

Modelling Base flow Enhancement in Response to Soil and Water Conservation Measures using QSWAT+ in the Northeastern Highlands of Ethiopia

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Abstract

Land degradation has a significant impact on the Northeastern highlands of Ethiopia, resulting from topographic complexity, intensive cultivation, poor land-use management, and erratic rainfall. As the water deficit is one of the limiting factors for rainfed agriculture, it worsens the scenario in drought-prone areas. Irrigation from stream base flow is considered as a solution to reduce moisture shortage in the Northeastern highlands to support agriculture and sustain rural livelihoods. However, recurrent drought, land degradation, and low dry period base flow have a significant negative impact on the availability of water for irrigated agriculture. To solve such problems, massive watershed scale soil and water conservation projects has been implemented on the highlands of Ethiopia since 2010. Despite significant investment in conserving soil and water resources at watershed scale, most watershed treatments lack impact evaluation and estimation of enhanced base flow. To fill this gap, the QSWAT+ model was used to analyze hydrological phenomena and assess how watershed changes impact the hydrological cycle using 17 years of meteorological input data with the specific objective to compare base flow enhancement on paired micro-watersheds, Amanuel and Degnu, in response to watershed treatment. The results indicate that watershed treatment could enhance 79% of the base flow due to 47% of the watershed treatment. QSWAT+ successfully models baseflow, achieving Nash-Sutcliffe Efficiency (NSE) values of 0.92in both, and Coefficient of Determination (R^2) values of 0.93 and 0.92 for Amanuel and Degnu, respectively. The model results help effectively allocate water resources and implement sustainable watershed management practices.

Keywords : Baseflow, Micro-watershed, QSWAT+, Soil and Water Conservation
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1. INTRODUCTION

Land degradation is the principal environmental global problem, including in the most developed countries like USA and China (Adugnaw, et al., 2018; Ali & Surur, 2012; Berihun, et al., 2020; Guzman, et al., 2013), which is caused by human intervention in food, shelter, and energy demands (Boyd, et al., 2000; Dabi, et al., 2017; Igwe, et al., **2017**). Land degradation leads to the loss of fertile soil, water, and forest resources at an alarming rate (Guzman, et al., 2013; Haileslassie, et al., **2005;** Abraha, 2009; Marie-Agnes, et al., 2014), and that will have negative impact on the growth and development of future generations. The Ethiopian highlands are one of the most degraded regions in the world (Adugnaw, et al., 2018; Berihun, et al., 2020; Dubale, 2001; Pla, 2014; Shiferaw & Holden, 1998**).** Human activities such as uncontrolled grazing, massive deforestation, and removal of crop residues by burning biomass, and intensive cultivation for a long period of time without treatment, are the major factors that facilitate land degradation to limit rainfed agriculture (Adugnaw, et al., 2018; Bashir, et al., 2018**).** This is because soil erosion contributes to the loss of precious soil resources (Dabi, et al., 2017; MOA, 2016; Abebe, 2018) that are the basis of agricultural production and provide numerous other ecosystem services. Land degradation impact is critical in the Northeastern highlands of Ethiopia, resulting from topographic complexity, intensive cultivation, which removed land cover, poor land use management techniques, and erratic rainfall patterns (Melese, et al., 2023). As the water deficit is the biggest limiting (Yihun, et al., 2016**),** and the greatest challenging (Tilahun, et al., 2011) factor for sustainable agricultural development in Ethiopia, it will be the worst scenario in drought prone areas like northeastern highlands.

Irrigation from surface and subsurface sources is considered as a solution to reduce moisture shortage in the northeastern highlands to support agriculture for sustainable rural livelihoods (Altchenko & Villholth, 2015). Irrigation from stream flows, springs, deep and shallow wells, rainwater harvesting, and highland lakes are the major water sources (Awulachew, et al., 2008). When compared with rainwater harvesting and surface dams, irrigation from streams and spring flows (base flow) provides comparative advantages for agricultural development. However, recurrent drought occurs at about three-year return intervals (Abduselam, 2017), associated with land degradation, high surface runoff due to land degradation, and low groundwater recharge in the main rainy season, have significant negative impact on water availability in the dry period (Nyssen, et al., 2010), which affects agricultural production using irrigation.

Moreover, Rainfall variability spatially and temporally, and extreme events like drought and flood resulted from climate change critically affected the availability of water in the dry season (Wakjira, et al., 2020). As a result of these factors, availability of water critically influences the local community in northeastern highlands (Nyssen, et al., 2010) making the highland farmers travel long distances in search of water for different purposes including rainfed agriculture which is one of the highly dependent water availabilities and most affected sectors by moisture deficit.

To combat such problems different interventions were implemented in most of the watersheds of the Northeastern highlands of Ethiopia aiming at reducing water deficit for agriculture (Adugnaw, et al., 2018), and enhance stream base. Soil conservation measures are the most common techniques for converting excess rainwater(runoff) into soil moisture and groundwater reserves to achieve sustained base flow in the dry season (Mohammed, et al., 2025). Despite the huge amount of implemented soil and water conservation structures on the highlands, the hydrological responses to land management practices are not yet quantified (Adugnaw, et al., 2018; Igwe, et al., 2017), and are not well-documented (Nyssen, et al., 2010).

Conducting a comparative study on the hydrological response to land management practices to enhance base flow is, therefore, imperative (Nyssen, et al., 2010; Mohammed, et al., 2025), and has to be evaluated and compared the treatment with the control (untreated watershed) (Mohammed, et al., 2025; Mulatu, et al., 2020). Currently, Hydrological models have been applied extensively around the world for the last three decades at the watershed level to monitor the hydrological responses to soil and water conservation (Fathia, et al., 2023; Mulatu, et al., 2020). In recent years, watershed-scale modeling has become an important scientific research and management tool, particularly for understanding hydrological processes at the watershed level.

Modeling the hydrological response to SWC measures is, therefore, essential for a reliable assessment of their impacts at the watershed level (Majed, 2009; Muhidin, et al., 2025; Sitterson, et al., 2017). Determining the primary drivers of hydrological systems and modeling processes, such as groundwater recharge and base flow, is one of the crucial aspects of watershed management. Modeling helps gain a better understanding of hydrologic phenomena and how changes on the watershed affect the hydrological cycle (BYU, 2018; Sitterson, et al., 2017), and is used to visualize what occurs in water cycle due to changes in watershed characteristics and meteorological events (Muhidin, et al., 2025).

Hence, this research was carried out to evaluate the base flow in responses to watershed treatment on paired micro-catchments with the specific objective of evaluating the impact of watershed treatment on base flow enhancement.

2. MATERIALS AND METHODS

2.1 Location of the study area

This research was carried out at paired micro-watersheds of Yewel Mountain, Degnu and Amanuel, in Wereillu Woreda of Amhara Regional State, Ethiopia (**Figure 1**). Degnu extends from $10^0$50’00” to $10^0$52’00” N latitude and $39^0$26'20" to $39^0$27'23" E longitude with an altitude range from 2860 to 3160 m.a.s.l., Amanuel micro-Watershed covers from$10^0$50’23" to $10^0$52’07" N latitude and $39^0$25’37" to $39^0$26’30" E longitude with an altitude range of 2880 to 3260 m.a.s.l

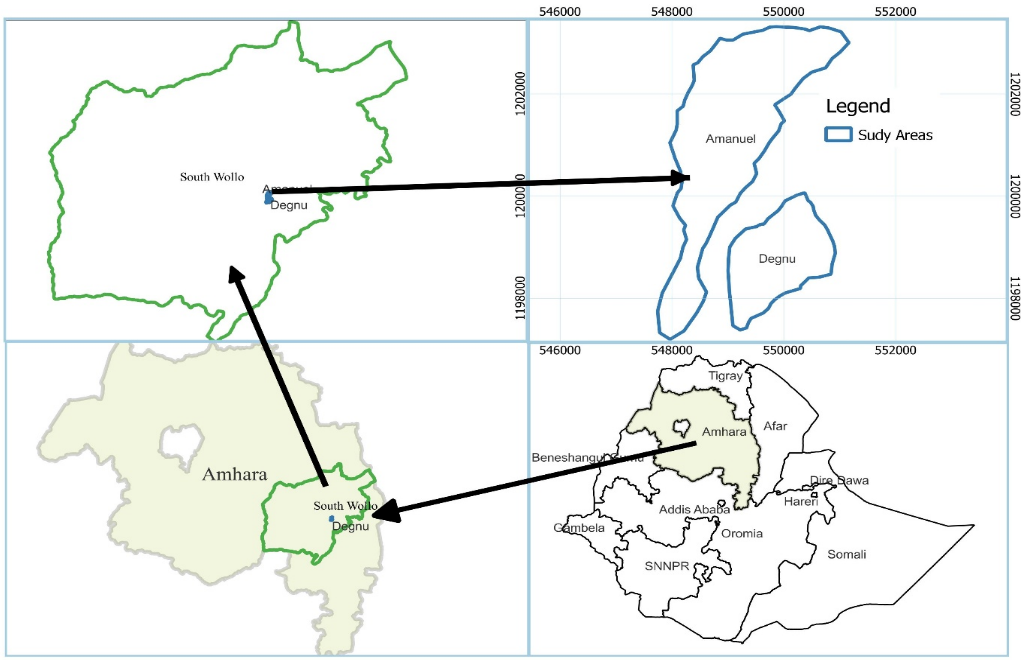

Fig 1. Location map of the study areas

2.2 Approaches

The approach to data collection and analysis was based on the conceptual model developed to understand the hydrologic cycle (**Figure 2**). The water balance equation governs the hydrological cycle by describing the flow of water into and out of a system for a specific period. **Figure 2** indicates that there are two outputs and one input component with reference to the watershed boundaries. The input component crossing the conceptual boundary is precipitation, while the output components are evapotranspiration and streamflow (surface runoff and base flow) exiting the watershed boundaries (Muhidin, et al., 2025).

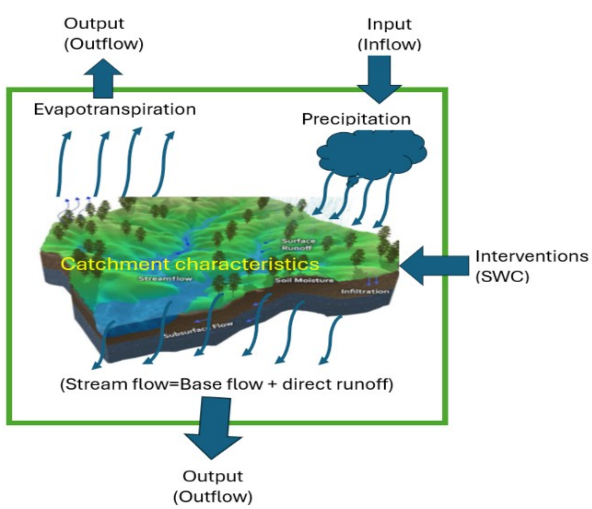

Fig. 2 Schematic diagram of the simplified water cycle

Adjacent micro-watersheds in the same agro-ecological settings are assumed to have similar evapotranspiration or have no significant difference in hydrologic responses to SWC measures (Muhidin, et al., 2025). The components that were responsible for the base flow variation of the micro-catchments are catchment characteristics and catchment (Mohammed, et al., 2025).

Thus, watershed characterization and treatment level inventories were made to easily compare the stream base flows between the two micro-watersheds in responses to watershed treatments. Watershed characterization helps to identify the existence of similarities or differences in the watershed parameters, such as watershed morphologies, land use, and slope classes (Mohammed, et al., 2025), and other parameters between the two micro-watersheds in which hydrological responses are dependent (Muhidin, et al., 2025). Hence, before comparing the base flow between the treated and untreated micro-watershed, characterization and treatment level inventories was carried out at each study sites. Watershed characteristics were identified to be similar while watershed treatment, which is the cause of variation in both dry and wet seasons, was significantly different.

2.3 Watershed Characterization

Micro-watersheds situated in the same agrological settings are assumed to have closely related landscape descriptions and, therefore, have comparable hydrological responses (Muhidin, et al., 2025). Major parameters were calculated and analyzed to see the difference and similarities between the two micro-watersheds.

Drainage pattern: Digital Elevation Model of resolution 30 by 30 m was used to generate drainage patterns and streamlines in QGIS 3.28 interface with ground truthing and drainage patterns for both micro-watersheds were generated and found to have 2nd - level stream order in Strahler's system (Mohammed, et al., 2025).

Topography: The same digital map, as the drainage pattern, was used to generate topographic/landform maps of the study sites. Rolling plain at the bottom and a hilly slope near the upper part are the major landform in both cases includes in (Muhidin, et al., 2025).

Watershed Morphology: If the watershed and hydrologic characteristics are related, quantitative indices must also represent the watershed form (Muhidin, et al., 2025). These indices were extracted from measured parameters and were calculated from measured data, but some of them were found by simply counting from the maps.

Land use/land cover: The two micro-watersheds have similar patterns in their land use/ cover with dominate areas covering cropped areas. Land use/cover and slope class distribution of the micro-watersheds.

Soil: The soils of both micro-watersheds are extracted from the national grid soil map of the Amhara region using the zonal statistics method in the QGIS 3.28 interface (Mohammed, et al., 2025). ***Soil textural*** **classes** were determined from particle size (clay, silt, and sand), ***extracted*** from the same grid map as soil types, using the soil textural triangle (Muhidin, et al., 2025). The textural class identified in both watersheds is Sandy loam, Silty clay loam, clay and Clay loam (Mohammed, et al., 2025). ***Soil depth*** in both the micro-watersheds ranges from deep to very deep (>150cm) in the lower part, and medium to shallow (<25 cm) soil in the upper part of both micro-watersheds (Muhidin, et al., 2025). ***Soil Bulk Density*** (BD), ***Soil carbon*** content (SOC), and ***Soil PH*** (PH) were also extracted from the national soil map of the Amhara region in the zonal statistic method. ***Available water*** content was taken from Hailu et al.,(**2015**) and standard table from literature was used to extract ***Hydrologic soil groups*** (HSG) values.

Climate: 30 years (1992-2022) rainfall data of Kabe station (just a few kilometers downstream of the research sites) was obtained from the Ethiopian National Meteorology institute. The data indicates that annual rainfall is about 844.67mm. The station record indicates the maximum annual rainfall is about 1,172 mm and the minimum was 436.60 mm.

Daily rainfall data was recorded using manual raingauge from 22/11/2020 to 8/11/2022), on both study sites for calibration and validation. Long-term (1992-2021) temperature data show that the mean daily minimum and maximum air temperatures are 8.73 and 18.38°C, respectively (Muhidin, et al., 2025).

Area Coverage of SWC measures: Physical soil and water conservation measures including soil bunds, stone-faced soil bunds, and loose stone check dams have been implemented in the Degnu micro-watershed since 2011 (Muhidin, et al., 2025). Physical soil and water conservation structure generated from the Google Earth Image of 2021 "***on-screen digitizing"*** method about covered about 47.21% and 6.91% of the total area at Degnu and Amanuel respectively.

2.4 Field Data Collection

2.4.1 Precipitation Data Collection

Manual raingauges were installed at/near the center of both micro-watersheds to collect precipitation data for this research period and compare it with the long-term data of the Kabe station. Daily rainfall data was collected every morning at 8:00 A.M except at the times of rainstorms and the data collection records were delayed until the rain stopped (Mohammed, et al., 2025). The data collectors recorded the depth of water in the rain gauge using the graduation on the manual raingauge itself and emptied the content after each record. The time interval between rainfall events was defined as being more than 6 hours; otherwise, it was considered the same rainfall event. Daily rainfall data were collected from 22/11/2020 to 8/11/2022 with some interruption from 26/10/2021 to 02/01/2022 due to the prevailing civil war in the study area (Mohammed, et al., 2025). The rainfall collected at each research site was compared with the rainfall at Kabe Meteorological Station data to test data similarity and the result indicates that the rainfall of the research sites is similar with the main Kabe Meteorological Station data.

2.4.2 Stream Flow Measurement

Stream gauging stations were established at the outlet of both micro-watersheds to measure stream flow discharges. Stream flow data were collected on the same date as the rainfall data collection period. A broad crest weir made from a masonry wall, as wide as the stream outlet, was constructed across the outlet of both streams to guide the stream flow over the weirs. The impermeable bedrock prevents groundwater outflow below the weir. As a result, all the stream flows (base flow and surface runoff) leave the micro-and watershed as the stream flows over the weir and Wooden staff, on which a steel meter was fixed, were used to measure the depth of water over the weir vertically (Muhidin, et al., 2025). The water depth measurement of the steam flow over the weir was done at 8:00 A.M. every morning and every 20 minutes during the flood events.
The depth of water over the weir was also converted to stream flow discharge based on the known weir formula given by:

$$Q=CBd^{3/2} \text{---} (1)$$

Where Q is the stream flow discharge (m^3/s), B is the width of the weir crest, length equal to the bottom width(m), d is the upstream head (water depth) measured from the bottom(m), and C is the discharge coefficient(unitless) (Muhidin, et al., 2025). Some literature recommended C to be 1.71 for broad-crested weirs. However, most researchers recommended that the calculated values are better than taking fixed literature values (1.71). Broad-crested weir calculator was employed to generate the discharge coefficient values given by:

$$C = 1.0929 * \left[\frac{1-0.2222}{1+\left(\frac{H_1-\Delta Z}{L_{crest}}\right)}\right] \text{--} (2)$$

where C is the Coefficient of discharge(unitless), H_1 is the water height at the approach channel, ΔZ is the weir height, and L_{crest} is the Length of the weir along the flow, all in SI units.

2.4.3 Data normalization and testing

In many applications of data-driven comparisons, the hydrological variable to be analyzed and compared needs to be in the proper input structures (Gerald & Dimitri, 2007). In this study, micro-watersheds (Amanuel and Degnu) vary in size, which affects the final output or model results water balance including stream flow (Mohamoud, 2004). However, comparing small watersheds is better than large watershed comparisons, for large watersheds create more variability because of the differences in watershed parameters such as drainage area size, land use and slope. In contrast to large watersheds, small watersheds give better results because they have similar landscape descriptors (Mohamoud, 2004). Thus, comparison of the model results was done either on normalization (value per unit area) basis or depth units to avoid drainage area size factor. As most of the model results are in depth unit(mm) for most parameters, depth units are adopted for comparison of outputs.

An Independent T-test was also applied on normalized data for mean comparisons to see the statistically significant difference between the input parameters of watershed characterization and land scape descriptors in both micro-watersheds before conducting the hydrological output comparison in response to soil and water conservation practices. SPSS ver. 21 was used to test the statistically significant differences between the variables to be compared (Gerald & Dimitri, 2007).

2.5 Model Selection

There are many different types of models to simulate hydrological processes, with some working better in certain situations than others (Muhidin, et al., 2025). Comparing models for hydrological process simulations to real-world water balance is a challenge (Smith, 2008). An important question to be addressed is to select the appropriate model that gives closest result to real-world values (Kikoyo & Oker, 2023). However, models differ in terms of complexity, data requirements, underlying equations, assumptions, and performance in simulating hydrological processes (Sitterson, et al., 2017).

Reviewing data requirements, physical meaning, user-friendliness, and spatial resolution are all necessary to determine which model type should be selected (Muhidin, et al., **2025)**. The Soil Water Assessment Tool (SWAT) and Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) models are widely recognized in the literature for their robustness and applicability in hydrological simulation**s** (Imiya, et al., 2022)**.** SWAT and HEC-HMS are commonly used for hydrological analysis and environmental risk assessment, developed as a river basin scale model suited for large complex watersheds (Imiya, et al., **2022**; Miguel, et al., **2024**)**.**

For this study, the QSWAT+ model, an extension of QSWAT, was selected because of its simplicity, minimal parameter requirement, user-friendliness, spatial flexibility, applicability to small micro-watersheds (Sitterson, et al., **2017),** and consideration of different components of the outputs (Imiya, et al., **2022),** such as surface runoff, soil moisture content, groundwater recharge, base flow and some more outputs (Muhidin, et al., **2025**)**.**

QSWAT+ model is a semi-distributed watershed-scale continuous-time model that operates on hourly, daily, monthly and annual steps at a smaller micro-watershed (Patricia, et al., **2021**)**.** QSWAT Plus is a QGIS plug-in to create, run, and visualize the SWAT result (Imiya, et al., **2022**). QGIS is an open-source public-domain software(**https://qgis.org**) capable of executing hydrological processes at the watershed level (Chris, **2023**). Even though SWAT and HEC_HMS models are used in modeling in a small watershed up to 1.62 km^2(162 ha), the QSWAT+ model has a better performance in modeling hydrological processes (Imiya, et al., **2022)** at even a smaller spatial scale, as small as 0.066 km^2 (6.6 ha), which actually represents the size of farmlands in the agricultural sector (Kikoyo & Oker, **2023**)**.** When compared to the HEC_HMS and older SWAT, QSWAT+ model has a comparative advantage over them in modeling small micro-watersheds at daily timesteps (Muhidin, et al., **2025**)**.**

Currently, QSWAT+ is the latest model applied for watershed-based hydrologic analysis because of its capability to accommodate various outputs (Muhidin, et al., **2025;** Yihun, et al., **2023**). Moreover, SWAT+ adopts most of the theoretical and empirical equations and assumptions in the old SWAT model, with a few significant changes incorporated in it to address some of the limitations in older version of SWAT (Kikoyo & Oker, **2023**)**.** QSWAT+ has been developed to quantify the impact of land management practices on both large, complex, and simple small watersheds on various time steps (Muhidin, et al., **2025**), and allows a basin to be divided into subbasins based on topography to incorporate spatial details in small micro-watersheds (Johnson, 1**962**)**.** Each subbasin is further divided into hydrological response units (HRUs), which are unique combinations of slope, soil, and land cover (Muhidin, et al., 2025), and individual HRUs are simulated independently, area-weighted, and added for each subbasin, to route through a stream network to the basin outlet.

2.6 Model application.

2.6.1 Input data and model structure.

The inputs for QSWAT+ model are Digital Elevation Model (DEM), Land use & Soil Maps, and Meteorological data. DEM_30 is freely available from the ASTER satellite digital data. Land use maps of both micro-watersheds were generated from Google Earth in 2021 by the "***on-screen digitizing***" method and saved as a KML file (Muhidin, et al., **2025**), and converted to layers for compatibility with the QGIS interface. Soil maps were extracted from Amhara regional soil grid using zonal statistics meths in QGIS. All maps were converted into a similar projection system (UTM projection). Land use and soil maps were generated as shape files, all larger than the actual watershed boundary, to avoid shortfall of the DEM-30 layers during the watershed delineation process in running the QSWAT+ model. Finally, the shape files of land use and soil maps were rasterized using the QGIS analysis tool (Muhidin, et al., **2025**). Soil parameters and climate data were used as input for QSWAT+. **Figure 3** indicates the structure of the QSWAT+ Model.

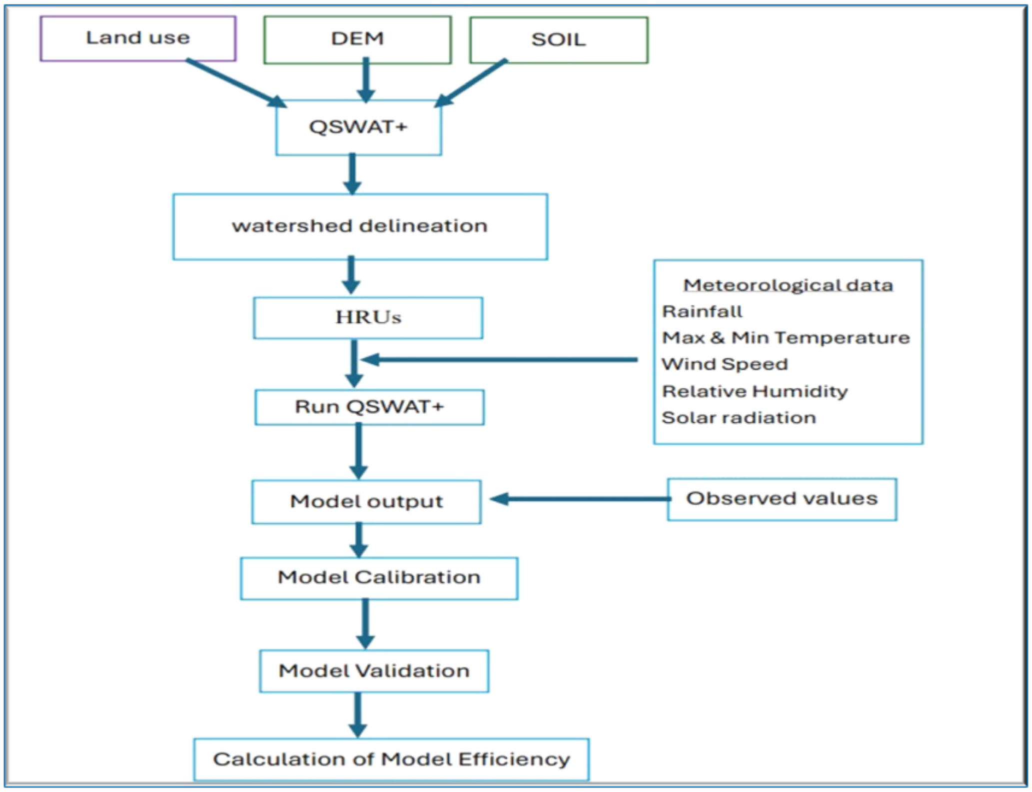

Fig. 3 Model structure for SWAT plus

After model selection, QSWAT+ was provided with input files (Met. data) in the form of a table in CSV format and raster maps of DEM, land use and soil with its look-up table to generate the output from both micro-watersheds. Two years of warmup periods were established for running this model. After the first run, adaptation (input modification) was made for the best fit of the output, and the model was re-run.

2.7 Model Output

2.7.1 Model Calibration

Before conducting calibration of parameters, sensitivity analysis was performed (Table 2) with selected parameters (cn2, alb, alpha, esco, epco) chosen based on a review of the existing literature (Muhidin, et al., 2025) in the "**Latin hyper-cubic one factor at a time**" method with the objective function of ***Nash-Sutcliffe Efficiency*** *(*NSE), PBias and Coefficient of determination(R^2). However, the relative sensitivity of parameters is dependent on the variables included in the objective function and the time step considered (Ana, et al., 2020)**.** After running the sensitivity analysis, the most sensitive parameter was the curve number (nc2), which was used for parametric calibration.

Table 2. Sensitivity analysis result of the micro-watersheds

watershed	group	Change type	Name	Sensitivity
Amanuel	hru	percent	cn2	0.792
	hru	replace	epco	0.003
	hru	replace	esco	0.17
	sol	replace	alb	0.0002
	aqu	replace	alpha	0.04
Degnu	hru	percent	cn2	0.974
	hru	replace	epco	0.013
	hru	replace	esco	-0.001
	sol	replace	alb	0.00001
	aqu	replace	alpha	-0.002

Following the sensitivity analysis, model calibration was carried out, and the model was re-run for new values to find a "**best range**" for the calibrated parameter and ensure high-quality simulations with the specified objective functions. Calibration and validation periods were established in SWAT+ Toolbox V.2.3 following the split-sample approach, by dividing the period into two, 22/11/2020 – 25/10/2021 for calibration, and 03/01/2022 – 08/11/2022 for validation. Stream flow Calibration was conducted at a daily-time step in the **Latin-hypercubic Sampling Iteration** (CALSI) algorithm. Both the calibration and validation periods comprise dry and wet seasons to assess parameter timescale transferability. Table 3 indicates the values of the specified objective functions in the model calibration. Similar results are documented in (Mulatu, et al., 2020; Kikoyo & Oker, **2023**)**.**

Table 3. The value of objective functions after calibration

Watershed	group	Name	Abs. Min	Abs. Max	Best Value	NSE	MSE	RMSE	P Bias
Amanuel	HRU	cn2	35	95	2.98	0.91	0.006	0.078	21.74
Degnu	HRU	cn2	35	95	5.06	0.95	0.000	0.013	7.33

2.8 Model Testing/Validation

As discussed in (Gezahegn, et al., **2025**)**,** model validation is one of the most important steps in water balance modelling. Model validation is testing calibrated model findings using independent datasets without making any additional adjustments of the model parameter (Gezahegn, et al., **2025**)**.** The performance of the calibrated model in the validation period provides us confidence in modeling results when calibrated model is used for simulating stream flow outside the measured period. When the model is used for predicting streamflow under future climatic change scenarios, it has to be tested/validated. Hence, the final calibrated parameter ranges must be assessed for the validation periods with the same number of simulations as the calibration iterations. Therefore, parameter sets sampled from the final calibrated ranges were assessed in terms of model goodness-of-fit statistics (NSE, PBias and R^2). It is recommended that the "b***est simulation***" is the simulation with one single set of parameters that yielded the best objective function value (Muhidin, et al., **2025**)**.** In this study, the simulation achieving the highest average objective function value was selected. Considering the streamflow at gauging station, it was preferred to set the stream flow as the "***best simulation***" in NSE, R^2 and PBias to evaluation of model performance. The Nash-Sutcliffe coefficient (NSE), Determination Coefficient (R^2) and percent bias (P bias) are internally calculated by the model to evaluate the performance of the model, and manually calculated by:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2} \quad \text{--(3)}$$

Where O_i is observed value for time i, P_i is the predicted value for the same period, O_{avg} is the average of observed values for the same period, and n is the number of observations in the time intervals. The coefficient of determination, R^2 provides how-well the correlation between measured and simulated value (Muhidin, et al., **2025**)**,** and is calculated as:

$$R^2 = \left(\frac{\sum_{i=1}^{n}(O_i - O_{avg})(P_i - P_{avg})}{\left[\sum_{i=1}^{n}(O_i - O_{avg})^2 \sum_{i=1}^{n}(P_i - P_{avg})^2 \right]^{0.5}} \right)^2 \quad \text{--(4)}$$

where additional parameter P_{avg} is average of the predicted values. PBias determines the average tendency of simulated data to be greater or lesser than their observed counterparts, the ideal value of P Bias is zero (Sitterson, et al., 2017)**.** The P Bias is also calculated as:

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i)100}{\sum_{i=1}^{n} O_i} \quad \text{--(5)}$$

Different literatures put reference values for the performance rating of the model parameters as "***very good***", "***good***", "***satisfactory***" and "***unsatisfactory***" (Gezahegn, et al., **2025**; Johnson, **1962**)**.** These ratings, however, are not strict, and the objective of the study and site conditions, as well as the model size area, must be taken into account when model performance is evaluated (Joseph, et al., **2019**)**. Table 4** shows the general performance rating values of the objective function.

Table 4 General performance rating for recommended statistics (after Gezahegn et al 2025)

Performance rating	NSE	PBias	R^2
Very good	0.75 <NSE <1	PBias < ± 10	$0.75 < R^2 < 1$
Good	0.65 < NSE <0.75	±10 <P bias < ±15	$< 0.65\ R^2 < 0.75$
satisfactory	0.5 < NSE <0.65	±15 P bias < ±25	$0.5 < R^2 < 0.65$
Unsatisfactory	NSE <0.5	P bias < ±25	$R^2 < 0.5$

The result indicates that the model is performing well with NSE values of 0.92 at both micro-watersheds, and coefficient of determination (R^2) 0.92 and 0.93 at Degnu and Amanuel respectively. The P Bias also shows model performance values -0.12 and -0.13, all of which fall within a very good range in both watersheds. However, the values of models result and manually calculated slightly differed, i.e. model overestimated the values of NSE, R^2 and P Bias.

3. RESULT

3.1 Base flow enhancement

The QSWAT+ model offers more than 47 graphical and tabular outputs. The graphical outputs are in un-editable format while tabular outputs are in txt and CSV file formats, and editable for further analysis. Hence, the hydrological outputs are extracted from a CSV file of the model output. The model output indicates that normalized monthly base flow at treated micro-watershed is significantly higher than untreated one (**Figure 4**).

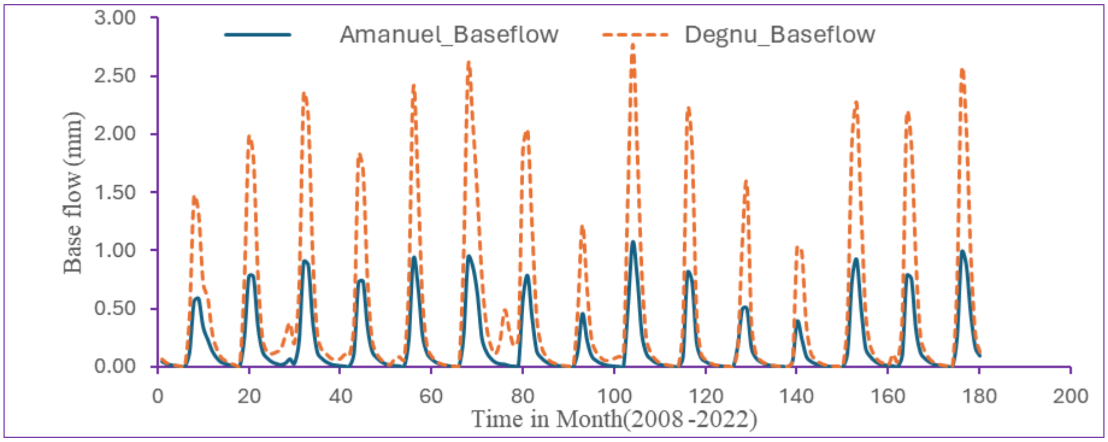

Fig. 4 Monthly Base flow pattern of the micro-watersheds

The base flow variations are clearly seen in the cumulative hydrographs (**Figure 5**). However, the total /cumulative base flow does not indicate which month of the year has better enhanced base flow for proper water allocation for different purposes such as domestic water supply, irrigation and risk assessment. The monthly distribution on normalized base flow is indicated in **Table 5**. This result indicated that the maximum difference in base flow is high in September, followed by August, October and November respectively.

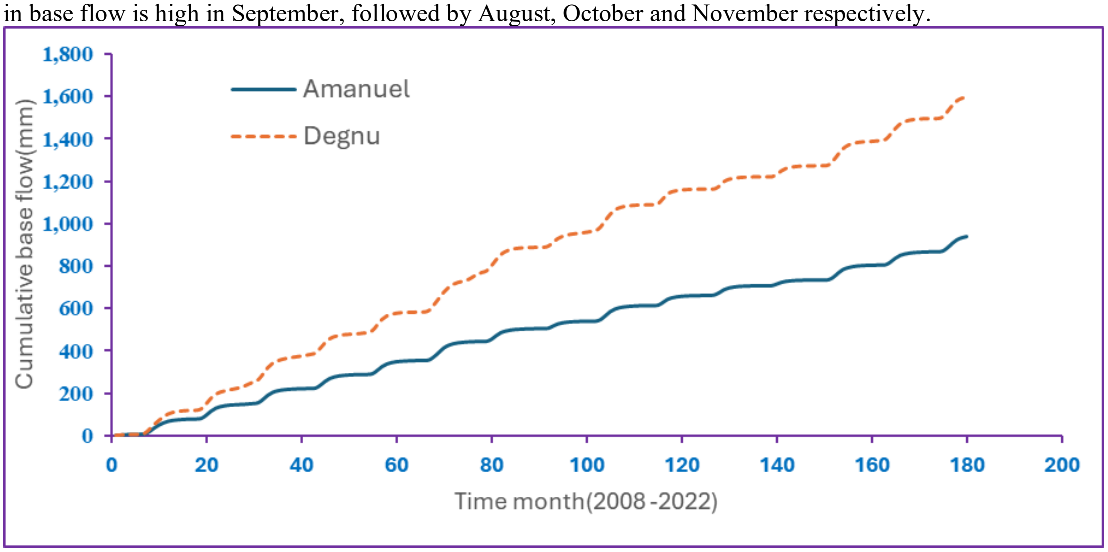

Fig. 5 Cumulative base flow of micro-watersheds

Table 5. Monthly base flow enhancement

Month	Amanuel	Degnu	Difference(mm)	Difference (%)
Jan	**2.54**	**4.61**	**2.07**	**81**
Feb	**1.43**	**2.72**	**1.30**	**91**
Mar	1.00	2.33	1.33	133
Apr	0.64	2.53	1.90	297
May	0.53	3.03	2.51	477
Jun	0.38	2.61	2.23	590
Jul	2.28	6.18	3.90	171
Aug	11.71	19.92	8.21	70
Sep	**15.97**	**24.21**	**8.24**	**52**
Oct	**12.43**	**19.75**	**7.32**	**59**
Nov	**7.05**	**12.28**	**5.23**	**74**
Dec	4.33	7.72	3.38	78
Mean	**5.02**	**8.99**	**3.97**	**79**

3.2 Flow Duration Curve (FDC)

The flow duration curve(FDC), a plot of the percentage of exceedance against stream flow, is a useful tool in appraising the watershed characteristics of drainage basins (Ridolfi, et al., 2018; Engda, 2009; Luan, et al., 2021), and was used to describe the flow variability at two paired micro-watershed of the study area (Berihun, et al., 2020). FDC is used to compare the hydrological responses between the treated and untreated micro-watershed at high flow conditions, represented by the Q_1 index, medium flow conditions represented by the Q_{50} index, and low flow conditions represented by the Q_{95} index (Mohamoud, 2004).

In this study, the total duration method is used to derive the area-normalized flow duration curves. From the model output analysis, the percentage of exceedance that daily flow exceeded the mean flow at the treated micro-watershed is about 28.18 %, whereas it is only 21.55% at the untreated micro-watershed. This shows that the treated micro-watershed has 6.63% more mean base flow than the untreated micro-watershed.

Figure 6 revealed that the FDC for untreated (Amanuel) micro-watershed has the highest Q_1 indicating high flood hazards while Degnu has a higher Q_{95} index which shows sustained base flow in the dry season.

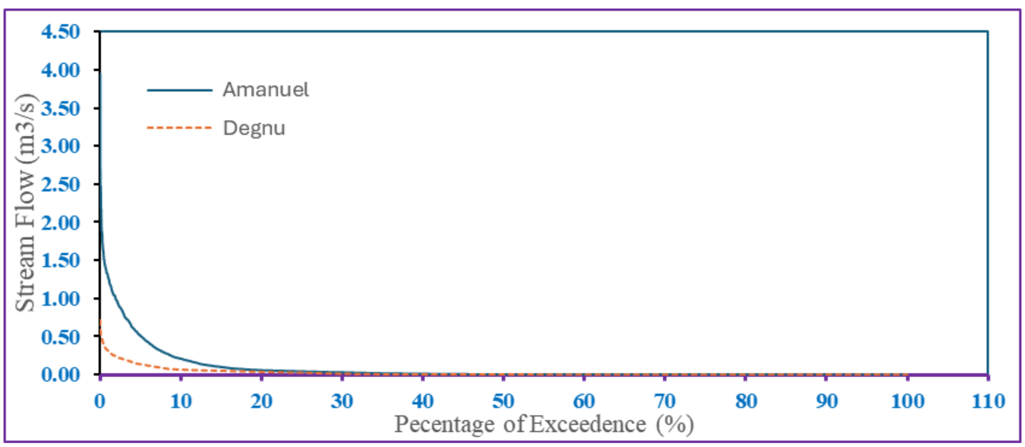

Fig. 6 Flow duration curve of the stream flow

4. DISCUSSION

4.1 Base flow enhancement

From tabular model output analysis, it was observed that higher total stream flows were obtained at untreated micro-watershed than the treated for all rainfall events that are attributed to watershed size. In comparing the hydrological response of paired micro-watersheds, variables should be in a similar context (Muhidin, et al., **2025)**. Micro-watersheds having different sizes have different total volumes of stream discharges. In large watersheds, heterogeneity is more than small watersheds because small watersheds show a high degree of homogeneity in landscape descriptors (Muhidin, et al., **2025)**. Thus, comparing small watersheds is better than comparing large watersheds. As discussed in Machado et al; (**2022),** large watersheds experience uneven rainfall distribution that often leads to an uneven distribution of stream flows whereas small watersheds have a tendency to have uniform distribution of rainfall, and their hydrologic response reflects uniformity in the entire watershed (Mohamoud, **2004)**. Hence, to make the comparison of the response reasonable and avoid the effect of size, all the stream flows were converted to specific/normalized discharges. Normalized discharges (L^3 Km^{-2}) were employed to avoid the influence of the watershed size in comparing hydrologic responses.

From the model result, maximum base flow was observed in September resulted from delayed stream flow at the end of the main rainy season which is attributed to watershed treatment. However, the most important component of the base flow is its monthly distribution which helps to allocate stream for different uses such as supplementary irrigation, domestic water supply and other water demands. In most cases, supplementary irrigation demand is in September and October whereas full irrigation water demand is in the dry season which extends from December to February. Thus, enhanced base flow in September and October is critical for supplementary irrigation water demand. The model output indicates that the enhancement of base flow in September, October and November is about 52%, 59% and 74% respectively in treated micro-watershed with total mean monthly base flow enhancement is about 79%, which is much higher in the treated micro-watershed when compared with untreated one (Table able5**)**. The model results demonstrate that watershed treatment has a significant influence on stream base flow.

The analysis at HRUs level is more detailed than sub-basin level results that indicates what happened at each combination of the parameters in the process of water balance analysis. The most important parameter that determines the water cycle in the watershed is the curve number. The model result demonstrates that the lower curve number exhibited at treated and higher at untreated micro-watershed. Low annual average curve number at Degnu (**68.26**) is the characteristics of low annual surface runoff components (***175.75*** mm) which is the result of watershed treatment whereas high area weighed curve number (**85.6**) at Amanuel resulted in higher annual surface runoff (***323.84*** mm). With the same rainfall, low surface runoff results in high groundwater recharge and higher dry period flow in the treated than untreated. The value of curve number is the result of land use/soil/slope combinations at HRUs level.

Maximum curve numbers (98.5) are exhibited in Urban Silt clay soil (URML/SICL/>30), grass silt clay (GRAS/SICL/>30) and Shrub Silt clay soils (SHRB/SICL/>30) with slope ranges more than 30% combination while the minimum (69.9) was observed in agricultural soils (AGRC/SL/15-30) with the slope ranges from 15 to 30% combination at Amanuel. The model indicates that urban/settlement areas, grass land and Shrub land with silt clay soil combination result in higher curve number values which in turn helps to generate high surface runoff and yielded low base flow. The maximum curve number (89.66) at Degnu was observed in Settlement with clay soil at slope greater than 30% (URML/CL/>30) combinations followed by agriculture with clay soil at slopes greater than 30%(AGRC/CL/>30) while the minimum curve number (41.79) is in the forest sandy loam soil at slope ranges 15-30% (FRST/SL/15-30) and forest at slope greater than 30%(FRST/SL/>30) combination. The model result indicates that settlement/ urban and agricultural lands with clay loam soil combinations at all slopes results in higher curve number values whereas the minimum values were exhibited in forest lands which agrees with the result of Elizabeth, et al., (**2013**). From both micro-watersheds, the most important determining factor for curve number is soil texture and land use. The contribution of slope is not significant to affect the curve number values.

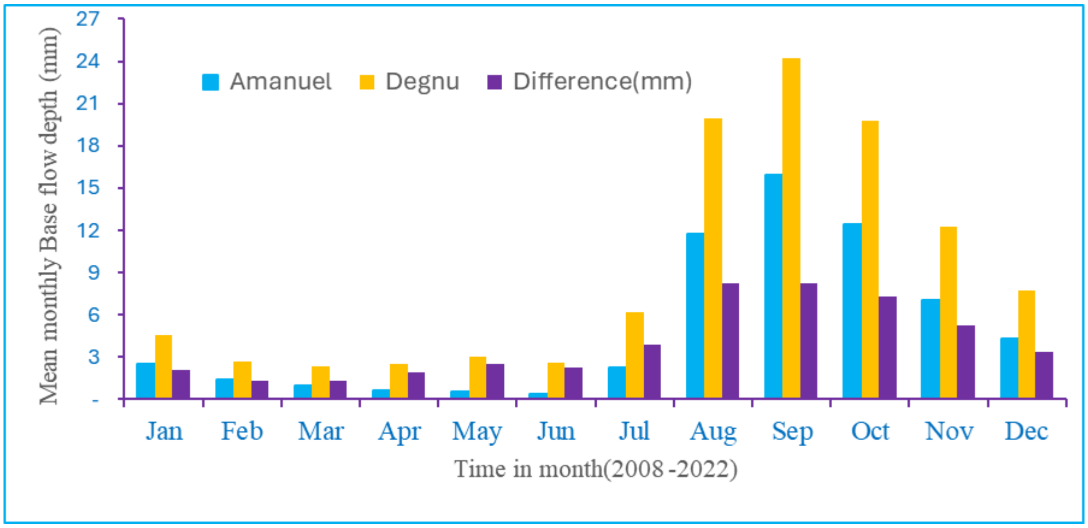

Fig. 7 Mean monthly base flow distribution(mm)

4.2 Flow Duration Curve (FDC)

Flow duration indices are the most widely used methods in comparing hydrological response at the watershed level (Mohamoud, 2004**),** and was used in this study to explain the hydrological responses of the micro-watershed study (**Figure 6**). Generally, FDC is applicable in water resource management at the basin scale for proper allocation of water for different uses such as domestic water supply, irrigation, flood risk management, industry, and other ecosystem services. The allocation of water, however, depends on the flow conditions (Muhidin, et al., 2025**).** Water resource allocation is commonly utilizing the low flow condition(Q_{95}) for ecosystem service, the medium flow condition(Q_{50}) for irrigation, and the high flow condition(Q_1) for flood risk assessment (Muhidin, et al., 2025**).** The model result indicates that the treated micro-watershed has better low flow condition which indicates the dry period flow was enhanced in the treated than untreated micro-watershed resulted from watershed treatment. The smooth curve of FDC in the treated watershed (Figure **6**) is the characteristics of sustained flow. Hence, watershed treatment helps to sustain dry period flow and reduce flood risks in the wet season.

5. CONCLUSION

In this research, 17 years (2006 to 2022) of Meteorological input data were used to run the QSWAT+ model in comparing the impact of SWC measures in two paired micro-watersheds. The results indicate that QSWAT+ successfully models surface runoff at a daily time step, achieving Nash-Sutcliffe Efficiency (NSE) values of 0.92 in both, and Coefficient of Determination (R^2) values of 0.93 and 0.92 for Amanuel and Degnu, respectively.

The model output indicates that treated (Degnu) micro-watershed generated more Specific base flow discharges in the dry season than untreated (Amanuel) one, which exhibited minimum specific discharge in the same period. The model results demonstrate that watershed treatment has a significant influence on groundwater recharge which in turn enhances stream base flow.

Treated micro-watershed shows smooth and gentle FDC depicting reduced surface runoff in the wet season and sustained flow in the dry season.

The model result offers valuable information for policymakers, land-use planners, and water resource managers in effective allocation of water resources for various uses based on flow conditions and seasons. Additionally, it can support the implementation of appropriate watershed management practices to promote the sustainable utilization of resources.

The authors recommended that this research can be further developed to include larger areas having the outlet moved downstream of the existing gauging site and incorporating the sediment outflow. Automating the data collection in rainfall, stream flow and sediment will improve the precision of the results.

Authors' Contribution

- **Mohammed Seid Muhidin-** Conceptualization, investigation, methodology, software application, validation, and analysis.
- Mekonen Ayana: Supervision, Evaluation and Editing
- Zelalem Biru Gonfa: Comment and Evaluation of the research
- Tena Alamirew Agumassie: Comment and Evaluation of the research
- Gizaw Dest Gessesse: Source supply and field materials provision

Declarations:

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Consent to publish: This manuscript is not published elsewhere or under consideration for publication.
Ethics approval: not applicable for watershed study

Data Availability Statement: All relevant data are included in the paper, and any supplementary information, if required, can be provided upon request from corresponding author.

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Conflicts of Interest: We declare that there is no conflict of interest in financial or non-financial matters among authors and other parties.

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