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Evaluating Sediment Prediction Capability of Two Hydrological Models in Ribb and Kessie Watersheds, Upper Blue Nile Basin, Ethiopia

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Abstract: In Ethiopia's Upper Blue Nile Basin, soil erosion, land degradation, sedimentation of reservoirs, shortening of the useful lives of infrastructure, & lakes and loss of agricultural soils are serious issues. The capacity to estimate the yield of sediment in the Ribb and Kessie watersheds is investigated using the parameter-efficient semi-distributed watershed model and the soil and water assessment tool. This study's goal was to assess the sediment prediction abilities of two hydrological models in the Upper Blue Nile Basin over a variety of watershed sizes. In the Upper Blue Nile Basin, the Ribb (1472 km^2) and Kessie (24,171 km^2) watersheds were chosen. The stream flow data for the Ribb watersheds from 2002 to 2011 and 2012 to 2017 were used for model calibration and validation, and a suspended sediment rating curve was created utilizing some measured values. Similar to this, the sparse sediment data for the Kessie watershed stream flow from 1997 to 2006 and 2007 to 2013 was produced using the sediment rating curve from Ministry of Water and Energy data. The model efficiency on daily time step scale during calibration and validation periods for parameter-efficient semi-distributed watershed model (NSE= 0.62, 0.68), (NSE= 0.41, 0.58) and soil and water assessment tool (NSE= 0.52, 0.63), (NSE= 0.55, 0.61) were obtained for Ribb and Kessie watersheds respectively. The measured and predicted discharge and sediment showed a range of satisfactory to very good agreement as a consequence. The model's output on a monthly time step scale likewise varied and was superior to that on a daily time step scale. Overall model performance showed that the PED-W model was more suitable than the SWAT model for predicting stream flow and sediment yield in the chosen watershed. This was caused by PED-W being oversaturated and plots being scaled up, which is the case in the Ethiopian highland.

Keywords: Hydrological Model, Kessie, Ribb, Upper Blue Nile Basin

1. Introduction

The high rates of soil erosion in the river basin and sediment transport in the river system contribute to increased sedimentation problems in the lake and reservoirs as well as the downstream regions. Land degradation problems in the country are largely a result of ineffective soil conservation measures, inefficient land management systems, and rapidly expanding population [1].

In Ethiopia, soil erosion rate is a significant issue because of topographic and land use land cover variability. Studies in the Upper Blue Nile river basin have been conducted to address these issues. [2] At El Deim, close to the Ethiopian border, conducted research on the sediment balance in the Blue Nile River Basin. The study successfully predicted the sediment and discharge using the SWAT model. The Anjeni gauged catchment (110 ha) used the same SWAT model to simulate a sediment yield, and the results were quite satisfactory [3]. M. A. Moges et al. [4] evaluated the accuracy of their use of the PED-W model to calculate the sediment budget of Lake Tana, a tropical lake in the Blue Nile Basin. The outcome was excellent. Similar to this, the PED model was used to simulate the yield of sediment in the Anjeni, Andit Tid, and Maybar catchments (477 ha, 113 ha, and 112 ha), with acceptable results [5-8].

In order to reduce sediment issues and create appropriate land use planning and management, it can be helpful to choose the most practical and effective tools [9]. The issue of which hydrological model to use, however, is one that researchers, managers, and policymakers must address. (e. g. AnnGNPS, HBV, SWAT, PED-WM, etc.) is the most appropriate, effective, and efficient to predict soil erosion rates (SE, Mg km^{-2} a^{-1}) and sediment yield (SSY, Mg $km^2/^a$) under present or future climate, land use, land cover, and management scenarios [10].

Significant advancements have been made in the last few decades in our understanding, characterization, and modeling of SE, SSY, and SY at different spatial and temporal scales. However, the majority of models only consider a few types of erosion processes (such as sheet, rill, and gully) and require long-term data, with a focus on relatively small spatial units (such as plots or small catchments) [11-12] Thorough sediment rating curves based on empirical knowledge from a particular region are one way to try and improve our prediction of the erosion process [6].

The majority of models that were previously used in the highlands of Ethiopia, like SWAT [1, 13, 14] had difficulties capturing dynamics because the Universal Soil Loss Equation predicted erosion in all but WEPP, and the underlying runoff mechanism in these models is based on infiltration excess. Many water-related projects have been built in the Blue Nile River Basin for irrigation, hydroelectric generation, water supply, and other purposes. Unfortunately, the majority of the structures are impacted by sediment buildup in the sub-basin-generated reservoirs, which reduces storage capacity and the structure's usable life. Because there is a problem with the project's design document's underestimation of sediment output due to the lack of sediment data in the basin as a result of fewer sediment yield measurement gauging stations [2, 7].

For this investigation, two hydrological models were considered. Several academics have praised the SWAT model for accurately predicting watershed hydrology and sediment yield in addition to being used in numerous areas (including Ethiopia). It also integrates over all water circulation in basins and has an efficient long-term simulation [4, 13, 15] compared to a completely distributed model, the PED-W model was chosen because it accurately captured the primary hydrological processes in the catchments. This model is preferred in watersheds with a monsoonal climate. Yet, due to its recent innovation and application of the saturation excess runoff concepts, the PED model was favored by several studies [16, 17].

Therefore, the goal of this study is to assess the hydrological models PED-W and SWAT's ability to predict sediment yield in the Ribb and Kessie watersheds of the Upper Blue Nile Basin. Additionally, it attempts to address calibrating and validating the SWAT and PED-W modes as well as assessing the sediment prediction abilities of the two hydrological models using statistical model performance criteria in the Ribb and Kessie watersheds. Lastly, this study has been served as a gap-filler for decision-makers, designers, and engineers for river basin development, soil and watershed management, conservation methods, detail hydrological analysis, and the implementation of water resource policy.

2. Materials and Methodology

2.1. Study Area and Data Availability

Ribb watershed is geographically located at 11°42′34′′–12°13′45′′N and 37°36′6’’–38° 14′20′′E, with an elevation range between 1787 to 4112m a. s. l (Figure 1). The total area of this watershed is 1472 square kilometers near Addis zemen /flow gauging station/. It is located in the Lake Tana sub-basin, Amhara regional state (South Gonder) near Lake Tana, the source of the Blue Nile. The river discharges mean annual average of 14.17m^3/s at the Addis zemen gauging station.

Geographically, the Kessie watershed is situated between 37°42°N and 10°05°E and 38°19°N and 12°52°E, with an elevation range of 1216 to 4084 m a. s. l. Near the flow gauging station for the Kessie stream, this watershed has a total area of 24,171 square kilometers. The Blue Nile Basin, a section of the Abbay Basin, is where it is situated. The Kessie watershed area's mean annual rainfall, surface runoff, and sediment yield are 1654 mm, 502 mm, and 68 79 tons/ha/year, respectively, with some minor spatial variation.

2.2. Data Collection

Topographic data, Digital Elevation Model (DEM) data, meteorological data (rainfall, temperature, sunshine, wind speed, and relative humidity), soil data, land use and land cover data, and hydrological data (stream flow and sediment) were all used to achieve the study's goal. The Ministry of Water, Irrigation and Electricity and the National Meteorological Agency, respectively, were the sources of the meteorological, hydrological, soil, and land use and land cover data. The Kessie watershed study used Gonder, Enfranz, Debretabor, Bahir Dar, Adet, Motta, and Dangila stations, while the Ribb watershed study used Debretabour, Alem Ber, Addis zemen, and Gassay meteorological stations. 16 years of meteorological data from 2002 to 2017 for the Ribb watershed and 17 years from 1997 to 2013 for the Kessie watershed were utilized for the calibration and validation of the selected hydrological models.

2.3. Reliability of Data

A straightforward normal ratio and Thisson polygon (for rainfall, discharge), arithmetic mean, and XLSTAT excel model (for temperature, relative humidity, sunshine, etc.) were used to fill in missing values and notable outliers at the initial screening. All of the meteorological data was subjected to detailed hydrologic screening after the initial screening was finished to ensure the accuracy of the data against various indexes. Using the double mass curve and petittit test techniques, respectively, the consistency and homogeneity of the data were assessed.

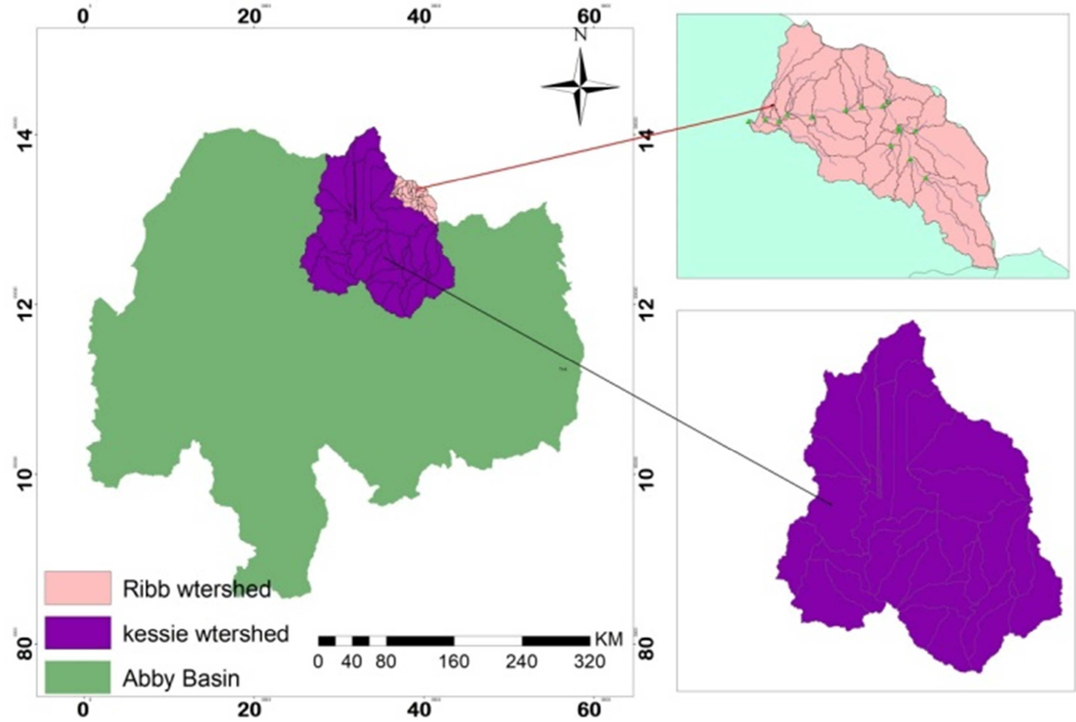


Figure 1. *Location of the study area.*

2.4. Model Inputs

Daily precipitation, daily observed flow, temperature, projections of potential evapotranspiration, digital elevation models, and catchment characteristics of the region are required as model inputs for semi-distributed models.

2.4.1. Determination of Areal Rainfall

Rain gauges only provide a point sample of a storm's overall distribution. However, in actuality, hydrological analysis necessitates an understanding of the region's rainfall. The Thiessen polygon method was chosen for this study due to its solid theoretical foundation and accessibility of computational tools. A strong network of representative rain gauges is necessary for the method to work, though (Taesombat & Sriwongsitanon, 2009).

2.4.2. Stream Flow Data

The Ministry of Water, Irrigation, and Electricity (MoWIE) provides the daily discharge for the study area (Kessie and Ribb watersheds). The daily discharge has complete data composition for the considered stations to represent the study area, in contrast to the daily precipitation. The discharge gauge stations are situated at the gauging stations for the Ribb and Kessie rivers, respectively, at the Addis Zemen and Kessie outlets.

2.4.3. Catchment Characteristics

The catchment area can be divided into various sub-basins and those sub-basins can be further divided into Hydrological Response Units (HRUs) because the SWAT model operates as a semi-distributed model.

2.4.4. Potential Evapotranspiration (PET)

For the purposes of this study, the daily potential evaporation is calculated using the temperature-based Enku's simple temperature method (Enku & Melesse, 2014).

$$ET_o = \frac{[T_{max}]^n}{k} \quad (1)$$

Where ETo is the reference evapotranspiration (mm/day), n is 2.5 which can be calibrated for local conditions, and k is the Coefficient which can be calibrated for local conditions. The coefficient, k could be approximated as $\mathrm{k} = 48 * \mathrm{Tmm} - 330$ where Tmm is the mean annual maximum temperature.

2.5. Watershed Models

The Soil and Water Assessment Tool (SWAT) and the Parameter Efficient Semi-Distributed Watershed (PED-W) model have both been tested to simulate sediment yield in the Ribb and Kessie watersheds. Every model utilizes a different theory of rainfall-runoff generation, necessitating the use of unique spatiotemporal and hydro-meteorological data sets.

2.5.1. Parameter Efficient Semi-Distributed Watershed Model (PED-W)

The semi-distributed conceptual water balance model created by T. S. Steenhuis *et al.* [18] is combined in the PED model, with the [19] sediment model. The first incorporates saturation excess runoff principles [4, 20].

Daily rainfall, evapotranspiration, the areal fraction, the maximum storage for each zone, and the interflow and base flow time are required as model inputs for the PED model. Three zones make up the watershed (study area) in the PED model: two produce surface runoff, and one contributes to the interflow and base flow of the watershed. The valley bottoms, which become saturated during the primary rainy season, and degraded hillsides with a slowly permeable sub-horizon at a shallow soil depth, are the areas with defined surface runoff. The third zone is made up of the hillsides where rainwater infiltrates and either contributes to interflow (zero order reservoirs) or base flow (first order reservoirs) [4, 16, 19].

The sediment concentration from the runoff-producing area (Cr, g L^{-1}) can be multiplied by the relative area and the flux per unit area to get the sediment load per unit watershed area (Y, g m^{-2} d^{-1}).

$$Y = A_1\, q_{r1}[a_{s1} + H(a_{t1} - a_{s1})]qr^n + A_2\, q_{r2}[a_{s2} + H(a_{t2} - a_{s2})]{q_{r2}}^n \tag{2}$$

Where, q_{r1} and q_{r2} are the runoff rates expressed in-depth units for contributing area A_1 (fractional saturated area) and A_2 (fractional degraded area), respectively. Theoretically, for both turbulent flow and a wide field, n is equal to 0.4 [21].

2.5.2. Soil and Water Assessment Tool (SWAT)

For catchment scale simulations, SWAT is a physically grounded continuous model [1, 10-12, 22]. Based on soil type, land use, and slope classes, the catchment is divided into hydrological response units (HRUs), which are typically several square kilometers in size. With regards to land cover, soil type, and slope class within a watershed, the HRUs are used to describe spatial variability or heterogeneity. For each HRUs unit, the model calculates relevant hydrologic components like evapotranspiration, peak runoff rates, groundwater flow, and sediment yield. O. Access et al. [1] claim that SWAT is integrated into a GIS interface.

Depending on the HRU, the model will either use the Curve Number or the Green and Ampt infiltration method to predict surface runoff. Assuming that all eroded sediments within an HRU reach the river, the Modified Universal Soil Loss Equation (MUSLE) is used to calculate soil erosion at each HRU [11].

This model can describe water and sediment circulation, vegetation growth, and nutrient circulation. Its inputs include daily rainfall data, maximum and minimum air temperature, solar radiation, relative air humidity, and wind speed.

SWAT calculates the surface erosion within each HRU with the Modified Universal Soil Loss Equation (MUSLE) [23].

$$Sed = 11.8 * \left(Q_{surf} * q_{peak} * area_{hru}\right) * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG^{0.56} \tag{3}$$

Where, Sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m³⁄s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the soil erodibility factor, C_{USLE} is the cover and management factor, P_{USLE} is the support practice factor, LS_{USLE} is the topographic factor, and CFRG is the coarse fragment factor.

2.6. Sensitivity Analysis

Sensitivity analysis investigates how modifications to the values of the parameters impact the overall shift in the model's output. This can be accomplished through the use of straightforward sensitivity analysis, where only one parameter is altered, or more sophisticated arrangements that examine the relationships between a numbers of parameters. As a result, an analysis of the data's overall sensitivity for the PED-W and SWAT models was done. The model was calibrated using the parameters that were found to be the most sensitive.

2.7. Model Evaluation and Selection Criteria

By comparing predicted values to observed values, the effectiveness of SWAT and PED-WM was assessed. Four model evaluation statistics, including the Root Mean sq\. Error (RMSE), Percent Bias (PBIAS), Nash-Sutcliffe Efficiency (NSE), and coefficient of determination (R^2), were used in this study to measure the goodness of fit [24].

To forecast sediment yield in a watershed, many researchers employ various model selection criteria [11, 16, 22, 25]. These criteria include prediction accuracy as measured by the degree of agreement between measured and predicted soil erosion or sediment yield data, the ability to provide details about the main sediment transport and erosion processes within catchments, the amount and quality of input data needed, and the model calibration requirements and models' potential for use in scenario studies of changing climatic conditions, land use, and land management. SWAT and PED-W are chosen from the various watershed models that are available to model the sediment yield of the Kessie and Ribb watersheds. Since the SWAT model has an efficient long term simulations, integrates over all water circulation in basin, received praise from numerous researchers for accurately simulating watershed hydrology and sediment yield in addition to being applied in various locations (including Ethiopia) [1, 13, 15, 16, 20, 22].

PED-W was chosen for this study because: i) it accurately represented the main hydrological processes in the catchments. ii) Watersheds with a monsoonal climate can benefit from the PED-W model. iii) Because it is semi-distributed and has a structure that is more based on physical principles than the lumped models, it requires less input data from the user than a fully distributed model. On the other hand, the PED model was chosen by many researchers because it is a recent innovation and takes saturation excess runoff principles (infiltration process principles) into account rather than others [2, 4, 16, 17, 19, 20, 22].

The PED model did well in predicting discharge and sediment concentrations for the entire Blue Nile Basin at the Sudan-Ethiopian border as well as for three small upland watersheds in the Ethiopian highlands [19].

3. Result and Discussion

The study's findings and analysis are presented in the following three main sections. The findings of this study were presented based on the model sequence as PED-W and SWAT hydrological models. The results included data quality analysis, model calibration, validation, and evaluation of model efficacy. In the beginning, PED-W and SWAT models on the Ribb and Kessie watersheds presented the stream sediment flows prediction.

3.1. Data Quality Analysis

The Pettitt test and double mass curve were used, respectively, to determine the homogeneity and consistency of the data. A 95% confidence level was used to evaluate the Pettitt result and identify any non-homogeneity. The test revealed that the average annual maximum and minimum temperature values for each watershed were homogeneous, and the outcome also showed that the stations were homogenous, stationary, and independent (the data is not dependent on other stations). In order to correct precipitation records for non-representative factors like a change in location or exposure of the rain gauge, the double mass curve technique was used.

3.2. PED-W Calibrated Parameters

When compared to Kessie, the fractional areas for the Ribb watershed only add up to 0.60, or 60% (Table 1). An area proportion of 1 indicates that the long-term discharge measured at the outlet is equal to the calculated interflow, base flows, and storm flow. In other words, since the average of net precipitation (i. e., discharge) over the long term in the PED-W model equals the average of discharge over the long term, (ie; rainfall less evaporation), all precipitation eventually exits the system. However, the total contributing fractional areas of the Ribb watershed are 0.60, or 60%, which means that the net input of precipitation is much greater than the discharge at the outlet (Addis zemen gaging station). Because of inaccurate measurement of the discharge or unexplained net precipitation flowing beneath the gauge and into Lake Tana, M. A. Moges et al. [4] claim that the higher bed levels, which are clearly visible by the Ribb river's strong flows, are to blame for [26] this miscalculation. The result shows that the measured flow is much less than the simulated flow. The absence of rainfall, which facilitated subsurface flows and decreased the flow at the gauging stations, is the final cause of the contributing areas' failure to add up to one. The same phenomenon occurred for this study as well.

Table 1. *PED parameters value of hydrological and sediment load for Ribb and Kessie rivers.*

Hydrology	Parameters		Unit	Calibration	
				Ribb	**Kessie**
Discharge	Saturated area	Area A1	%	0.5	0.1
		$S_{max,}$ A1	mm	75	53
	Degraded area	Area A2	%	0.1	9.0
		$S_{max,}$ A2	mm	5	20
	Infiltration area	Area A3	%	59.5	91
		$S_{max,}$ A3	mm	150	100
	Subsurface	$BS_{max,}$	mm	65	210
		$t^{1/2}$	days	20	12
		τ^*	days	60	24
	Sub- surface flow	α_B	$(gL^{-1})(mmd^{-1})^{-0.4}$	0.0	0.0
		α_I	$(gL^{-1})(mmd^{-1})^{-0.4}$	0.0	0.0
Sediment	Saturated area	α_t	$(gL^{-1})(mmd^{-1})^{-0.4}$	1.0	5.0
		α_s	$(gL^{-1})(mmd^{-1})^{-0.4}$	1.5	0.5
	Degraded area	α_t	$(gL^{-1})(mmd^{-1})^{-0.4}$	6.0	6.0
		α_s	$(gL^{-1})(mmd^{-1})^{-0.4}$	0.5	0.5

A1, A2, and A3 are area fractions of the saturated, degraded, and recharge hillside areas respectively. Smax is the maximum water storage capacity; BSmax is the maximum base flow storage of linear reservoir; t ½ is the time taken in days to reduce the volume of the base flow reservoir by half under no recharge conditions or base flow half-life time in days; τ∗ is the duration of the period after a single rainstorm (until interflow ceases) or interflow in days; as and at are coefficient of sediment source and transport model for components of base-flows (B), interflow (I), saturated area (1) and degraded area (2).

The transport capacity from the saturated area at the outlet of Ribb (at = 1) is discovered to be less than Kessie (at = 5) and less than (at = 18) recent studies shown by [4]. There isn't a clear explanation for why this is the case, but an active gully formation may be to blame (Tilahun, 2014). This would explain why the Ribb watershed, the smallest area, has much higher concentration times than Kessie, the largest area. The saturated area of Ribb at the outlet has a source limiting coefficient that is higher than Kessie. This is caused by the Ribb River's disturbed bank, in particular, the unconsolidated soil in the channel bottom from the falling banks, and the ongoing construction of a dam nearby. The differences between Ribb and Kessie's sediment transport and source limit are caused by slope variation, the presence of active gullies at the saturated areas, and agricultural practices.

3.3. PED-WM Sensitivity Analysis

The results of sensitivity analysis in stream flow gave the degree of sensitivity of nine parameters which was important for the manual calibration methods. Among these parameters the saturated area (A1), degraded area (A2), hill-side area (A3), maximum soil storage for base flow (BSmax), and base flow half-life ($t^{1/2}$) are sensitive parameters. From the nine inputs, the PED- W model parameter five parameters were found the most sensitive, including saturated area (A1), degraded area (A2), hillside (A3), maximum soil storage in the saturated area (Smax), and recession coefficient (K). a Portion of infiltration area, A3 was the most sensitivity parameters for both watersheds, meaning maximum runoff was generated from the hillside area. Similarly, in sediment load analysis sensitivity was done by manual calibration methods by using two parameters: including sediment transport and sediment source from A1 (saturated area) and A2 (degraded area) (at, as). From these parameters, sediment transport from the degraded area is the most sensitive for both watersheds.

3.4. PED-W Model Calibration and Validation

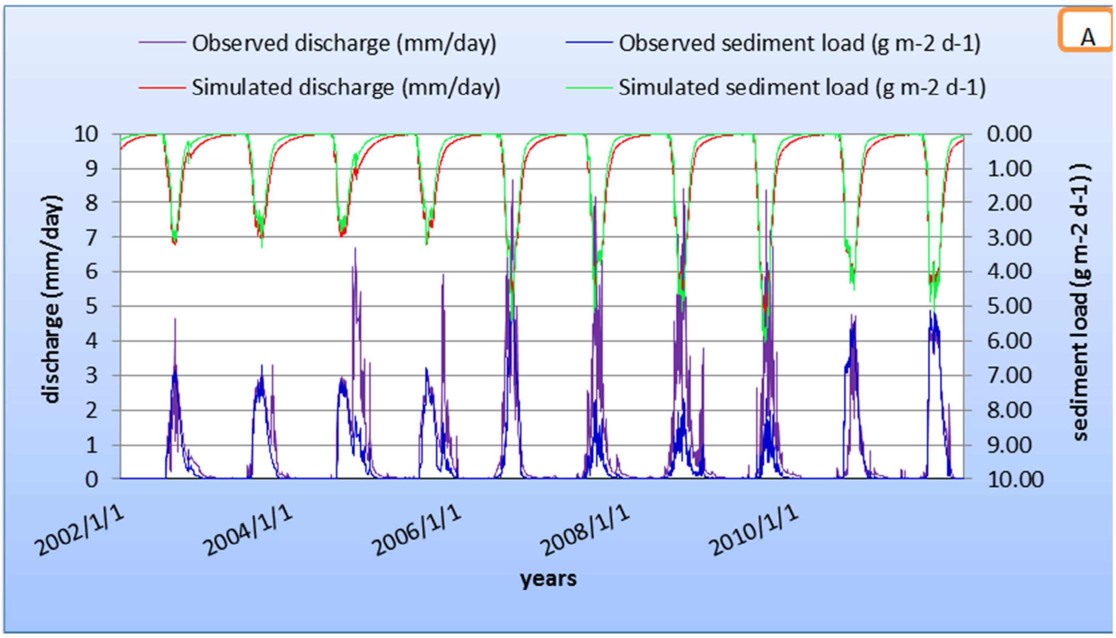
For the PED-W model, all nine input parameters for discharge and six parameters for sediment were calibrated. The starting values for calibrating parameters were based on the reaearch [4, 16, 17, 22] and the research [4, 16, 19, 20, 22] for discharge, and the research [4, 16, 19, 20, 22] for sediment. These initial values were changed manually through randomly varying input parameters so that the best "closeness "and "goodness of fit" was achieved between predicted and observed suspended sediment flow in the watersheds. The PED-W model calibrated the sediment followed by calibrating the shape of the hydrograph from 2002 to 2011 for the Ribb watershed and 1997- 2006 for the Kessie watershed. The calibrated model was validated from 2012 to 2017 and 2008 to 2013 for two watersheds respectively. During the calibration and validation period of the PED-W model on a daily time, with step NSE values of (0.62, 0.55) the observed and simulated sediment result of the Ribb watershed was less than [4, 16, 17, 19, 20, 22] (0.70, 0.73).

Table 2. *Calibration and validation performance of sediment yield by PED-W model.*

watershed	description	Daily				Monthly			
		R^2	NSE	RMSE	PBIAS	R^2	NSE	RMSE	PBIAS
Ribb	Calibration	0.68	0.62	0.57	±1.08	0.75	0.72	0.52	±0.89
	Validation	0.57	0.55	0.89	±1.08	0.70	0.65	0.53	±1.02
Kessie	Calibration	0.73	0.68	0.50	±1.98	0.88	0.78	0.35	±2.56
	Validation	0.67	0.61	0.58	±1.05	0.72	0.70	0.52	±1.07

The hydrograph pattern for the Ribb watershed demonstrates that the relationship between the daily observed and simulated sediment load was satisfactory based on the Nash and Sutcliffe efficiency and based on the coefficient of determination, R^2 result during the calibration period of 2002 to 2011 (0.62 and 0.55), respectively. The hydrograph for the Ribb watershed during the calibration and validation periods shows the observed and simulated discharge and sediment linked peak to peak, rising to rise, and recession to recession.

Monthly calibration for the Kessie watershed demonstrates that the model was able to simulate the peak flows and sediment loads quite well (very good for flow and good for sediment load), as well as capture the dry period characteristics. For flow and sediment load, respectively, the Nash-Sutcliffe Efficiency (NSE) yielded 0.99 and 0.72. Similar to this, for the Ribb watershed, the monthly time step calibration of the model's Nash-Sutcliffe Efficiency (NSE) performance is equal to 0.83 and 0.70 for flow and sediment load, respectively. The measured and simulated flow and sediment exhibit very good agreement in this case. The simulated results were higher than the observed values for both watersheds. This was brought on by issues with sediment and discharge measurement as well as a flaw in the chosen hydrological models.



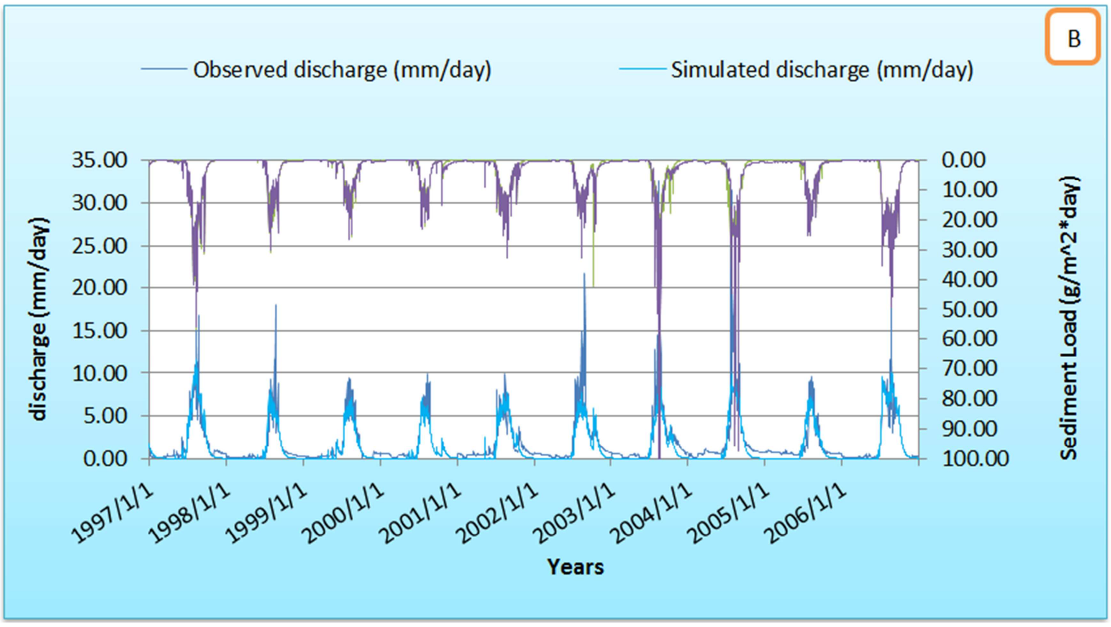


Figure 2. *Daily predicted and observed stream flow and sediment load for Ribb and Kessie watersheds during (A) & (B) calibration period (2002-2011) and (1997-2006).*

3.5. SWAT Sensitivity Result

SWAT-CUP 2012 version 5.1 was used to conduct the parameter sensitivity analysis. Ribb and Kessie watersheds have 6 (SUFI-2 algorithms). For the sensitivity analysis of the prediction of stream flow for both watersheds, 11 hydrological parameters were tested. The groundwater delay (Gw-Delay, days), groundwater "revap" coefficient (Gw-Revap), channel effective hydraulic conductivity (Ch-K2, mm/h), and threshold depth of water in the shallow aquifer for "revap" or percolation to the deep aquifer (REVAPMN, m) were the sensitive parameters analyzed for stream flow calibration in both watersheds. Six hydrological parameters were used: a linear parameter (Spcon) for calculating the maximum amount of sediment that can be restrained during channel sediment routing; channel cover factors (Ch-Cov1 and Ch-Cov2); a channel erodibility factor (Ch-Erod); a USLE equation support practice factor (USLE-P); an exponent parameter (Spexp) for calculating the sediment restrained in channel sediment routing; and a USLE equation topographic factor (USLE-. K).

The most important and delicate hydrological parameters for flow simulation were base flow alpha factors (ALPHA-BF), which may represent the maximum groundwater coverage in the chosen watersheds. The two models are better at predicting subsurface flow than surface runoff. The second and third important factors for both watersheds were Ch-N2 and Sol-Awc. The most sensitive hydrological parameters for the Kessie and Ribb watersheds, respectively, were determined by the Global Sensitivity Analysis method (t-stat & p-value), with the exponent parameter for calculating sediment restrained in channel sediment routing (Spexp) due to the influence of sediment flow by Lake Tana or effect of natural reservoirs and USLE equation topographic factor (USLE-K) due to maximum variation of watershed elevation range.

3.6. SWAT Model Calibration and Validation

The observed daily or monthly time step stream flow and sediment are used to calibrate the SWAT model, and the best fit parameter sets are chosen. After the model was set up, the simulation of the stream and sediment flow was carried out for the study area catchments for the calibration periods (1999-2008 for Kessie watersheds and 2004-2013 for Ribb watersheds) using the sensitive parameter values.

For this study's validation periods of 2014–2017 for Ribb and 2009–2013 for the Kessie, the watershed was used to test the model parameters against a different, independent set of stress conditions. When the validated model parameter sets fail, the model is deemed unreliable and should not be used. The model needs to be re-calibrated using a fresh set of model parameters, then validated until it meets the calibration targets internals of objective function values.

With regard to the two catchments' observed sediment flow data, the simulation results from calibration and validation were compared. Based on the NSE result (Table 3), the comparison between the observed and simulated flow and sediment value for ten years of simulations indicated that there is a satisfactory agreement between observed and simulated sediment for the Ribb watershed and a good agreement for the Kessie watershed on a daily time step (0.52, 0.41 for Ribb and 0.63, 0.58 for Kessie). Results of the Ribb catchment's SWAT model sediment calibration and validation were almost identical to those obtained [18] (0.51, 0.48) for the daily time step. The results for sediment monthly calibration and validation were also somewhat comparable to the research [14] (0.78, 0.59). The NSE result on SWAT CUP version 5.1 in monthly time steps is similar.

[2] Calibration and validation technique was preferable to Kessie watershed's 6 (0.71, 0.58).

The SWAT model's ability to predict flow and sediment yield in the Ribb and Kessie watersheds has been demonstrated by its monthly calibration and validation. The observed and simulated flow and sediment for Ribb have demonstrated a very good and good agreement by NSE model performance criteria (0.78, 0.73) from SUFI-2 algorithms calibration methods. The calibration results for flow and sediment for Kessie catchments similarly revealed very good agreement between the observed and simulated values (0.87, 0.78) (Table 3). Simulated results for both watersheds overestimated both flow and sediment; this could be due to issues with measuring gauging stations that were under recorded and missing data in the outlet points.

3.7. Sediment Yield

In this study, the SWAT and PED models—which were calibrated and validated at Ribb and Kessie gauging stations—were used to forecast the sediment yield at Adis Zemen and Kessie outlets, with their corresponding distribution among the sub-basins. According to this simulation, the annual yield of sediment at the Adis Zemen outlet for the Ribb catchment from 2002 to 2017 was 25.7 tons/ha/year for SWAT and 26.2 tons/ha/year for PED. The outcome was less than [13] and nearly identical to the research [4, 16], these [17, 19, 20] result of 25 tons/ha/year using the PED model. The result of the SWAT model's analysis of the Anjeni catchment was 27.8 tons/ha/year. Similar to this, based on this simulation, the annual sediment yield at the Kessie outlet for the Kessie catchment is in the range of 68.9 tons/ha/year during the year 1997 to 2013 using SWAT and 70.2 tons/ha/year using PED. Based on these findings, soil erosion in the two watersheds is categorized as middle (20–71 tons/ha/year) [14].

3.8. Model Performance and Comparison

The SWAT model was used to simulate a daily time step of the observed sediment, with NSE of 0.52 and 0.41, R^2 of 0.59 and 0.53, and RMSE of 0.68 and 0.78, compared to the PED-W model, which had NSE of 0.62 and 0.55, R^2 of 0.68 and 0.57, and RMSE of 0.57 and 0.89 during. Similar to that, in the Kessie watershed, the daily observed sediment was simulated using the SWAT model with NSE of 0.63 and 0.58, R^2 of 0.66 and 0.62, and RMSE of 0.56 and 0.57, whereas for the PED-W model was NSE of 0.68 and 0.61, R^2 of 0.73 and 0.67, and RMSE of 0.50. The result of the PED-W model on sediment prediction was within the range of similar studies in Upper Blue Nile: PED-WM, [1, 4, 16]; likewise, for the SWAT model, the prediction model performance results agreed with [12, 16, 18, 22].

According to the results of this study's calibration and validation, the PED-W model is the best and preferred model for simulating stream flow and sediment for both watersheds (Ribb and Kessie) under a monsoon climate. When we compared the PED-W model to the SWAT model, the values of the regression coefficient (R2), Nash Sutcliffe (NSE), root mean square error (RMSE), and percent bias (PBIAS) showed that there was good agreement between observed and simulated flow and sediment. The Kessie Watershed's sediment and flow predictions performed marginally better than Ribb's.

Although the PED-W model's data input requirements are lower than those of the SWAT model, overall model performance showed that the PED-W model was accurate and suitable for simulating flow and sediment in both watersheds. Because the PED-W model's mechanisms for runoff simulations were based on saturation excess and scaling-up estimates of plot erosion.

Table 3. *Calibration and Validation Performance of Sediment by the SWAT Model.*

Watershed	Description	Daily				Monthly			
		R^2	NSE	RMSE	PBIAS	R^2	NSE	RMSE	PBIAS
Ribb	Calibration	0.59	0.52	0.68	±0.98	0.75	0.73	0.51	±0.99
	Validation	0.53	0.41	0.78	±0.72	0.69	0.63	0.59	±1.04
Kessie	Calibration	0.66	0.63	0.56	±1.08	0.78	0.76	0.45	±1.59
	Validation	0.62	0.58	0.57	±1.21	0.75	0.71	0.48	±1.07

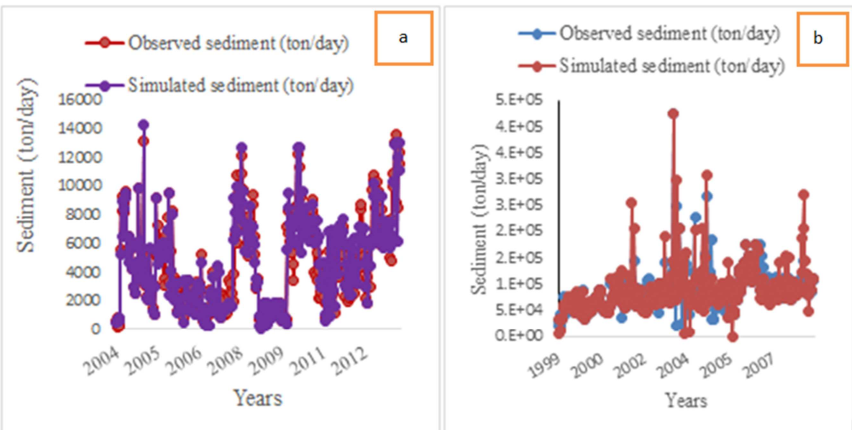


Figure 3. *Daily predicted and observed sediment load for Ribb and Kessie watersheds during the calibration period (2004-2013).*

4. Conclusion and Recommendation

During the calibration and validation periods, PED-W was used to simulate the sediment yield at a daily time step, with NSE values for SWAT of 0.52, 0.41, and 0.63, 0.58 and for PED-W of 0.62, 0.55, 0.68, and 0.61. The predicted discharge and sediment yield for each outlet runoff amount for both watersheds were compared to the actual data.

In comparison to SWAT, the PED-W model was relatively more accurate in predicting the discharge and sediment at the gauging stations Addis-Zemen and Kessie for the Ribb and Kessie watersheds, respectively. When compared to the SWAT model, the PED-W model was also the most effective at forecasting stream flow and sediment yield across a range of watershed sizes (small to large). This was caused by PED-W being oversaturated and plots being scaled up, which is the case in the Ethiopian highland.

The calibrated models can be used to further analyze how climate and land use change, as well as other possible management plans, will affect stream flow and soil erosion. The study's findings may assist various stakeholders, policymakers, and managers in developing and putting into practice appropriate soil and water conservation strategies, as well as assist the designer of hydraulic structures in deciding on the most suitable and effective hydrological models to simulate sediment yield from the basin and quantify sediment accumulation in reservoirs.

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