



RESEARCH PAPER

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SWAT+-based water balance assessment of Ipil watershed in Bohol, Philippines: Spatial and temporal patterns of water availability

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ABSTRACT

The Ipil Watershed in Bohol, Philippines, was evaluated for water balance using the Soil and Water Assessment Tool Plus (SWAT+) Model. Geospatial datasets, including a digital elevation model, land use, soil type, and slope data, were used to define the watershed, while climate inputs from Department of Science and Technology-Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA) covering 2014–2024 were used for simulation. To estimate the main hydrological components, such as precipitation, evapotranspiration, surface runoff, groundwater recharge, and water yield, the model was assessed under uncalibrated, calibrated, and validated conditions. The results demonstrated that by reducing excessive runoff and increasing evapotranspiration, calibration improved model realism and produced more balanced hydrological outputs. Water production and runoff were unevenly distributed among subbasins, with larger values concentrated in the eastern and central areas of the watershed, according to spatial analysis. Strong seasonal variation was revealed by temporal analysis, with an extraordinary annual peak flow of 131.17 m<sup>3</sup>/s recorded in 2021 and a larger average flow during the rainy season (31.39 m<sup>3</sup>/s) than the dry season (15.83 m<sup>3</sup>/s). However, the insignificant baseflow and groundwater outputs indicate constraints in subsurface parameterization. In general, the SWAT+ model performed well in evaluating watershed hydrology and pinpointing regions susceptible to seasonal water scarcity and flooding. The results provide a solid scientific foundation for the Ipil Watershed's planning for climate adaptation, watershed management, and the sustainable distribution of water resources.

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## INTRODUCTION

Water balance estimation is a crucial tool for assessing water availability and its movement of. Cognizance of the water balance would help convey the numerous challenges posed by water scarcity, floods, and environmental degradation. Water is an essential resource for the general public's domestic consumption, agriculture, industry, and ecosystems worldwide (FAO, 2016; IFAD, 2023). Significantly, water scarcity has increased, while expanding climate variability, rapid population growth, and unsustainable land-use practices have altered hydrologic processes worldwide (Huntington, 2006; IPCC, 2021). With rising water consumption, the Philippines' freshwater supplies are under the utmost pressure, increasing the need to ensure water accessibility and quality to meet the water supply demands of thousands to millions of people (Beven, 2012).

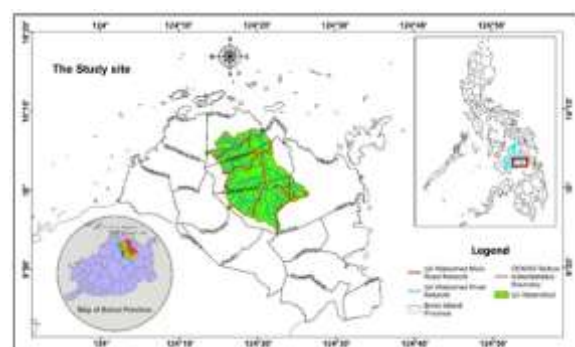
The Province of Bohol faces significant ecological pressure; its watersheds, most notably, have not yet been quantitatively assessed for the local water balance components and water yield estimation, particularly in the Ipil Watershed. These watersheds play a significant role from an ecological and socio-economic perspective in the Second Congressional District of Bohol; however, there is limited research on how to manage water resources. Although many existing studies focus on resource use or water quality, they rarely incorporate hydrologic modeling to simulate how land-use and climate variables interact to influence water availability. Therefore, this study aims to estimate and analyze the main water balance components including Precipitation, evapotranspiration, surface runoff, lateral flow, infiltration, water yield, and groundwater recharge, of the Ipil Watersheds in Bohol Island, Philippines, using the SWAT+ model to generate science-based insights on the hydrologic behavior that can guide for effective water resource management, and local climate adaptation and sustainable planning, also to provide a policy recommendations to the local and national policy makers.

Addressing this gap is important for designing effective water resource management strategies and for supporting communities most vulnerable to related climate water stress. To ensure a transparent and robust assessment, this also accounts for inherent challenges such as potential resolution limits in satellite data and provincial data scarcity.

## MATERIALS AND METHODS

### Study site

The study was conducted in the Ipil Watershed, situated on Bohol Island, Philippines (Fig. 1). The watershed lies within the northeastern municipalities of the island. It is bordered by Talibon to the north, Pilar and Alicia to the south, Ubay to the east, and Danao to the west. The Ipil Watershed traverses the municipalities of Danao, San Miguel, Ubay, Trinidad, Getafe, Talibon, Bien Unido, Dagohoy, and Pilar. It plays a crucial role in sustaining the 2<sup>nd</sup> Congressional District of Bohol, serving as a vital source of water for agricultural irrigation, industrial use, domestic consumption, and biodiversity conservation. Its significance extends beyond the local water supply, as it supports the livelihoods of surrounding communities and contributes to the area's overall economic development. However, the watershed is highly susceptible to land-use changes and climate variability, both of which influence water availability for the region's agricultural systems. Additionally, the area experiences seasonal rainfall fluctuations, extreme weather events such as typhoons, and increasing urbanization.



**Fig. 1.** Shows the map of the study site, and an inset map of the preferred ipil watershed

### Design

This study employs a quantitative, modeling-based approach using the Soil and Water Assessment Tool Plus (SWAT+) to estimate and analyze the major components of the water balance. The methodology encompasses data collection, model setup, simulation, scenario analysis, calibration and validation, model check, and interpretation of the results.

### Instruments

This study employs specialized tools and software for hydrologic modeling, calibration, spatial analysis, statistical evaluation, and field validation, each selected for its relevance and effectiveness at the watershed scale. SWAT+ (Soil and Water Assessment Tool Plus), a process-based, semi-distributed hydrologic model developed by USDA-ARS, serves as the primary modeling tool. SWAT+ simulates key water balance components such as precipitation, runoff, evapotranspiration, infiltration, and groundwater recharge at various temporal scales. It requires comprehensive input data, including climate variables, land use, soil characteristics, topography, and land management practices, and provides daily, monthly, and annual estimates of hydrologic variables, offering critical insights into the watershed's water dynamics.

To streamline model setup and spatial data integration, QSWAT+ (QGIS-SWAT+ Interface), an open-source GIS-based interface, is utilized. QSWAT+ enables efficient delineation of watershed boundaries, creation of sub-basins, and definition of hydrologic response units (HRUs) by integrating spatial data such as digital elevation models (DEMs), land cover, and soil maps. It also organizes the input files needed to run SWAT+ simulations in the SWAT+ Editor.

For model calibration and validation, SWAT+ Toolbox was employed, allowing to run model, parameterization, observation, sensitivity analysis, calibration (manual and automatic) parameters, and model check. This tool facilitates comparison between

observed and simulated streamflow and other hydrologic variables to assess model accuracy and robustness in representing the watershed's hydrologic response. Additionally, a handheld Global Positioning System (GPS) and mobile phone survey were used to marked locations during fieldwork for ground-truthing of spatial data. These tools help validate key features such as stream locations, land cover types, and elevation points, ensuring consistency between modeled and actual watershed conditions. The coordinates collected during field validation are crucial for refining watershed boundaries and verifying DEM accuracy for the study area.

### Data collection

The data required for the study were gathered through a combination of secondary data, spatial data processing, and field verification.

### Coordination meeting and levelling off

The researcher sought permission through a formal letters addressed to the respective national and local government agencies such as the Provincial Environment and Natural Resources Office (PENRO) Bohol, the Community Environment and Natural Resources Office (CENRO) Talibon, Bohol, the Philippine Atmospheric, Geophysical and Astronomical Services Administration PAGASA Bohol, the Department of Public Works and Highways (DPWH) 2<sup>nd</sup> Engineering Office, Bohol, and the Local Government Units (LGUs) that covers within the Ipil Watershed area to allow the researcher obtain and access the specific data and support in the conduct for field validation activities.

All procedures adhered to ethical standards, ensuring the responsible use of data and non-invasive field verification throughout the study.

### Secondary data collection

#### Datasets

Hydrologic, meteorological (climatic), and land information datasets were obtained from credible national and local agencies. Climatic data, such as precipitation, temperature, humidity, and wind

speed, were obtained from the Department of Science and Technology (DOST-PAGASA) Central Office and Bohol Experimental Station (BES), Ubay, Bohol the local weather stations in the province. These datasets were requested from the above-mentioned offices via physical and online database through email and official websites.

#### *River discharge/Streamflow*

The river discharge/streamflow datasets were obtained from the Department of Public Works and Highways (DPWH) database with the approval of the head of office. The Drainage-Area Method (DARM) to estimate the streamflow at ungauged watershed based on the streamflow data from the nearby gauged river of the watershed and drainage area (Risley *et al.*, 2008). The Gabayan River streamflow data in the Canawa, Candijay, Bohol were utilized, since the Ipil River as one of the ungauged watersheds in the Bohol Island. These river discharge records are used in the calibration and validation processes in running SWAT+ for modeling. Currently Ipil River has no established streamflow gauge.

#### *Land use and land cover*

The land use/land cover (LULC) data were obtained from the DENR-National Mapping and Resource Information Authority (NAMRIA) and validated on the ground by the agency in 2020. This dataset was among the main components used in the creation of Hydrologic Response Units (HRUs).

#### *Soil type and slope*

The soil map and soil type classification were obtained from the Digital Soil Map of the World of the Food and Agriculture of the United Nations database. This dataset is also among the main components in the creation of HRUs. The DSMW dataset among the fitted soil types in the SWAT+ model.

#### *Digital elevation model*

The Interferometric Synthetic Aperture Radar (IFSAR) with a 10 m resolution was obtained from the DENR-National Mapping and Resource Information Authority (NAMRIA) through the ERDB-Watershed

and Water Research Development and Extension Center (WWRDEC). This dataset was used for watershed delineation.

#### *Watershed boundary*

The CENRO Talibon Administrative boundary, watershed boundary map, river map was obtained from the GIS Section of CENRO Talibon, Bohol. The Ipil Watershed areas were overlaid onto the municipal boundaries. The Ipil Watershed lies in 61 barangays of 7 municipalities.

#### **Geospatial data processing**

Using the QGIS and ArcGIS interface, spatial layers (land use, soil, slope, and elevation) were prepared to support the delineation of watershed, sub-basins and hydrologic response units (HRUs) in QSWAT+. These spatial inputs are essential for simulating hydrological processes using the SWAT+ model.

#### **Field verification and ground validation**

The actual survey of land cover, river/stream networks, and topographical features of the selected sites within the Ipil Watersheds was verified and marked with the geographic coordinates using a handheld Global Positioning System (GPS) and mobile phone (OruxMap) survey applications. These activities were done to ensure the accuracy of input data and validate through a drone aerial survey and remote sensing classifications.

#### **Data processing**

The hydrologic modeling of the Ipil Watershed was carried out using SWAT+, an advanced and flexible version of the Soil and Water Assessment Tool. Through QSWAT+, a plugin in QGIS, the researcher is able to map the watershed and define Hydrologic Response Units (HRUs).

Using the SWAT+ Editor and related tools, simulation parameters were set up, land management practices were handled, and the input and output data. To delineate the watershed, the researcher relied on key geospatial datasets: a high-resolution Digital Elevation Model (DEM), land use

and land cover maps, soil types, and slope data. These inputs allow the establishment of watershed boundaries, stream networks, and sub-basin features based on flow direction and accumulation, forming the spatial backbone of the model. Within each sub-basin, HRUs were created to represent unique combinations of land use, soil type, and slope class.

This approach helped capture the natural variability of hydrological processes across the watershed. To keep the model both accurate and efficient, slope thresholds of 8%, 18%, 30%, and 50% were applied. Calibration and validation followed a structured process. Started with sensitivity analysis using the Sobol method to identify the most influential parameters. Both manual and automatic calibration were then used to align simulated results with observed data.

Finally, model performance was evaluated using statistical measures such as  $R^2$ , Nash-Sutcliffe efficiency (NSE), Pearson's  $r$ , mean square error (MSE), RMSE-to-standard deviation ratio, and percent bias (PBIAS). These checks ensured that the model reliably represented the watershed's hydrologic responses.

#### **Water balance components estimation**

Water balance outputs were extracted from SWAT+, including: (a) precipitation (PRECIP), (b) evapotranspiration (ET), (c) surface runoff (SURQ), (d) lateral flow (LATQ), (e) infiltration, (f) water yield, and (g) groundwater recharge. These components were analyzed seasonally and annually to understand watershed hydrology.

#### **Spatial and temporal analysis (GIS integration)**

GIS software (QGIS) was used to visualize: (a) the spatial distribution of water balance, (b) the Hotspots of water scarcity or surplus, and (c) Sub-watershed level differences in water yield. Time-series plots would be generated to assess trends and variability in hydrologic response under different scenarios.

## **RESULTS AND DISCUSSION**

### **Water balance dynamics of the ipil watershed**

The water balance components of the Ipil Watershed were analyzed under uncalibrated (2014–2020), calibrated (2015–2017), and validated (2017–2020) conditions to evaluate the hydrological behavior and model performance. These components represent the partitioning of precipitation into atmospheric losses, surface flow, and subsurface storage, which collectively define watershed response (Arnold *et al.*, 1998; Beven, 2012). A clear redistribution of water balance components is observed after calibration, highlighting the importance of parameter adjustment in improving hydrological realism (Arnold *et al.*, 2012).

### **Estimation of water balance components**

Table 1 presents the SWAT+ simulation results for the Ipil Watershed. It provides an initial representation of its hydrological processes using 2014–2024 climate data from DOST-PAGASA. The table summarizes the estimated values of key water balance components under three modeling conditions: uncalibrated (2014–2020), calibrated (2015–2017), and validated (2017–2020). Precipitation, as the main hydrologic input, was highest during the uncalibrated period at 3,360.68 mm. It decreased to 1,972.89 mm and 1,854.00 mm during the calibrated and validated periods, respectively. This decrease is likely due to differences in temporal coverage and improved data representation during calibration.

Evapotranspiration (ET), a major output component, increased significantly from 922.43 mm in the uncalibrated simulation to 1,345.24 mm and 1,203.31 mm in the calibrated and validated runs, indicating a more realistic allocation of water to atmospheric losses, which is characteristic of tropical watersheds where ET typically comprises a large portion of precipitation (Allen *et al.*, 1998). In contrast, surface runoff (SURQ) showed a substantial decline from 2,249.51 mm in the uncalibrated model to 539.51 mm and 568.79 mm in the calibrated and validated simulations, suggesting that the initial model overestimated runoff and did not adequately capture infiltration and retention processes.

**Table 1.** Water balance results of ipil watershed

Water balance ratios	Uncalibrated 2014-2020 mm	Calibrated 2015-2017 mm	Validated 2017-2020 mm
Input			
Precipitation	3,360.68	1972.89	1854.00
Output			
Evapotranspiration (ET)	922.43	1345.24	1203.31
Surface run-off (SURQ)	2,249.51	539.51	568.79
Lateral flow (LATQ)	18.62	0	0
Storage			
Infiltration	45.59	0	0
Groundwater recharge	21.19	0	0
Water Yield	2,268.13	539.51	568.79

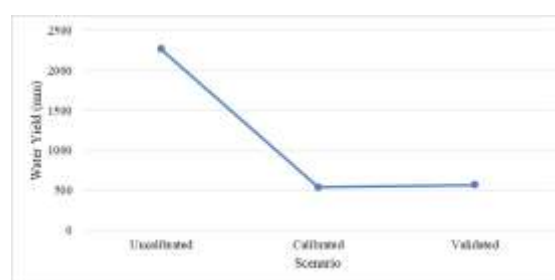
Lateral flow (LATQ) had a minimal contribution of 18.62 mm under uncalibrated conditions. It was absent in the calibrated and validated outputs, indicating either negligible subsurface lateral movement or limitations in model parameterization. Likewise, infiltration and groundwater recharge were initially estimated at 45.59 mm and 21.19 mm, respectively. Both were reduced to zero after calibration. This suggests that subsurface storage processes were not sufficiently represented in the final model. Water yield followed the same pattern as surface runoff. It decreased from 2,268.13 mm in the uncalibrated condition to 539.51 mm and 568.79 mm during calibration and validation. This reflects improved simulation of streamflow generation.

Finally, the calibration process effectively redistributed the watershed water balance by reducing excessive runoff and increasing evapotranspiration, resulting in a more hydrologically realistic model response; however, the absence of infiltration and groundwater recharge points to potential limitations in representing subsurface hydrological processes (Arnold *et al.*, 1998).

### Hydrograph interpretation and water yield response to calibration

The significant reduction in water yield from the uncalibrated to the calibrated and validated simulations was presented in Fig. 2. This indicates that the initial model setup overestimated streamflow, a common issue in hydrological modeling when parameters governing runoff, infiltration, and evapotranspiration are not properly calibrated. After calibration, the water yield values became consistent,

suggesting improved model performance and reduced bias. This improvement confirms that calibration plays a critical role in enhancing the accuracy of hydrological simulations. Studies have shown that uncalibrated SWAT/SWAT+ models often generate excessive surface runoff due to poor parameterization, whereas calibration redistributes water into more realistic components such as evapotranspiration and soil water storage (Arnold *et al.*, 2012; Abbaspour *et al.*, 2017). The stabilization between calibrated and validated results further indicates that the model can reliably simulate watershed hydrology under varying conditions. However, the lower water yield may also suggest reduced groundwater contribution, which could affect the sustainability of streamflow during dry periods, as baseflow is largely dependent on subsurface storage processes (Gassman *et al.*, 2007).

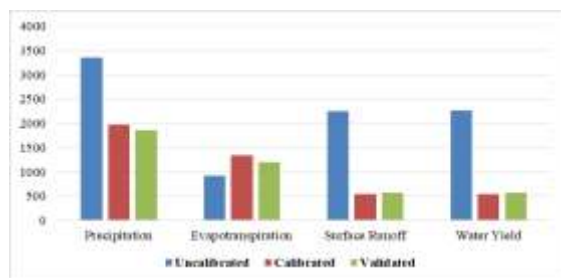


**Fig. 2.** Hydrograph of simulated water yield under uncalibrated, calibrated, and validated conditions in the ipil watershed

### Major water balance components

Fig. 3 shows the distribution of precipitation, evapotranspiration (ET), surface runoff, and water yield under different model conditions. After calibration, evapotranspiration increased, while

surface runoff and water yield decreased significantly. This indicates a redistribution of water balance components toward more realistic hydrological processes. The increase in evapotranspiration suggests that the model better represents atmospheric water losses, which are typically dominant in tropical watersheds. Research shows that ET often accounts for a large portion of precipitation in watershed systems, especially in vegetated areas (Pandey *et al.*, 2021).



**Fig. 3.** Comparison of major water balance components under different model conditions

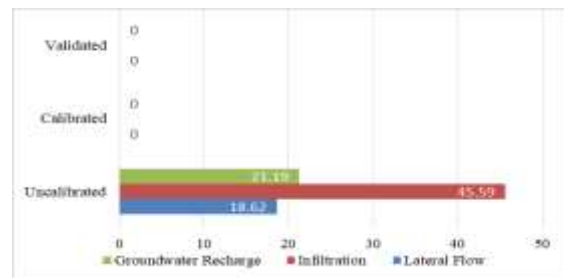
Meanwhile, the reduction in surface runoff reflects improved simulation of infiltration and soil water storage. This aligns with hydrological theory, where excessive runoff in uncalibrated models is corrected during calibration (Bieger *et al.*, 2017). This implies that the Ipil Watershed likely has higher water retention and vegetation-water interaction capacity than initially estimated. However, reduced runoff and water yield may also indicate lower streamflow contribution, which can influence downstream water availability.

### Subsurface hydrological components

Fig. 4 shows that infiltration, groundwater recharge, and lateral flow were present only in the uncalibrated simulation, but were zero after calibration and validation. This indicates that subsurface hydrological processes were not effectively represented in the final model outputs.

The absence of subsurface components suggests limitations in model parameterization or insufficient input data, particularly for soil and groundwater characteristics. In reality, infiltration and groundwater recharge are essential components of watershed

hydrology, contributing significantly to baseflow and sustaining streamflow during dry periods. Studies emphasize that groundwater recharge directly feeds baseflow, which is a major contributor to river discharge, especially during low-flow conditions when surface runoff is minimal (Melati *et al.*, 2019; Schilling *et al.*, 2021).



**Fig. 4.** Subsurface hydrological components of the ipil watershed

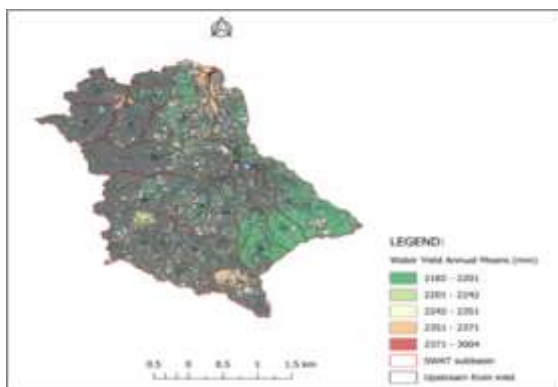
Furthermore, groundwater systems play a critical role in maintaining streamflow during drought, highlighting the importance of subsurface processes in overall watershed hydrology (Hellwig *et al.*, 2021). This result implies that the SWAT+ model in your study may be overly dominated by surface processes, potentially underestimating groundwater contributions. For watershed management, this could lead to a figure incomplete assessment of water availability, particularly during dry seasons. Therefore, further refinement of soil parameters, aquifer properties, and groundwater routines is recommended to improve model performance.

### Spatial distribution of annual water yield in the ipil watershed

The spatial distribution of annual mean water yield across the subbasins of the Ipil Watershed showed values ranging from approximately 2,182 to 3,004 mm, indicating moderate to high water production throughout the watershed (Fig. 5). Higher water yield zones are concentrated in selected eastern and central subbasins, while relatively lower values are observed in the northwestern and southwestern portions.

This spatial variation suggests that some sub-basins contribute more effectively to streamflow generation

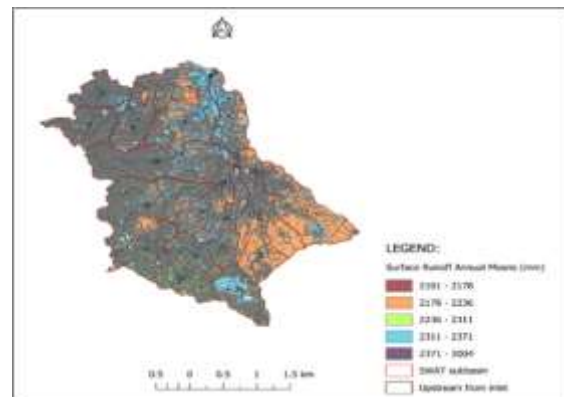
than others. Areas with higher water yield are commonly associated with favorable topography, higher rainfall reception, steeper slopes, or reduced evapotranspiration losses. In contrast, lower-yielding zones may reflect greater infiltration, higher vegetation water use, or storage within the soil profile. Similar studies using SWAT+ reported that water yield is strongly influenced by land use, slope, soil hydraulic properties, and rainfall distribution. The map indicates that high-yield subbasins are important sources of surface water and may serve as priority areas for water resource planning, reservoir supply, or watershed protection. However, these same zones may also be more sensitive to erosion and flash runoff if vegetation cover declines. Lower-yield zones may function as recharge or retention areas, helping regulate downstream flows. Under future climate or land-use change scenarios, these spatial contrasts may intensify, making targeted subbasin management essential.



**Fig. 5.** Spatial distribution of annual mean water yield across the subbasins of the ipil watershed

### Spatial distribution of annual surface runoff in the ipil watershed

The annual mean surface runoff distribution across the watershed, with values ranging from 2,101 to 3,004 mm (Fig. 6). Elevated runoff is visible in portions of the eastern, northeastern, and some lower subbasins, while comparatively lower runoff occurs in interior and western areas. The spatial dominance of runoff in certain zones indicates areas where precipitation is more rapidly converted into overland flow rather than infiltrating into the soil. This often occurs in steeper terrain, compacted soils, disturbed land cover, or areas with lower infiltration capacity.



**Fig. 6.** Annual mean surface runoff distribution across the watershed

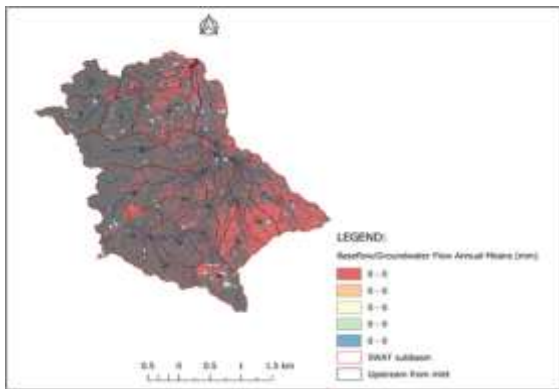
Studies show that land conversion, reduced forest cover, and impervious or degraded surfaces significantly increase runoff generation in SWAT-based watershed simulations (Bieger *et al.*, 2017; Tumsa *et al.*, 2022).

High-runoff subbasins may face greater risks of flooding, channel erosion, sediment transport, and nutrient export during intense rainfall events. These areas should be prioritized for soil and water conservation measures, such as reforestation, contour farming, riparian buffers, and infiltration-enhancement practices. Lower-runoff areas may provide more hydrologic buffering capacity. Under projected climate change with more intense rainfall, runoff-prone zones may become increasingly vulnerable.

### Spatial distribution of annual baseflow/groundwater flow in the ipil watershed

Fig. 7 shows the annual mean baseflow or groundwater flow distribution. The legend indicates values of 0 mm across mapped classes, suggesting that the calibrated SWAT+ simulation produced negligible or no groundwater contribution to streamflow across the watershed. This result implies that subsurface flow processes were either minimal in the current parameterization or not adequately captured by the model inputs and calibration settings. In watershed hydrology, baseflow is typically a critical component sustaining river discharge during dry

periods, especially when rainfall and direct runoff are absent. Recent SWAT+ studies note that groundwater processes are sensitive to aquifer parameters, percolation settings, soil depth, and recharge estimates, and can be underestimated when subsurface data are limited (Bailey *et al.*, 2025; Zhang *et al.*, 2023). The near-zero baseflow suggests that the model's dry-season streamflow may be underestimated, which can affect water availability assessments during drought or low-rainfall months. This also indicates a need for further refinement of groundwater parameters, soil hydraulic data, and recharge processes. For management purposes, reliance solely on modeled surface water may overlook important groundwater resources. Future scenario analyses should improve groundwater representation to produce a more complete water balance.

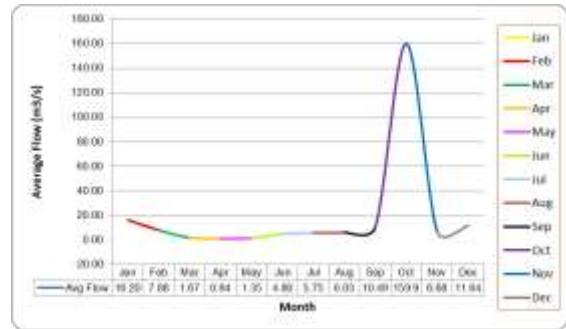


**Fig. 7.** Annual mean baseflow or groundwater flow distribution

**Temporal distribution**

Temporal analysis indicates a strong seasonal pattern in water availability within the watershed. Peak flows occur during the rainy season, characterized by high-intensity precipitation events, while significantly reduced flows are observed during the dry season (Fig. 8).

The hydrograph shows pronounced variability, with extreme peak flows followed by prolonged low-flow periods. This suggests that water availability is highly dependent on rainfall patterns, making the watershed vulnerable to both flooding and water scarcity.



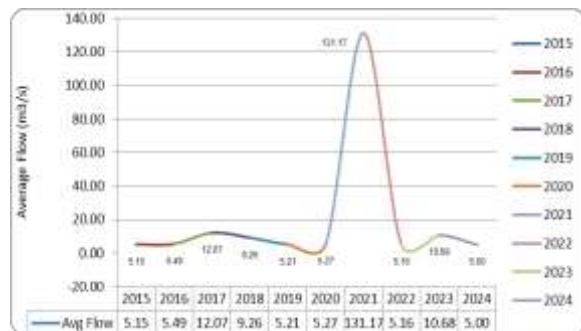
**Fig. 8.** Annual temporal distribution

**Annual average flow of the ipil watershed (2015–2024)**

Most years recorded relatively low and stable average flows ranging from 5.00 to 12.07 m<sup>3</sup>/s, specifically in 2015, 2016, 2017, 2018, 2019, 2020, 2022, 2023, and 2024 (Fig. 9). However, a sharp and exceptional increase was observed in 2021, with average flow reaching 131.17 m<sup>3</sup>/s, the highest discharge of the 10-year period. Flow then declined abruptly in 2022 to 5.16 m<sup>3</sup>/s, followed by a moderate increase in 2023 (10.68 m<sup>3</sup>/s) before decreasing again in 2024 (5.00 m<sup>3</sup>/s). The generally low interannual flow in most years suggests that the watershed typically experiences moderate discharge, while the extreme spike in 2021 indicates an anomalous hydrological event, such as intense rainfall, prolonged storm activity, or tropical cyclone influence. In tropical regions like the Philippines, annual streamflow variability is strongly influenced by monsoon rainfall, tropical cyclones, and interannual climate oscillations such as El Niño–Southern Oscillation (ENSO), which can intensify flood-producing rainfall or drought conditions (David *et al.*, 2019; Cinco *et al.*, 2022). The extreme 2021 discharge indicates that the Ipil Watershed is vulnerable to sudden high-flow events, which may increase risks of flooding, channel erosion, sediment transport, and damage to downstream communities or infrastructure.

At the same time, persistently low flows in most years suggest potential constraints on water availability in both normal and dry years. These findings highlight the need for adaptive watershed management strategies, including flood mitigation planning, streambank stabilization, and dry-season water

storage systems. Future climate projections indicating more intense rainfall extremes in Southeast Asia may further amplify such variability.

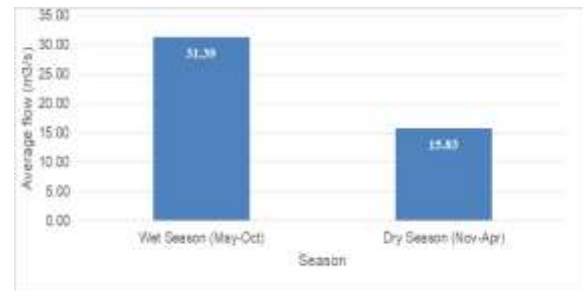


**Fig. 9.** Annual average flow of the ipil watershed (2015–2024)

### Seasonal average flow of the ipil watershed

Fig. 10 compares the average streamflow between wet and dry seasons in the Ipil Watershed. The wet season (May–October) recorded a substantially higher mean flow of 31.39 m<sup>3</sup>/s, while the dry season (November–April) had a lower mean flow of 15.83 m<sup>3</sup>/s. This indicates that streamflow during the wet season is nearly double that of the dry season. The higher wet-season flow reflects the strong influence of rainfall inputs during the southwest monsoon and tropical weather systems, which increase runoff generation and channel discharge. In contrast, reduced rainfall during the dry season limits surface runoff and stream recharge, resulting in lower flows.

This seasonal hydrologic pattern is typical of Philippine watersheds where rainfall seasonality strongly controls streamflow response (Cruz *et al.*, 2017). The strong contrast between wet- and dry-season flows suggests that water availability in the Ipil Watershed is highly seasonal. During wet months, excess flows may increase flood risk but also offer opportunities for water harvesting and storage. During dry months, lower flows may constrain domestic, agricultural, and ecological water demands. This means watershed planning should include seasonal water allocation strategies, rainwater storage, small impounding systems, and watershed rehabilitation to enhance infiltration and sustain dry-season baseflow.



**Fig. 10.** Seasonal trends (wet and dry seasons)

Under future climate change, longer dry spells and more intense wet-season storms may further widen this seasonal imbalance.

### CONCLUSION

The study demonstrated that the SWAT+ Model is an effective tool for evaluating the hydrological behavior of the Ipil Watershed. Calibration significantly improved simulation performance by decreasing overestimated surface runoff and increasing evapotranspiration, resulting in a more realistic watershed water balance. Spatial results showed that water yield and runoff vary among subbasins, indicating that some areas contribute more to streamflow generation and flood potential than others. Temporal results confirmed strong annual and seasonal variability in water availability, with peak discharge in 2021 and substantially higher flows during the wet season compared to the dry season. These findings suggest that the watershed is vulnerable to both flooding during high-rainfall periods and reduced water availability during dry months. Although the model effectively represented surface hydrological processes, the absence of groundwater and baseflow outputs indicates the need for further refinement of subsurface parameters. Therefore, the study provides valuable baseline information for improving watershed planning, water security, and climate resilience in the Ipil Watershed.

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