This study utilized both primary and secondary datasets. Primary data consisted of field soil surveys and laboratory analyses, whereas secondary data included soil type, topographic, land-use, and climatic datasets. The SWAT (Soil and Water Assessment Tool) model was employed to simulate watershed hydrological processes, particularly streamflow and sediment yield. Spatial analyses were conducted using Landsat 8 Operational Land Imager/Thermal

96 Infrared Sensor (OLI/TIRS) and Sentinel-2 MultiSpectral Instrument (MSI) satellite imagery.
 97 Land-use and land-cover (LULC) changes were identified using a supervised classification
 98 approach based on the Maximum Likelihood algorithm.
 99

100 **Table 1. Data sources used in this study.**

Data Type	Data Source
Satellite imagery (Landsat 8 OLI/TIRS and Sentinel-2 MSI)	USGS, ESA
Rainfall and climate data	NASA POWER, BMKG Jember
Soil type and topographic data	DEMNAS, FAO
Field soil observations and laboratory analyses	Field survey and laboratory analysis

101

102 **2.2 Hydrological Modeling Using The SWAT Model**

103 Hydrological simulations were performed using the Soil and Water Assessment Tool (SWAT),
 104 a semi-distributed, physically based watershed model designed to simulate the effects of land
 105 use, soil properties, topography, and climate on watershed hydrological processes. The SWAT
 106 modeling procedure consisted of the following steps:

107 **2.2.1 Watershed Delineation.**

108 Digital Elevation Model (DEM) data and the river network were used to delineate the
 109 watershed boundary and divide the study area into multiple sub-basins. This process
 110 established the spatial framework for subsequent hydrological simulations.

111 **2.2.2 Hydrologic Response Unit (HRU) Definition.**

112 Hydrologic Response Units (HRUs) were generated by overlaying land-use, soil type, and
 113 slope maps. Each HRU represents a unique combination of these characteristics and contains
 114 information on sub-basin identification, land-use class, soil type, slope category, and HRU
 115 area.

116 **2.2.3 Climate Data Input.**

117 Daily climatic variables, including precipitation, maximum and minimum air temperature,
 118 relative humidity, solar radiation, and wind speed, were incorporated into the SWAT model.
 119 The simulation period was determined according to the availability of the climate dataset.

120 **2.2.4 Model Simulation.**

121 After all spatial and climatic input data had been prepared, the SWAT model was executed to
 122 simulate watershed hydrological processes. The principal model outputs analyzed in this study
 123 were streamflow and sediment yield, which were subsequently evaluated using statistical
 124 methods to characterize the hydrological condition of the Bajing Sub-Watershed.

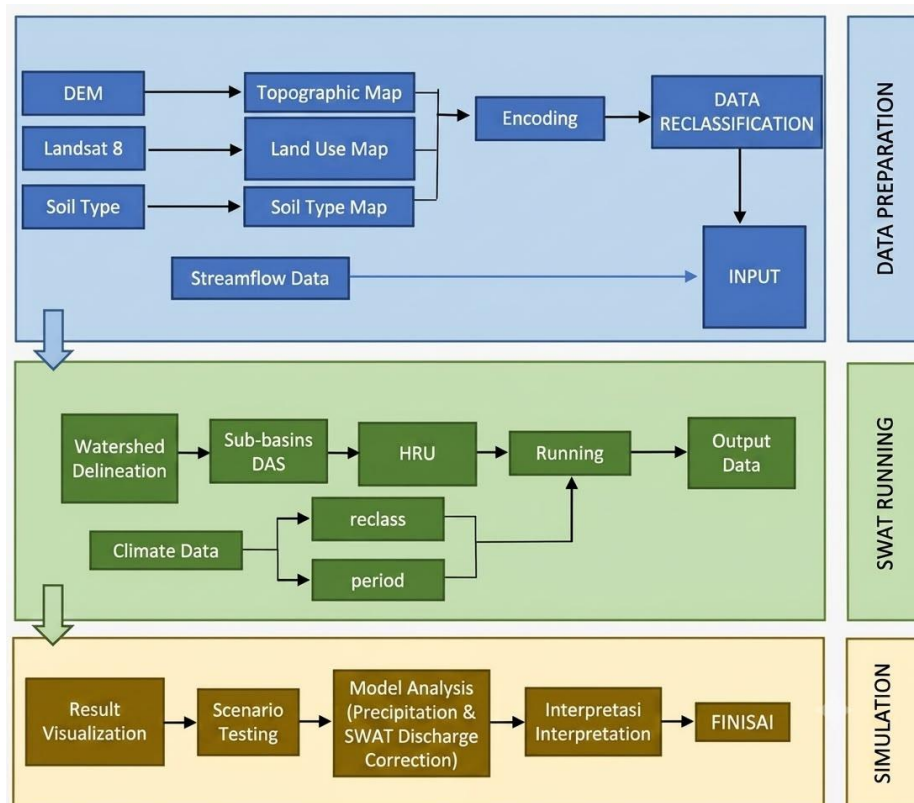


Fig. 2. SWAT Simulation

3. RESULTS AND DISCUSSION

3.1 SLOPE

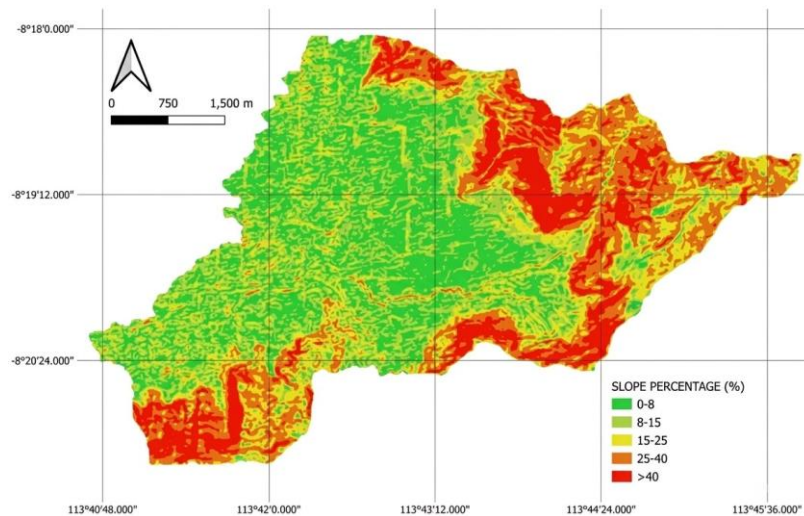
Slope is one of the key factors controlling surface runoff and soil erosion processes. Spatial analysis revealed that the Bajing Sub-watershed exhibits considerable variation in slope classes, as presented in Table 2.

Table 2. Slope Classification of the Bajing Sub-watershed

Slope (%)	Class	Area (Ha)	Percentage (%)
0-8	Datar	756.07	27,61
8-15	Landai	649.81	23,74
15-25	Agak curam	482.51	17,64
25-40	Curam	497.78	18,19
>40	Sangat curam	351.81	12,82

The results indicate that the study area has diverse topographic conditions, with flat (27.61%) and gentle (23.74%) slopes being the dominant classes. These slope classes indicate that most of the area has relatively stable topography and can potentially support agricultural, plantation, and other land-use activities with relatively low erosion risk. Low-gradient slopes tend to minimize surface runoff and soil loss compared with steeper slopes (de Oliveira Serrão et al., 2022; dos Santos et al., 2023). The moderately steep slope class (17.64%) indicates increasing susceptibility to erosion due to the greater flow energy associated with surface runoff, which can accelerate soil particle detachment and transport. Therefore, land use in this zone requires more intensive soil conservation measures, such as terracing, contour planting, and ground-cover vegetation (Liu et al., 2024; Hermiyanto et al., 2025). Cultivation remains feasible under conservation-oriented management; however, land use should be adjusted to

the land-carrying capacity and physical characteristics of the area to minimize the potential for soil degradation. In contrast, areas with steep (18.19%) and very steep (12.82%) slopes have significant limitations for intensive land utilization because of their high susceptibility to erosion, landslides, and land degradation. Steeper slopes contribute to accelerated surface runoff and sediment production; therefore, these areas are more appropriately designated for protection or conservation purposes to maintain slope stability, reduce sediment delivery to the river system, and support the sustainability of the overall hydrological functions of the watershed (Chen et al., 2022; Zhang et al., 2025). Integrated landscape conservation approaches, including reforestation and the establishment of protected zones, have been demonstrated to effectively reduce erosion and improve ecosystem functions in steep terrain.



<https://tanahair.indonesia.go.id/>
Fig. 3. Slope map

3.2 SOIL TYPES

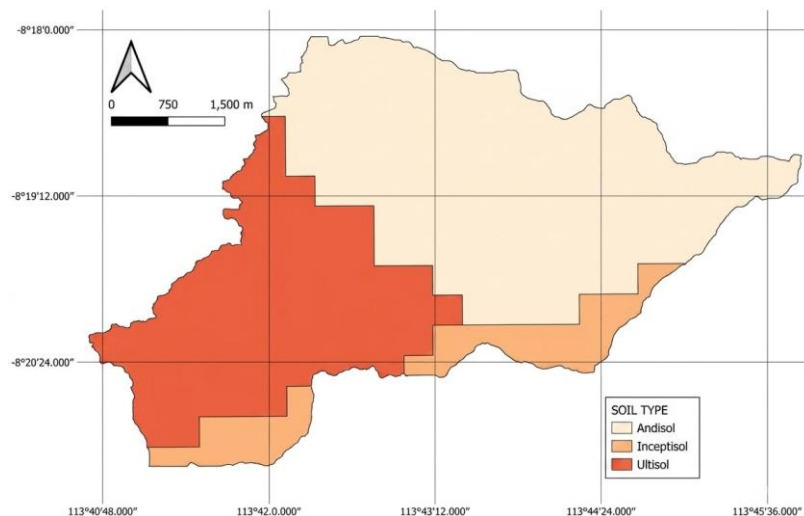
Variations in soil types influence infiltration, water-holding capacity, and hydrological responses. The results of the soil map interpretation are presented in Table 3.

Table 3. Soil Type Classification of the Bajing Sub-watershed

FAO Soil Type	Area (ha)	Percentage (%)
<i>Andisol</i>	1495	54,60
<i>Ultisol</i>	956	34,92
<i>Inceptisol</i>	287	10,48

The results show that Andisol is the dominant soil type in the study area, covering 1,495 ha (54.60%). Andisols develop from volcanic parent materials and are characterized by high porosity, friable soil structure, and infiltration and water-storage capacities influenced by their specific mineralogical properties. These soils contain amorphous minerals such as allophane and imogolite, which influence their physical and chemical properties and generally provide high fertility potential, although this is also dependent on their organic matter content (García et al., 2021). However, under the conditions of the study area, the analysis indicates relatively low to very low organic carbon content, which may reduce aggregate stability and soil water retention capacity. Consequently, Andisols may remain susceptible to runoff and erosion under high-intensity rainfall events (Hou et al., 2025). Land use on Andisols should therefore

177 prioritize permanent vegetation, such as forests, agroforestry systems, or conservation-
 178 oriented cultivation, to maintain soil structure and minimize soil loss through erosion. Ultisols,
 179 covering 956 ha (34.92%), are characterized by advanced weathering, low inherent fertility,
 180 and limited organic matter content. Their structure tends to be less stable and their infiltration
 181 capacity is generally lower than that of Andisols (Apriliani et al., 2024). The relatively unstable
 182 physical properties of Ultisols may increase surface runoff and erosion when the land is
 183 intensively cultivated without adequate conservation measures. Therefore, Ultisol
 184 management should be integrated with appropriate soil-management practices, including
 185 organic matter amendments, cover crops, and surface-runoff control, to improve soil structure
 186 and reduce erosion. Meanwhile, Inceptisols, which cover 287 ha (10.48%), exhibit a moderate
 187 degree of soil development and relatively variable physical properties. Previous studies have
 188 indicated that Inceptisols may have relatively better water-storage capacity than Ultisols and
 189 soil textures that are more favorable for plant root development, making them potentially
 190 suitable for limited agricultural activities (Ermawati et al., 2023). Overall, the distribution of soil
 191 types indicates that a substantial proportion of the watershed has physical and hydrological
 192 limitations. Therefore, land management should be adapted to the characteristics of each soil
 193 type to optimize land utilization while maintaining the sustainability of watershed hydrological
 194 functions.



195 <https://www.fao.org/>
 196
 197 **Fig. 4. Soil type map**
 198

199 3.3 CLIMATIC CONDITIONS

200 Climate data were obtained from NASA POWER through the Data Access Viewer by entering
 201 the coordinates of the Baging Sub-watershed and selecting parameters including solar
 202 radiation, precipitation, air temperature, wind speed, and relative humidity. NASA POWER
 203 provides satellite-derived and reanalysis-based data with a spatial resolution of approximately
 204 $0.5^\circ \times 0.5^\circ$ (approximately 55 km), making it suitable for climate analyses over relatively broad
 205 areas. The data were downloaded in CSV format for subsequent processing. Meanwhile,
 206 climate data from a local weather station were obtained using direct measurements from
 207 instruments such as rain gauges, maximum–minimum thermometers, anemometers, and
 208 hygrometers. These data have daily to monthly temporal resolution and are therefore useful
 209 for validating satellite-derived climate data. For biophysical conditions, slope data were
 210 obtained from the National Digital Elevation Model (DEMNAS), released by the Geospatial
 211 Information Agency of Indonesia (BIG), with a spatial resolution of 8.25 m. The DEM data were

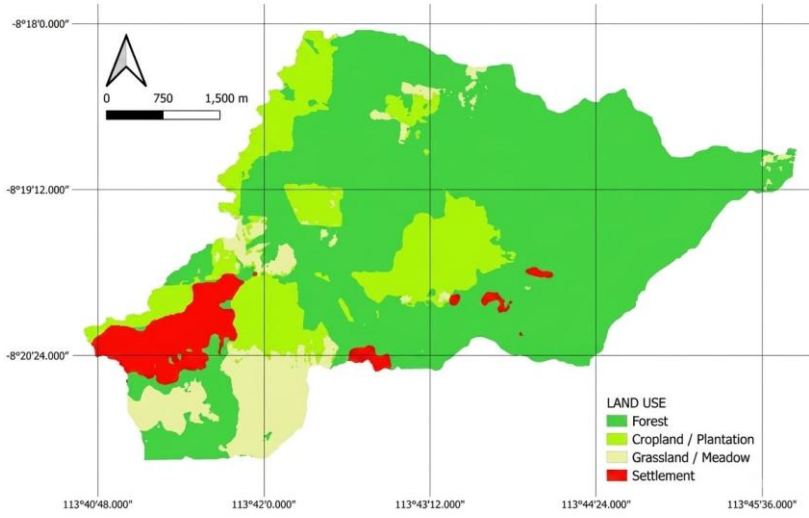
downloaded in GRID/TIFF format and processed using GIS software (QGIS) through terrain analysis to generate slope maps expressed in percentage or degrees. Soil data were obtained from FAO/UNESCO soil maps or SoilGrids, which provide a spatial resolution of 250 m. The soil data were clipped to the boundaries of the Bajing Sub-watershed and analyzed to extract USDA/FAO soil classes. All datasets from NASA POWER, DEMNAS, and FAO were processed using raster and vector-based GIS methods to generate spatially consistent climatic and biophysical information.

3.4 LAND COVER

Land-cover analysis was conducted to characterize the biophysical conditions and human activities within the Bajing Sub-watershed. The results are presented in Table 4.

Table 4. Land Cover of the Bajing Sub-watershed

Land Use	Area (ha)	Percentage (%)
Forest	1859	67,90
Cropland/Plantation	477	17,42
Residential	156	5,70
Grassland	246	8,98



<https://earthexplorer.usgs.gov/>

Fig. 5. Land-use map

The land-cover data indicate that the study area is dominated by forest, including primary and production forests, covering 67.90% of the area. This reflects relatively good vegetation cover, which plays an important role in maintaining watershed hydrological functions. Various studies have shown that forest cover contributes significantly to enhanced infiltration, reduced surface runoff, and erosion and sedimentation control through the functions of the canopy, litter layer, and well-developed root systems (Anley & Minale, 2024; Kulsoontornrat & Puangkaew, 2025). In general, forest dominance within a watershed is associated with greater flow-regime stability and reduced risks of flooding and land degradation.

In addition to forests, plantation areas covering 17.42% indicate land utilization by local communities, generally in the form of mixed plantations or agroforestry systems. Recent studies indicate that agroforestry systems can maintain hydrological and ecological functions

approaching those of natural forests, particularly by enhancing infiltration, reducing runoff, and minimizing soil loss when managed according to soil and water conservation principles (Bruijnzeel et al., 2025; Hoek van Dijke et al., 2022). Thus, mixed plantations can continue to function as hydrological buffers within the watershed when managed sustainably. Grasslands, which cover 8.98% of the study area, function as open areas or grazing land but may also become sources of runoff and erosion when vegetation cover is sparse or degraded, particularly on moderate to steep slopes. Recent studies have shown that grassland degradation can substantially increase surface runoff and sediment production compared with forested or agroforestry areas (González-Cao et al., 2022). Therefore, grassland management should be implemented carefully to prevent accelerated land degradation. Residential areas account for only 5.70% of the study area, indicating relatively low urbanization pressure. Nevertheless, residential development can affect hydrological processes through the expansion of impervious surfaces, which accelerate surface runoff and reduce infiltration. Despite their limited spatial extent, several studies have confirmed that residential expansion in upstream and middle watershed areas can significantly alter hydrological responses (Xu et al., 2025; Zwirgmaier et al., 2024). Overall, the dominance of natural and semi-natural vegetation provides substantial opportunities for maintaining and optimizing sustainable watershed management.

3.5 HYDROLOGICAL ANALYSIS USING SWAT

The Soil and Water Assessment Tool (SWAT) model was implemented using QGIS 3.40.9 with the SWAT+ 3.0.8 module. The modeling was conducted to estimate the hydrological response of the Bajing Sub-watershed.

3.5.1 Sub-watershed Delineation

The delineation process divided the study area into four sub-basins based on topography and the river network. This subdivision is important for understanding the spatial distribution of runoff and erosion processes.

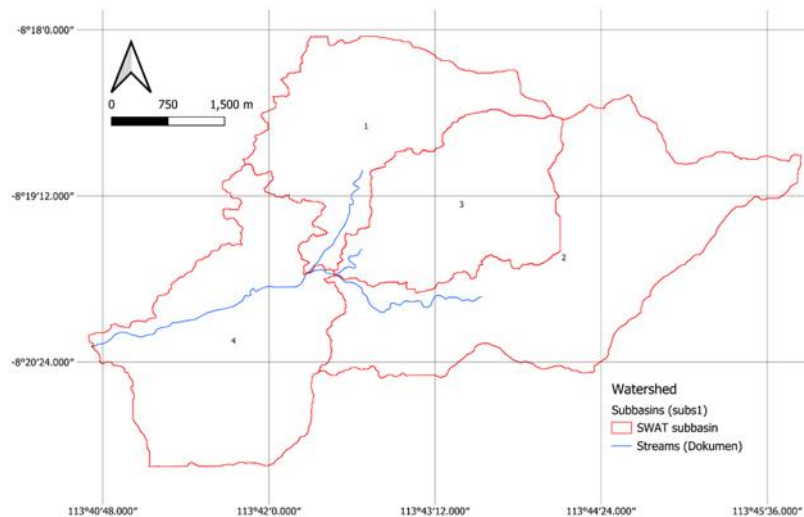


Fig. 6. Sub-basin delineation

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Table 5. Sub-basin

Sub-sub Basin	Area (ha)	Percentage (%)
1	537.67	19,64
2	944.54	34,50
3	496.36	18,13
4	759.42	27,74

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3.5.2 HRU Formation

Hydrologic Response Units (HRUs) were generated through an overlay process involving land cover, soil type, and slope classes to produce hydrologically homogeneous land units. Each combination of these parameters represents the smallest unit with similar biophysical characteristics, including infiltration capacity, surface-runoff potential, and response to rainfall. By grouping the study area into representative HRUs, the SWAT model can simulate hydrological processes more accurately, including surface runoff, erosion, evapotranspiration, and water movement through the soil profile. This approach ensures that spatial variations in field conditions are adequately represented, thereby producing more realistic hydrological analysis results that correspond to the spatial characteristics of the Baging Sub-watershed.

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3.5.3 Climate Data for the Model

The climate input data are presented in Table 6.

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Table 6. Annual Climate Data for the Baging Sub-watershed, 2016–2024

Year	Precipitation (mm/year)	Solar Radiation (MJ/m ² /day)	Wind Speed (m/s)	Relative Humidity (%)	Maximum Temperature (°C)	Minimum Temperature (°C)
2016	3159	9.42	2.89	82	29.14	25.87
2017	1940	9.22	3.39	82	28.24	25.94
2018	1503	9.67	3.49	80	28.42	25.94
2019	1311	10.13	3.31	80	28.90	25.94
2020	2232	9.52	3.40	81	28.88	25.86
2021	2556	9.28	3.13	82	28.47	25.93
2022	2674	9.10	3.08	83	28.48	25.93
2023	1604	9.80	3.26	82	28.56	25.93
2024	1621	9.48	3.34	82	29.31	25.85

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<https://power.larc.nasa.gov/>

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During 2016–2024, the climatic variables exhibited clear interannual variability, particularly in precipitation. The highest annual precipitation occurred in 2016 (3,159 mm/year), whereas the lowest occurred in 2019 (1,311 mm/year), indicating pronounced differences between wet and dry years. Interannual precipitation variability is a common characteristic of tropical regions and is frequently associated with monsoon dynamics and global climate phenomena such as the El Niño–Southern Oscillation (ENSO), which strongly influence the intensity and distribution of annual rainfall (Marzuki et al., 2025). In contrast, solar radiation remained relatively stable, ranging from 9.10 to 10.13 MJ/m²/day, but tended to increase during years with lower precipitation. This pattern indicates an inverse relationship between precipitation and solar radiation, whereby reduced cloud cover during dry periods increases the amount of solar radiation reaching the Earth's surface (Chai et al., 2021; Sardans et al., 2024). Wind speed, ranging from 2.89 to 3.49 m/s, and relatively high and stable relative humidity (80–83%) reflect a humid climatic regime with relatively low variability in non-precipitation climatic variables, which is typical of maritime tropical environments (Hendrawan et al., 2024). Maximum air temperature (28.24–29.31 °C) and minimum air temperature (25.85–25.94 °C)

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exhibited relatively limited interannual variation, indicating the annual thermal stability characteristic of tropical regions. Overall, the climatic dynamics of the study area were primarily governed by variations in precipitation and solar radiation rather than by other climatic variables. These variations have direct implications for water availability, evapotranspiration rates, and watershed hydrological balance and should therefore be considered in water-resource management planning and climate-variability adaptation strategies (Thakur et al., 2025).

3.5.4 SWAT Model Reclassification

The reclassification of SWAT input codes corresponding to the thematic maps is presented in Table 7.

Table 7. Reclassification of Model Inputs

Map	Classification	SWAT code	Area	
			Ha	%
Batas Sub Das				
Land Cover	Forest	FRST	1.859	67,90
	Plantation	AGRR	477	17,42
	Residential	URML	156	5,70
	Grassland	RNGB	246	8,98
Total			2738	100
	<i>Andisol</i>	Tv38-1bc 4580	1495	54,60
	<i>Ultisol</i>	Je65-2-3a-3752	956	34,92
	<i>Inceptisol</i>	I-Lc-3b-4510	287	10,48
Total			2738	100
Slope	Flat	-	756	27,61
	Gentle	-	650	23,74
	Moderately steep	-	483	17,64
	Steep	-	498	18,19
	Very steep	-	351	12,82
Total			2738	100

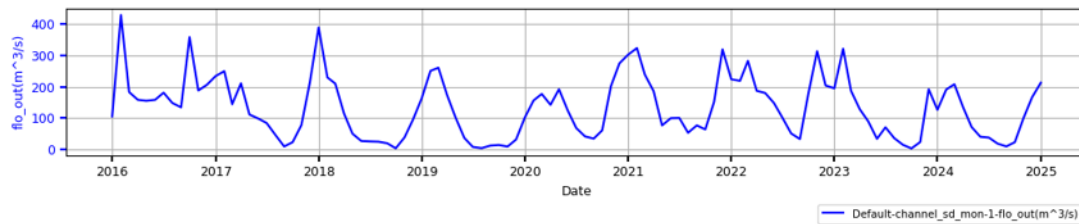
Input data coding was conducted to ensure that all spatial parameters could be properly recognized and processed by the SWAT model. For the land-cover map, each class was assigned a standard SWAT code, including FRST for forest, AGRR for plantations, RNGB for grassland, and URML for residential areas. This coding ensures that each land-cover category is recognized by SWAT according to its respective hydrological attributes, including surface-runoff characteristics, evapotranspiration, and ground-cover properties. For soil data, each FAO-classified soil type, including Andisol, Ultisol, and Inceptisol, was linked to the corresponding identification codes in the SWAT soil database through attributes such as Tv38-1bc-4580, Je65-2-3a-3752, and I-Lc-3b-4510. Meanwhile, slope was classified into flat, gentle, moderately steep, steep, and very steep classes and subsequently used as a criterion in the formation of Hydrologic Response Units (HRUs). Although slope classes do not have specific SWAT codes in the table, each slope class was represented as a separate spatial layer for the overlay process. This structured coding procedure enables land cover, soil type,

and slope characteristics to be consistently integrated, thereby generating valid HRUs for SWAT simulations.

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333 **3.5.5 Streamflow Simulation**

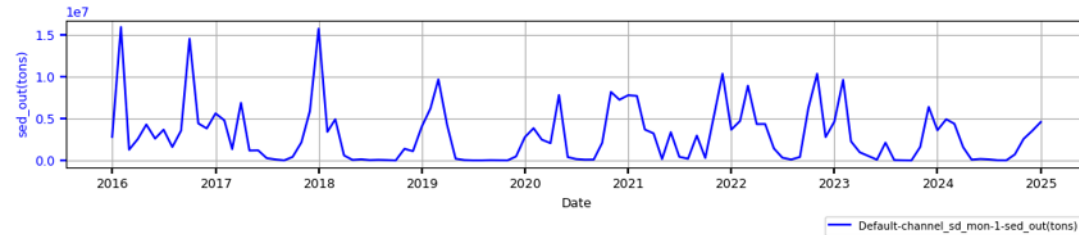
334 After all input data had been integrated, the SWAT model was run to simulate streamflow and
 335 sediment yield at the outlet of the Bajing Sub-watershed. The simulation accounted for the
 336 interactions among precipitation, infiltration, evapotranspiration, surface runoff, subsurface
 337 flow, and groundwater flow within the watershed water balance. The SWAT approach has
 338 been widely applied to simulate streamflow and sediment yield and to evaluate watershed
 339 hydrological responses to variations in biophysical conditions and land use



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Fig. 7. Monthly Simulated Streamflow from the SWAT Model



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Fig. 8. Monthly Simulated Sediment Yield from the SWAT Model

345 The simulation results presented in Figure 6 show a distinct seasonal streamflow pattern, with
 346 discharge generally increasing during the wet season, particularly from December to February,
 347 and decreasing during the dry season. The sediment-yield pattern in Figure 7 also tends to
 348 follow variations in streamflow, with higher values occurring during periods of high flow. This
 349 condition indicates that increased surface runoff and streamflow can enhance sediment
 350 mobilization and transport from the catchment area toward the outlet. This response results
 351 from the interaction among precipitation, topography, soil properties, and land use, which are
 352 subsequently examined quantitatively through statistical analysis (de Oliveira Serrão et al.,
 353 2022; Manawko Tefera & Kasiviswanathan, 2023).

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356 **3.6 STATISTICAL ANALYSIS OF STREAMFLOW AND SEDIMENT YIELD**
 357 **Table 8. Statistical Characteristics of Simulated Streamflow and Sediment Yield**

Streamflow	Streamflow	Sediment Yield
Max	430	1.60
Min	2.24	0.00
Average	132.93	0.30
Standard deviation (SD)	97.27	0.34
STDV.S		
Coefficient of variation (CV, %)	73.17	113.90
CV		
Trend	-0.43	0
Regresi		
Correlation coefficient (r)	0.9	

358 * Authors' analysis based on Excel data processing

359
 360 Statistical analysis was conducted to characterize streamflow and sediment yield generated
 361 by the SWAT simulation, including descriptive statistics, coefficient of variation (CV), trend
 362 analysis, and correlation analysis. Statistical assessment of SWAT outputs is important for
 363 evaluating the variability of streamflow and sediment yield and their relationships with
 364 biophysical conditions and land-use characteristics (Bak et al., 2025; Quamar et al., 2025). As
 365 shown in Table 8, streamflow ranged from a maximum of 430.00 m³/s to a minimum of 2.24
 366 m³/s, with a mean of 132.93 m³/s and a standard deviation of 97.27 m³/s. The coefficient of
 367 variation of 73.17% indicates a high degree of streamflow variability. The maximum streamflow
 368 occurred in February, whereas the minimum occurred in October, indicating a pronounced
 369 seasonal pattern associated with the distribution of precipitation. Meanwhile, sediment yield
 370 ranged from a maximum of 1.60 tons to a minimum approaching 0 tons, with a mean of 0.30
 371 tons and a standard deviation of 0.34 tons. The coefficient of variation reached 113.90%,
 372 indicating very high variability in sediment yield. This high variability suggests that sediment
 373 production is not controlled solely by streamflow but is also influenced by precipitation, slope,
 374 soil properties, and land use. SWAT-based studies have similarly demonstrated that land-use
 375 changes can affect surface runoff and sediment yield differently among sub-watersheds. The
 376 analysis yielded a streamflow trend value of -0.43, indicating a descriptive tendency toward
 377 decreasing streamflow, whereas the sediment-yield trend was approximately zero and
 378 therefore did not indicate a substantial descriptive change over the analyzed period.
 379 Furthermore, the correlation coefficient between streamflow and sediment yield was (r = 0.90),
 380 indicating a very strong positive relationship, whereby increases in streamflow tended to be
 381 accompanied by increases in sediment yield. However, this relationship does not imply that
 382 streamflow is the sole controlling factor of sediment yield, because erosion and sediment-
 383 transport processes are also governed by soil characteristics, slope, precipitation, and land
 384 use. To strengthen the interpretation, data distributions were visualized using boxplots, while
 385 the relationship between streamflow and sediment yield was examined using linear
 386 regression. This approach is consistent with SWAT-based studies that employ statistical and
 387 non-parametric approaches to evaluate trends in flow, runoff, and sediment yield.

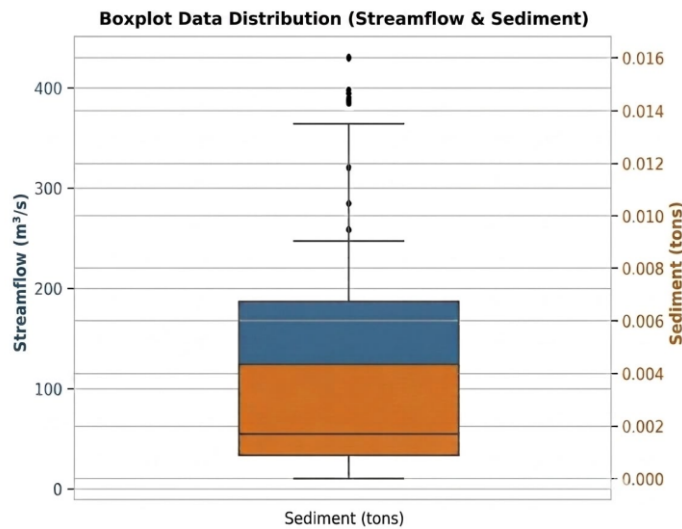


Fig. 8. Boxplot Distribution of Streamflow and Sediment Yield

Figure 8 presents the distribution of streamflow and sediment yield using boxplots. Both variables exhibit positively skewed distributions with several outliers, reflecting the occurrence of relatively high values during particular periods, especially when streamflow increased. Streamflow had a mean of 132.93 m³/s, a range of 2.24–430.00 m³/s, and a CV of 73.17%. Meanwhile, sediment yield had a mean of 0.30 tons, a range of 0–1.60 tons, and a CV of 113.90%. The substantially higher variability in sediment yield indicates that sediment-transport responses are more fluctuating and are controlled not only by streamflow but also by precipitation, slope, soil characteristics, and land use. SWAT-based research has likewise demonstrated that runoff and sediment yield are governed by interactions among land use/land cover (LULC), soil properties, and slope characteristics (Chen et al., 2022; Opiyo, 2024)

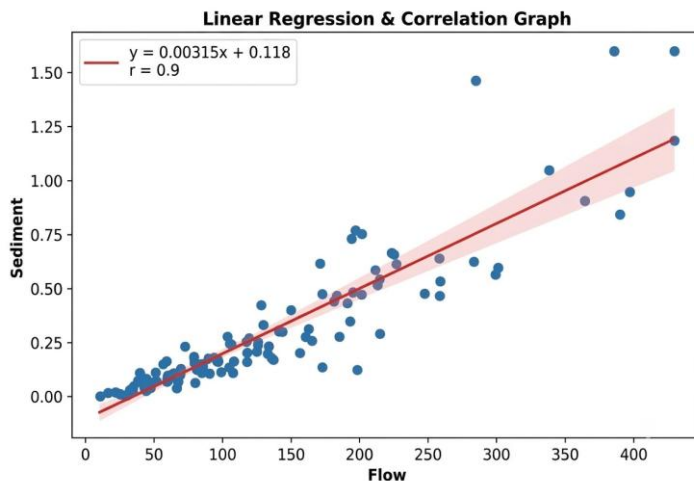


Fig. 9. Linear Regression and Correlation between Streamflow and Sediment Yield

Linear regression analysis revealed a very strong positive relationship between streamflow and sediment yield ($r = 0.90$; $R^2 = 0.81$), with the regression equation:

$$\text{Sediment Yield} = 0.00315 \times \text{Streamflow} - 0.118$$

The R^2 value indicates that approximately 81% of the variability in sediment yield can be statistically explained by variations in streamflow, while the remaining 19% is associated with other factors not represented in the regression equation. The positive regression coefficient indicates that increasing streamflow tends to be accompanied by increasing sediment yield, consistent with the enhanced capacity of flowing water to mobilize and transport eroded materials. Nevertheless, the relationship between streamflow and sediment yield is not necessarily linear under all hydrological conditions because sediment production is also influenced by sediment availability, soil properties, land-cover conditions, and slope characteristics (de Oliveira Serrão et al., 2022; Manawko Tefera & Kasiviswanathan, 2023).

4. CONCLUSION

This study assessed the hydrological conditions of the Bajing Sub-watershed, Jember, Indonesia, using the SWAT model and statistical analysis of streamflow and sediment yield. The results indicate that the watershed is generally supported by favorable land-cover and soil conditions, particularly the dominance of forest cover (67.90%) and Andisols (54.60%). However, steep to very steep slopes (31.01%) and substantial rainfall variability may increase the potential for runoff, erosion, and sediment transport.

SWAT simulations showed pronounced seasonal variability, with streamflow ranging from 2.24 to 430.00 m³/s and sediment yield from 0 to 1.60 tons. Streamflow and sediment yield exhibited a strong positive correlation ($r = 0.90$), with $R^2 = 0.81$, indicating that streamflow statistically explained 81% of the variation in sediment yield. These findings highlight the importance of maintaining forest cover, implementing soil conservation on steep slopes, and controlling land-use changes to sustain the hydrological function of the Bajing Sub-watershed.

COMPETING INTERESTS

"Authors have declared that no competing interests exist."

REFERENCES

Anley, M. A., & Minale, A. S. (2024). Modeling the impact of land use land cover change on the estimation of soil loss and sediment export using InVEST model at the Rib watershed of Upper Blue Nile Basin, Ethiopia. *Remote Sensing Applications: Society and Environment*, 34,

101177. <https://doi.org/https://doi.org/10.1016/j.rsase.2024.101177>

Apriliani, R., Sulisty, B., & Muktamar, Z. (2024). Improvement of Selected Soil Physical Properties and Mustard Yield After the Application of Tithonia Compost in Ultisols. *TERRA : Journal of Land Restoration*, 7(2 SE-Articles), 66–71. <https://doi.org/10.31186/terra.7.2.66-71>

Bak, S., Lee, S., Han, J., Jeong, Y., Choi, Y., Lee, G., Engel, B. A., & Lim, K. J. (2025). Enhancement of Sediment Routing Method of SWAT Model Considering Sediment Occurrence Trends of Rise and Fall of Streamflow. *JAWRA Journal of the American Water Resources Association*, 61(4), e70023. <https://doi.org/https://doi.org/10.1111/1752-1688.70023>

Bruijnzeel, L. A., Peña-Arancibia, J. L., Sheil, D., Ziegler, A. D., Zhang, J., Zwartendijk, B. W., Birkel, C., Sun, G., Wang, Y., & Zhang, X. (2025). Potential for improved groundwater recharge and dry-season flows through forest landscape restoration on degraded lands in the tropics. *Forest Ecosystems*, 14(2). <https://doi.org/10.1016/j.fecs.2025.100376>

Chai, R., Mao, J., Chen, H., Wang, Y., Shi, X., Jin, M., Zhao, T., Hoffman, F. M., Ricciuto, D. M., & Wulschleger, S. D. (2021). Human-caused long-term changes in global aridity. *Npj Climate and Atmospheric Science*, 4(1), 65. <https://doi.org/10.1038/s41612-021-00223-5>

Chen, H., Shi, R., He, J., Zheng, L., & Wang, W. (2022). Simulation analysis of runoff and sediment yield under the change of land-use type: A case study of the Upper Jianjiang River Basin, China. *Polish Journal of Environmental Studies*, 31(3), 2527–2536. <https://doi.org/10.15244/pjoes/143883>

de Oliveira Serrão, E. A., Silva, M. T., Ferreira, T. R., de Ataíde, L. C. P., dos Santos, C. A., de Lima, A. M. M., da Silva, V. de P. R., de Sousa, F. de A. S., & Gomes, D. J. C. (2022). Impacts of land use and land cover changes on hydrological processes and sediment yield determined using the SWAT model. *International Journal of Sediment Research*, 37(1), 54–69. <https://doi.org/10.1016/j.ijsrc.2021.04.002>

dos Santos, F. M., de Souza Pelinson, N., de Oliveira, R. P., & Di Lollo, J. A. (2023). Using the SWAT model to identify erosion prone areas and to estimate soil loss and sediment transport in Mogi Guaçu River basin in Sao Paulo State, Brazil. *Catena*, 222, 106872. <https://doi.org/10.1016/j.catena.2022.106872>

Ermawati, E., Kusuma, Z., & Wicaksono, K. (2023). Impact of Land Use on Soil Water Retention in Inceptisols of the Upper Konto Watershed. *JOURNAL OF TROPICAL SOILS*, 29, 167–177. <https://doi.org/10.5400/jts.2024.v29i3.167-177>

García, C. R., Brown, S., Krzic, M., Lavkulich, L., & Roa-García, M. C. (2021). Relationship of soil water retention characteristics and soil properties: A case study from the colombian andes. *Canadian Journal of Soil Science*, 101(1), 144–156. <https://doi.org/10.1139/cjss-2020-0066>

González-Cao, J., Fernández-Nóvoa, D., García-Feal, O., Figueira, J. R., Vaquero, J. M., Trigo, R. M., & Gómez-Gesteira, M. (2022). The Rivillas flood of 5–6 November 1997 (Badajoz, Spain) revisited: An approach based on Iber+ modelling. *Journal of Hydrology*, 610, 127883. <https://doi.org/https://doi.org/10.1016/j.jhydrol.2022.127883>

Hakim, F. L., Indarto, I., Hidayah, E., & Cahyono, B. E. (2023). Five decades of land use and land cover change in Bedadung watershed: Learning from Landsat data. *AIP Conference Proceedings*, 2583, 60007. <https://doi.org/10.1063/5.0117116>

Hendrawan, V. S. A., Mawandha, H. G., Sakti, A. D., Karlina, Andika, N., Shahid, S., & Jayadi, R. (2024). Future exposure of rainfall and temperature extremes to the most populous island of Indonesia: A projection based on CORDEX simulation. *International Journal of Climatology*, 44(10), 3529–3547. <https://doi.org/https://doi.org/10.1002/joc.8537>

Hermiyanto, B., Mawarni, C., Winarso, S., & Budiman, S. A. (2025). Soil quality assessment and land capability evaluation for determining integrated watershed management model through SWOT analysis and AHP method in Arjasa Sub-watershed, Indonesia. *Watershed Ecology and the Environment*, 7, 104–118. <https://doi.org/https://doi.org/10.1016/j.wsee.2025.02.001>

Hoek van Dijke, A. J., Herold, M., Mallick, K., Benedict, I., Machwitz, M., Schlerf, M., Pranindita, A., Theeuwen, J. J. E., Bastin, J.-F., & Teuling, A. J. (2022). Shifts in regional water

availability due to global tree restoration. *Nature Geoscience*, 15(5), 363–368.
<https://doi.org/10.1038/s41561-022-00935-0>

Hou, K., Wang, J., & Zhang, X. (2025). Simulation and Response of Runoff to Climate and Land-Use Changes in the Yanhe River Basin, Loess Plateau: A SWAT Model-Based Analysis. *Water (Switzerland)*, 17(7). <https://doi.org/10.3390/w17071042>

Indarto, I., Hidayah, E., & Setiawan, E. B. (2023). Water balance assessment, land use land cover change and increasing water demand in three major watersheds in Jember, East Java, Indonesia. *Geosfera Indonesia*, 8(2), 170–188. <https://doi.org/10.19184/geosi.v8i2.39131>

Kardhana, H., Lihawa, A. W., Rohmat, F. I., Wulandari, S., Harjupa, W., Adiprawita, W., Kardena, E., & Kusuma, M. S. (2024). Water Balance Analysis in the Majalaya Watershed: Two-Step Calibration and Application of the SWAT+ Model for Low-Flow Conditions. In *Water* (Vol. 16, Issue 23, p. 3498). <https://doi.org/10.3390/w16233498>

Kulsoontornrat, J., & Puangkaew, N. (2025). Assessing the impacts of land use and land cover changes on sediment yield using the SWAT model: A case study in the Khlong Bang Yai Watershed, Phuket Island, Thailand. *International Journal of Geoinformatics*, 21(5), 62–79. <https://doi.org/10.52939/ijg.v21i5.4161>

Liu, J., Zhang, X., Wu, X., Yang, Y., & Zheng, Y. (2024). Impacts of LULC changes on runoff from rivers through a coupled SWAT and BiLSTM model: A case study in Zhanghe River Basin, China. *Ecological Informatics*, 84, 102866. <https://doi.org/10.1016/j.ecoinf.2024.102866>

Manawko Tefera, W., & Kasiviswanathan, K. S. (2023). Potential assessment of calibration approaches using the SWAT hydrological model for streamflow and sediment yield for a large-scale catchment. *Hydrological Sciences Journal*, 68(13), 1895–1914. <https://doi.org/10.1080/02626667.2023.2243463>

Marzuki, M., Ramadhan, R., Yusnaini, H., Vonnisa, M., Muharsyah, R., Nugraha, Y., Sari, A. Y., & Erajalita, A. (2025). Long-Term Spatial–Temporal Variability, Trends and Extreme Rainfall Events Over Indonesia Based on 43 Years of CHIRPS Data. *International Journal of Climatology*, 45(14), e70107. <https://doi.org/https://doi.org/10.1002/joc.70107>

Opiyo, S. B. (2024). Modeling the impacts of land use and land cover changes on streamflow and sediment yield with the SWAT model in Migori River Watershed, Lake Victoria Basin Region, Kenya. *African Geographical Review*, 44(1), 48–69. <https://doi.org/10.1080/19376812.2024.2324279>

Quamar, S., Kumar, P., & Singh, H. P. P. (2025). Streamflow and sediment simulation in the Song River basin using the SWAT model. *Frontiers in Water*, Volume 7-2025. <https://doi.org/10.3389/frwa.2025.1500086>

Rafif, M. A., Widiarti, W. Y., Hidayah, E., Saifurridzal, S., & Ma'ruf, M. F. (2024). Effects of Land Use Change on Land Erosion and Land Critical Level Using GIS in the Mayang Watershed. *Geosfera Indonesia*, 9(2), 122. <https://doi.org/10.19184/geosi.v9i2.39670>

Sardans, J., Miralles, A., Tariq, A., Zeng, F., Wang, R., & Peñuelas, J. (2024). Growing aridity poses threats to global land surface. *Communications Earth & Environment*, 5(1), 776. <https://doi.org/10.1038/s43247-024-01935-1>

Thakur, V., Markonis, Y., Kumar, R., Thomson, J. R., Vargas Godoy, M. R., Hanel, M., & Rakovec, O. (2025). Unveiling the impact of potential evapotranspiration method selection on trends in hydrological cycle components across Europe. *Hydrology and Earth System Sciences*, 29(18), 4395–4416. <https://doi.org/10.5194/hess-29-4395-2025>

Tumsa, B. C. (2023). The response of sensitive LULC changes to runoff and sediment yield in a semihumid urban watershed of the Upper Awash Subbasin using the SWAT+ model. *Applied and Environmental Soil Science*. <https://doi.org/https://doi.org/10.1155/2023/6856144>

Xu, Q., He, S., Jiang, J., Zeng, Z., Wang, Z., & Duan, H. (2025). Assessing the compound impacts of urbanization and climate change on flood hazards in rapid urbanized basin: A case study of Chebei River Basin, South China. *Journal of Hydrology: Regional Studies*, 62, 102942. <https://doi.org/https://doi.org/10.1016/j.ejrh.2025.102942>

Zhang, L., Deng, C., Wei, J., & Zou, J. (2025). Assessing the impacts of climate change and

565 land use/land cover data characteristics on streamflow using the SWAT model in the Upper
566 Han River Basin. *Journal of Hydrology: Regional Studies*, 61, 102764.
567 <https://doi.org/https://doi.org/10.1016/j.ejrh.2025.102764>
568 Zwirgmaier, V., Reimuth, A., & Garschagen, M. (2024). How suitable are current approaches
569 to simulate flood risk under future urbanization trends? *Environmental Research Letters*,
570 19(7), 73003. <https://doi.org/10.1088/1748-9326/ad536f>
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