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Multi-site calibration of SWAT for the spatial distribution of sediment yield, Middle Awash Dam watershed, Ethiopia

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Abstract

Multi-site calibration of sediment yield has a significant effect on evaluating the spatial distribution of sediment yield of watershed and reservoirs sedimentation. Multi-site calibration was conducted at three gauging stations of the Proposed Middle Awash Dam watershed. The sequential Uncertainty fitting (SUFI-2) calibration uncertainty program (SWAT-CUP) has been used to calibrate and validate flow and sediment parameters using monthly flow and sediment rate observed data. P-factor and R-factor measured model calibration and uncertainty where the P-factor recorded 0.56-0.86/0.54-0.77 and R-factor 0.52-0.93/0.68-0.84 values respectively during the calibration and validation period for the three gauging stations. Model result showed the performance model was excellent during the calibration period with the coefficient of determination R2=0.78-0.82, Nash-Sutcliffe Efficiency ENS=0.77-0.79, Observation Standard Deviation Ratio RSR=0.44-0.48 and percent bias PBIAS=-13.3 to +14.3. Following the calibration process, the model estimated mean annual spatial distribution of sediment yield 7.23 ton/ha/yr at the outlet. Sediment yields spatial distribution showed that among the 19 sub-watersheds ranked based on their sediment yield contributions, eight sub-watersheds have a slope greater than 5%, which is relatively steeper and contributed average annual sediment yields of 16 ton/ha/yr. The temporal variability hydrograph showed 70.8 % of yearly sediment yield in the study area during the rainy season. The study results informed to development of watershed management strategies to minimize the sediment problems in the entire watershed.

Keywords: Hydrological modelling, Middle Awash Dam, sediment yield, spatial distribution, SWAT model

Introduction

The sediment yield from a watershed is an integrated result of all water erosion and transport processes occurring in the entire contributing area (Zhang et al., 2020). Surface soil erosion affects agricultural productivity and water infrastructures (Telles et al., 2013). Sediment inflows influence reservoirs service year (Brandt, 2000; ICOLD, 2012). Watershed sedimentation has been the results of poor land-use practices and a lack of suitable soil conservation measures. Sedimentation can cause a reduction in the storage capacity of reservoirs (Lee et al., 2010; Alemu, 2016). As the suspended sediment in the flowing water increases, the water quality in rivers and reservoirs has degraded.

In Awash River Basin, siltation of canals and reservoir sedimentation has considered a critical problem. The bathymetric survey conducted by Halcrow (1989) indicates Koka reservoir, which is part upstream of the proposed Middle Awash Dam, faces a sedimentation challenge with an average annual rate of 25 million m3/yr. A similar study by the Ministry of Water Resources (MoWR) shown the reservoir still lost its storage capacity with an average sedimentation rate of 12.08 million m3/yr (MoWR, 2002). The current capacity of the Melkassa reservoir has reduced to the level that it can no longer store water due to heavy siltation. Bishaw and Kedir (2015) reported that average annual sediment yields in the Awash River near Merti Bridge were 658,120 tons and increasing during the rainy season. This sedimentation becomes a fundamental problem for farms on the Metehara Sugar estate by reducing the canal system's capacity and height storage reservoirs (Zeleke, 2007). The estate costs a tremendous amount of money for maintenance (DHV, 1983).

Periodic evaluation is essential for sediment deposition pattern and assessment of sediment distribution of spatial and temporal variability. It has used to sustain the intended functions of reservoir construction like storage facilities for domestic and irrigation water supply, power generation and flood attenuation. Therefore, understanding watershed sediment processes is a criterion for effective watershed management.

SWAT has been used by researchers worldwide for estimation of sediment yield on a daily and monthly basis (Briak et al., 2016; Xu et al., 2009; Liu et al., 2015; Samad et al., 2016; Bossa et al., 2012; Le Roux, 2018). SWAT model applicability has been confirmed in Ethiopia in sediment yield estimation and spatial sediment distribution mapping (Tesema and Leta, 2020; Setegn et al., 2010; Welde, 2016). Researchers conducted SWAT model calibration, validation and uncertainty analysis to identify the most influencing hydrological parameters (Gyamfi et al., 2016; Singh et al., 2013; Manaswi and Thawait, 2014; Szezesniak and Piniewski, 2015). Calibration of the parameters can be conducted at multi-sites (Das et al. 2019; Piniewski and Okruszko, 2011; Chiang et al., 2014), single-site (Tesema and Leta, 2020). The authors have reported that multi-site calibration and validation efficiency were better than single sites focusing only on the outlet of data availability (Qi and Grunwald, 2005; Wang et al., 2012). In this study, we implemented an automated calibration procedure for further calibration, validation and uncertainty analysis of sediment parameters using SWAT-CUP (Abbaspour et al. 2007) sequential uncertainty fitting (SUFI-2) algorithm (Kumar et al., 2017). Using SWAT-CUP of sequential uncertainty fitting (SUFI-2) algorithm, research articles have been worked worldwide based on the calibration of sediment parameters (Hallouz et al., 2018; Mamo and Jain, 2013).

This study's primary objective was multi-site calibration of SWAT for Sediment's spatial distribution to the proposed Middle Awash Dam watershed. The objectives of this study are to estimate the sediment yield entry of sediment yield to the proposed Middle Awash Dam reservoir, and to assess the sediment yield distribution of the proposed Middle Awash Dam watershed. In this study, sediment parameters' multi-site calibration has been conducted after streamflow parameter calibration and validation. This technique's main advantage could be calibration from upstream to the downstream of the watershed, which increases the model calibration efficiency from upstream to downstream of the watershed hydrological parameters.

Material and methods

SWAT model description

SWAT (Arnold et al., 2012) has been using natural and human activity impacts on land surface to assess hydrological characteristics. In SWAT model, watersheds partitioned into sub-watersheds and stream networks using the digital elevation model (DEM). Sub-watersheds further sub-divided into the smallest simulation unit, Hydrological Response Units (HRUs). SWAT allows the users to choose slope classification. Four slope classes of 0-3%, 3-6%, 6-12%, and above 12% were defined. A 20% land use, 10% soil and 10% slope threshold are adequately assigned to create HRUs in the watershed to make the SWAT model more efficient in performing simulation (Neitsch et al., 2011). Sub-basins that contain a land use, soil or slope smaller than the threshold remain as the dominant land cover, soil or slope closest to it.

Hydrological variables such as runoff and sediment are simulated at each HRUs using multiple HRUs options assigned for this study and then accumulated into the sub-watershed level and routed through the stream channel to the main outlet of the watershed. The Routing phase of the SWAT hydrologic simulation consists of the transportation of hydrologic components in the stream networks. Manning's equation calculates the rate and velocity of flows of the study watershed. For this study, the flow routed by the variable storage method. The erosion and sediment yield characteristics of each HRU calculated using the Modified Universal Soil Loss Equation (MUSLE). In this study, SWAT uses the curve number method to compute the surface runoff volume. The soil hydrologic group contribution in estimating surface runoff has used the U.S. Natural Resource Conservation Service. The SWAT model for this study used the Penman-Monteith method to estimate the potential evapotranspiration (Monteith, 1965). Since the study area has sufficient time-series data, the Penman-Monteith method has used in several ways.

The water flow through the soil material in the SWAT model has implemented by using the water balance equation (Mutenyo et al., 2013). The water balance of any watershed is dependent on the moisture and energy inputs provided by the watershed climate. Data sets required by the SWAT model in this study are precipitation, air temperature, solar radiation, wind speed and relative humidity (Neitcsh et al., 2005). For each sub-watershed, the model generates a set of weather data. The values for any sub-watershed developed independently, and there will be no spatial correlation of generated values between the different sub-watershed (Arnold et al., 2012).

SWAT-CUP

The SWAT-CUP, an interfaces program of ArcSWAT, was used to calibrate and validate the SWAT model's sensitive parameters. SWAT-CUP designed to evaluate the performance of the calibration of the SWAT model. Thus, the advantage of the application is its ability to give a wide choice of functions and great interfaces for parameterization, calibration and validation of the model. The SWAT-CUP model's execution involves using output files generated by the SWAT model in ArcSWAT (Abbaspour, 2014). One of the calibration techniques in SWAT-CUP, Sequential Uncertainty Fitting (SUFI-2), has implemented in this study. The uncertainty analysis of SUFI-2 has quantified by the coefficient of linear correlation (R^2), the coefficient of Nash-Sutcliffe efficiency (NSE), the coefficient of Percent bias (PBIAS) and Root mean square error observation standard deviation ratio (RSR) between the observed data and simulated results.

Description of the study area

The proposed Middle Awash Dam watershed part of the Awash River basin is the location of 8°57.6'N, 40°9.6'E. A multipurpose dam will be used for nearby communities and Debu-Amibara irrigation sites (WWDSE, 2016). The geographical extent of the dam watershed, which ranges from 7°52' and 9°25' North, and 38°12' and 40°36' East and covers a total drainage area of 20,371km2 (Figure 1).

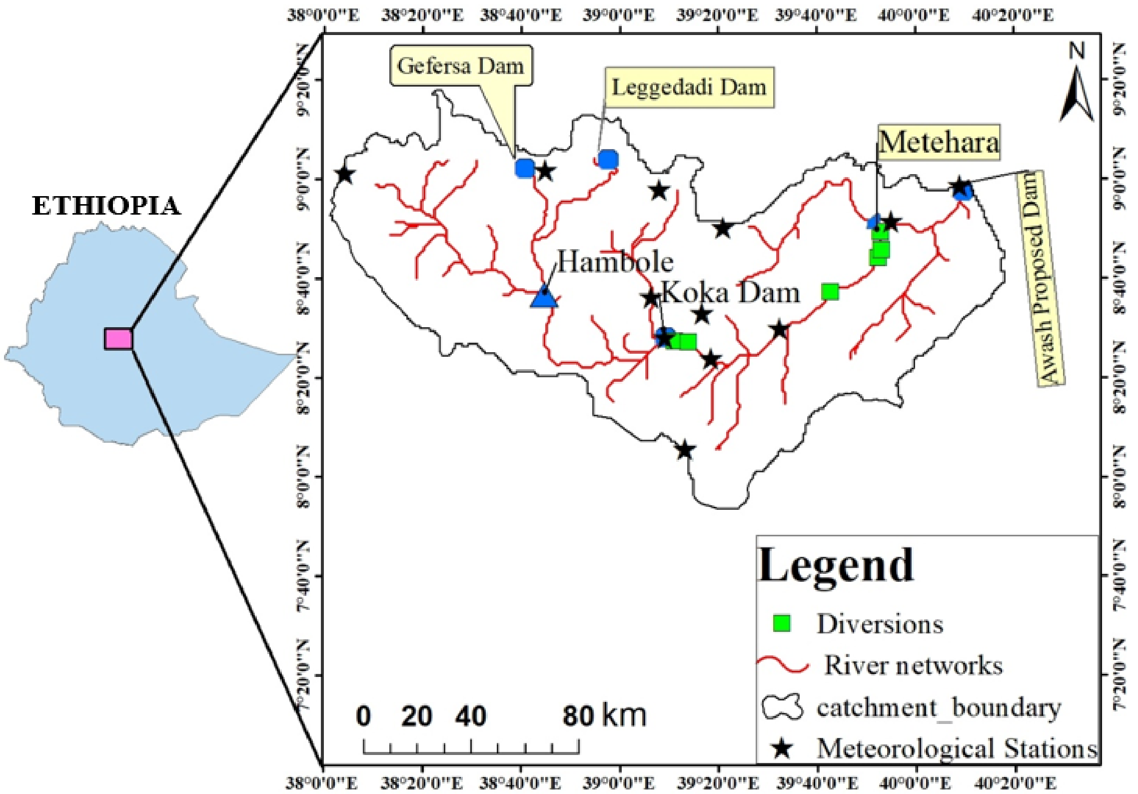

Figure 1. Location map of the proposed Middle Awash Dam watershed (MADWS) with Meteorological Stations

Data soures and compilation

We downloaded DEM of 30 m resolution (Figure 2) from the United States Geological Survey (USGS), SRTM (Shuttle Radar Topography Mission) for watershed delineation and stream network definition using SWAT (Waranyu and Anongrit, 2016). We used Ethiopia's 2008 LU/LC map ready by the Ministry of Agriculture (MoA) efforts with a 30m resolution was used to extract the LU/LC map of the study area (Figure 2). Ethiopia's soil shapefile map was obtained from MoA and clipped for the study area soil map with equal LULC and DEM projection (Figure 2). The watershed response rainfall events to runoff depend on the soil's chemical and physical properties (Buda & DeWalle, 2009). We used a Harmonized world soil database (Nachtergaele et al., 2010) to insert major soil types' basic physicochemical properties into the SWAT user soil database (FAO, 2002).

Daily weather data were obtained from National Meteorological Agency of Ethiopia from 1990-2014 (Table 1) for the study watershed. This study used streamflow from the

Ministry of Water, Irrigation and Electricity of Ethiopia from the hydrology and water quality department in the daily time series (1990–2010). The water abstraction and reservoir data were obtained from Awash River basin Master Plan (Halcrow, 1989). Streamflow data used to calibrate streamflow parameters at Hambole, Metehara and Awash. Hambole gauging station is located at the nearest upstream of Koka Dam Reservoir on Awash River's channel. Metehara and Awash gauging stations are situated middle and lower part of the watershed. All selected stations have good streamflow records with 9% missing data in the study baseline, especially from 1990 to 2007; the unrecorded data were filled by linear regression for the wet season (Elshorbagy et al., 2000) and recession curve method for the dry season (Gyau-Boakye and Schultz, 1994).

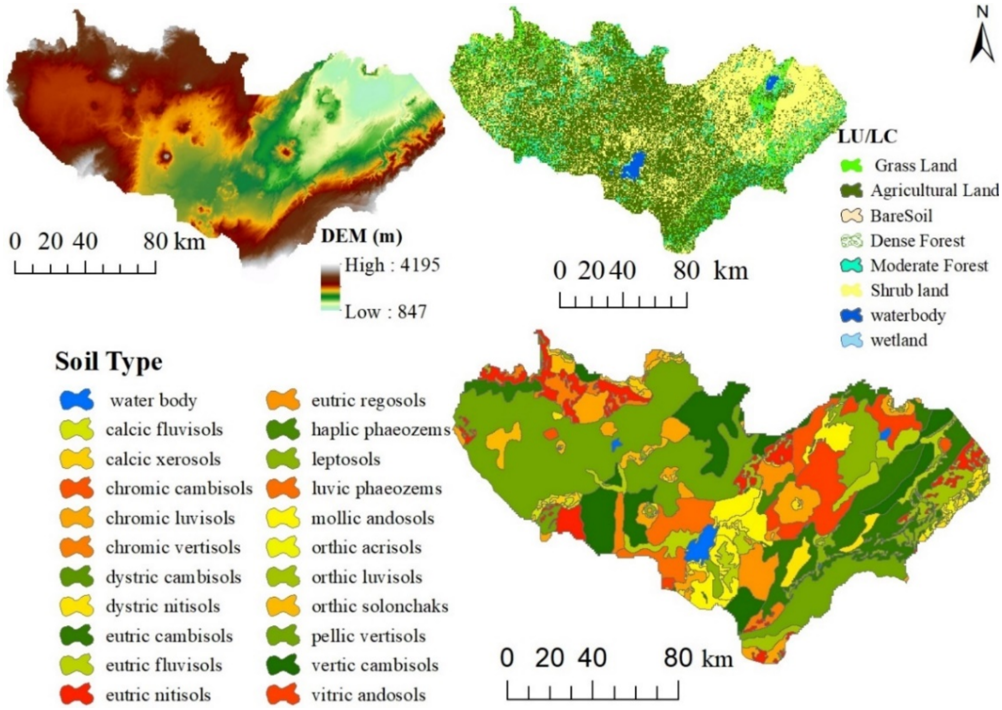

Figure 2. Proposed Middle Awash Dam watershed DEM (top left), LU/LC (top right) and Soil type bottom.

Table 1. Selected meteorological stations at Proposed Middle Awash Dam Watershed (1990 – 2014).

No.	Station	Lat.	Long.	Elevation (m)	Elements					
					RF	Tmax	Tmin	RH	SS	WS
1	Addis Ababa	9.03°	38.75°	2453	√	√	√	√	√	NA
2	Asgori	8.78°	38.33°	2072	√	√	√	NA	NA	NA
3	Nuraera	8.08°	39.9°	1140	√	√	√	√	√	NA
4	Awash 7kilo	8.98°	40.15°	944	√	√	√	NA	NA	NA
5	Chefe Donsa	8.97°	39.13°	2315	√	√	√	NA	NA	NA
6	Koka dam	8.47°	39.15°	1783	√	√	√	NA	NA	NA
7	Melkasa	8.4°	39.31°	1543	√	√	√	√	√	√
8	Mojo	8.61°	39.11°	1783	√	√	√	NA	NA	NA
9	Tulubolo	8.65°	38.2°	2072	√	√	√	NA	NA	NA
10	Ginchi	9.02°	38.07°	2324	√	√	√	NA	NA	NA
11	Metehara	8.86°	39.92°	962	√	√	√	√	√	√
12	Nazreth	8.55°	39.28°	1636	√	√	√	NA	NA	NA
13	Huruta	8.1°	39.22°	2200	√	√	√	NA	NA	NA
14	Bolo Giorgis	8.84°	39.35°	1963	√	√	√	NA	NA	NA

Sediment concentration was one of the inputs for sediment load calibration by SWAT. For this study, the sediment concentration data at the dam site (Awash gauging station) was not available. However, the Metehara gauging station located around 25km upstream of the dam site has sufficient sediment concentration data and gauges about 90% of Middle Awash Dam watershed area coverage. The remaining 10% (ungauged area) also has relatively similar soil, land use, and topography characteristics. Thus, we assumed it could be possible to use the equation of sediment yield rating curve (Clarke, 1994) developed at Metehara gauging station for computing the daily sediment load (ton/day) at the dam site by using the daily flow data measured at Awash gauging station. For sediment yield analysis at Hambole, the sediment rating curve for the Hambole gauging station adopted from the research conducted by Golla et al. (2006). After the rating curve has developed, discharges changed to sediment load (Morris and Fan, 1998).

Hydrologists preferably use a double mass curve to assess records' consistency at multiple locations, fill gaps and adjust inconsistent in records. We used the normal ratio method in this study to fill in the missing data of precipitation of each station is available, and the magnitude differs from that of each considered precipitation stations by more than 10%.

The SWAT model set-up has been created based on the proposed Middle Awash Dam watershed geospatial data such as DEM, LU/LC and soil maps (Abbaspour et al., 2015). In the current study, the watershed up to its outlet was subdivided into 70 sub-basins and further subdivided into 1319 HRUs. We took the threshold area of 15,000ha to create stream networks for simulation purposes properly. We were manually added the watershed outlet to generate streamflow lines and watershed boundaries. Moreover, based on SWAT manual document, reservoirs and water diversions (Berhe et al., 2017) has been considered in the SWAT model setup. Using the above information, the model automatically delineates a watershed area of 20,371km^2 (Figure 3).

Proceed to SWAT model sensitivity analysis, calibration, and validation using SWAT-CUP uncertainty analysis tool SUFI-2 (Abbaspour, 2014). The model was calibrated by changing the parameters systematically (Li et al., 2017). The calibration was conducted from 1/1/1992-12/31/1999 with the warm up period one-year 1991 and validation from 1/1/ 2000–12/31/2006 using the observed streamflow and sediment yield at Hambole, Metehara and Awash gauging stations. Global sensitivity analysis uses t-test and p-values to determine each parameter's sensitivity (Abbaspour, 2014).

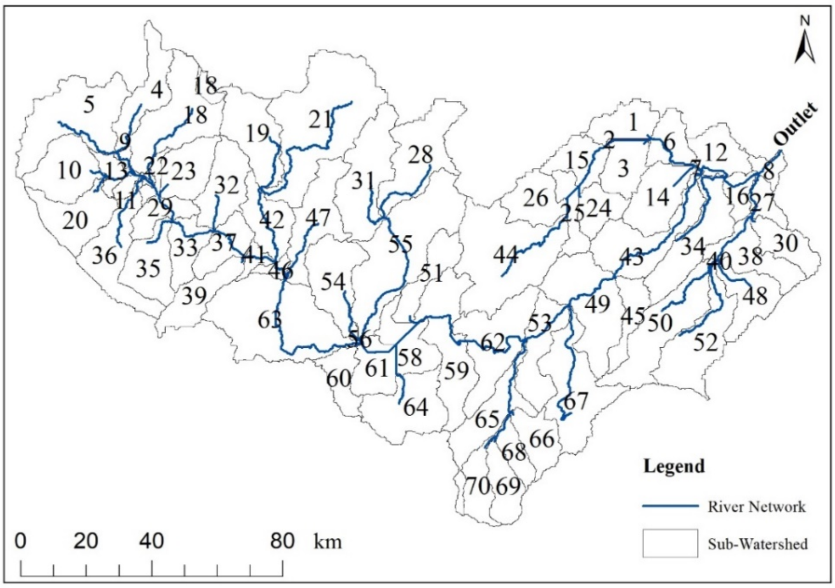

Figure 3. Sub-watershed and stream network of study watershed.

Model performance evaluation and uncertainty analysis

The SWAT performance evaluated using statistical measures to determine the quality and reliability of predictions compared to observed values. In this study the statistical indicators such as coefficient of determination (R^2), Nash-Sutcliffe modeling efficiency (ENS) (Nash & Sutcliffe, 1970), Root mean square error observation standard deviation ratio (RSR) and percent bias (PBIAS) have been used to check the accuracy of streamflow and sediment yield calibration and validations.

The guidelines by Moriasi et al. (2007) and Santhi et al. (2001) proposed the acceptable range of parameters assumed for Ens>0.5 and R^2>0.6 during the calibration of streamflow and sediment yields. PBIAS measures the tendency of simulated result is smaller or larger than the observed values (Gupta et al., 1999); 0 is the optimum value, the positive value indicates underestimation and negative value indicates an overestimation of the model output. RSR is error-index statistics (Singh et al., 2004). According to Singh et al. (2004) published guideline the lower RSR is the perfect model simulations; zero is the optimum value for RSR, which shows the positive the perfect model output.

$$R^2 = \left(\frac{\sum_{i=1}^{n} (Y_{obs} - \overline{Y}_{obs})(Y_{sim} - \overline{Y}_{sim})}{\sqrt{\left(\sum_{i=1}^{n} (Y_{obs} - \overline{Y}_{obs})^2\right)\left(\sum_{i=1}^{n} (Y_{sim} - \overline{Y}_{sim})^2\right)}} \right)^2 \quad \ldots(1)$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Y_{obs} - Y_{sim})^2}{\sum_{i=1}^{n} (Y_{obs} - \overline{Y}_{obs})^2} \right] \quad \ldots(2)$$

$$PBIAS = \frac{\sum_{i=1}^{n} (Y_{obs} - Y_{sim})}{\sum_{i=1}^{n} Y_{obs}} \times 100 \quad \ldots(3)$$

$$RSR = \frac{RMSE}{STDEV_{ob}} = \frac{\sqrt{\sum_{i=1}^{n} (Y_{obs} - Y_{sim})^2}}{\sqrt{\sum_{i=1}^{n} (Y_{obs} - \overline{Y})^2}}$$

$\overline{Y}_{obs}$

$\overline{Y}_{sim}$

Results and discussions

Sensitivity analysis was executed to identify parameters implemented in SWAT-CUP during the calibration and validation process (Figure 1). In table 3, 19 flow and 12 sediment yield parameters separated as default parameters. Four parameters, CN2, GW_DELAY, ALPHA_BF and CANMX showed high sensitivity (Table 3). These informed CN2 associations with precipitation to generate runoff in the watershed (Van Liew et al., 2005). Groundwater and base flow were the most important variables in the study watershed (Xue et al., 2014). Subsequently, the parameters SPCON, Ch_COV2 and USLE_K approved high priority for calibration of sediment load (Table 3); they were associated with channel sediment, channel cover and erodibility.

Table 3. Default parameters of streamflow and sediment load at proposed Middle Awash Dam Watershed.

	Parameter	Description of parameters	Range Value	t_stat	p_value	Rank
Streamflow Parameters	CN2	Runoff curve number	35 – 98	19.98	0	1
	GW_DELAY	Groundwater delay	0 – 500	-6.15	0	2
	ALPHA_BF	Baseflow	0 – 1	2.72	0	3
	CANMX	Maximum canopy storage	0-10	-2.69	0	4
	SOL_Z	Soil depth	0 – 3000	-2.06	0.03	5
	ESCO	Soil evaporation compensation	0 – 1	-1.9	0.06	6
	GW_REVAP	Groundwater revap coefficient	0.02 – 0.2	-1.39	0.16	7
	CH_N2	Manning's "n" value for the main channel	0 - 4	-1.36	0.17	8
	SLSUBBSN	Average slope length	0.01 –30	-1.15	0.25	9
	EPCO	Plant uptake compensation	0 – 1	0.79	0.43	10
	SOL_ALB	Soil Albedo	0 - 0.25	-0.73	0.46	11
	SURLAG	Surface runoff lag time	0 - 10	-0.7	0.48	12
	SOL_K	Saturated hydraulic conductivity	0 - 100	0.67	0.51	13
	SOL_AWC	Available water content of soil	0 – 1000	0.66	0.56	14
	GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur	0-5000	0.52	0.6	15
	CH_K2	Effective hydraulic conductivity of main channel alluvium	0 - 150	0.1	0.89	16
	RCHRG_DP	Deep aquifer percolation fraction	0 - 1	0.06	0.92	17
	REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur	0 - 500	0.05	0.95	18
	BIOMIX	Biological mixing efficiency	0 - 1	0.01	0.97	19
Sediment load Parameters	SPCON	Linear channel sediment routing	0.0001-0.01	0	-25.4	1
	CH_COV2	Channel cover	0.0-1.0	0	-6.01	2
	USLE_K	USLE soil erodibility	0-0.65	0	3.62	3
	USLE_P	USLE support practice factor	0.0-1.0	0.1	1.33	4
	R_NSED	equilibrium sediment concentration of reservoir	0-5000	0.18	1.29	5
	CH_COV1	Channel erodibility factor	0.0-1.0	0.2	0.87	6
	HRU_SLP	Average slope steepness	0-1	0.38	0.84	7
	R_SED	initial sediment concentration of reservoir	0-5000	0.73	0.73	8
	SLSUBBSN	Average slope length	10-150	0.85	0.63	9
	SPEXP	Exponential re-entrainment parameter	1.0-2.0	0.88	0.2	10
	USLE_C	USLE cover and management factor	0.0-1.0	0.93	0.12	11
	RSDIN	Initial residue cover [kg/ha]	0-1000	0.96	0.02	12

During calibration, relatively mismatching of hydrograph reports indicated between simulated and observed flow parameters. Therefore, by adjusting the sensitive flow parameters, model output data agreed with the observed flow data (Figures 4-5, Tables 4-5). Calibration and validation of flow and sediment carried out at sub-watersheds 42, 45 and 3 (Hambole, Metehara and Awash gauging station, respectively) (Figures 4-5). Table 4 shows the most sensitive streamflow parameters based on the associated low p_value ($p < 0.05$) and the corresponding high t_stat values. At the three calibration sites, such as Awash, Metehar and Hambole gauging stations, the runoff curve number was the first sensitive flow parameter and SPCON in sediment parameters (Table 4).

Table 4. Summary of calibrated parameters of flow and sediment.

SWAT code Parameters of flow	Range	calibrated results	SWAT code Parameter of sediment	Range	calibrated results
r_CN2	35 – 98	-0.0009	SPCON	0.0001-0.01	0.009
v_GW_DELAY	30_500	32.09	CH_COV2	0.0-1.0	0.3
v_ALPHA_BF	0 – 1	0.811	USLE_K	0-0.65	0.09
v_CANMX	0 – 10	2.03	USLE_P	0.0-1.0	0.81
r_SOIL_Z	0-5000	-0.0015	R_NSED	0-5000	3120
v_ESCO	0 – 1	0.06	CH_COV1	0.0-1.0	0.056
v_GW_REVAP	0.02–0.2	0.08	HRU_SLP	0-1	0.035
v_CH_N2	0 - 0.3	0.19	R_SED	0-5000	3020

Note: *v_means the existing parameter value is to be replaced by the given value.*
r_means the existing parameter value is multiplied by (1 + a given value).

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Generally, after calibration and validation have carried out successfully, the average annual sediment yield of the watershed at the outlet was estimated by the model as 12.8 million ton/year from 1992-2014 study period (Figure 5).

Table 5. Summary of calibrated and validated performance criteria 's for monthly flow and sediment yield simulations and model uncertainty measurements.

	Simulation (Months)	Station	Uncertainty Measures		Model performance indicators			
			P- factor	R-factor	R^2	ENS	RSR	PBIAS
Streamflow	Calibration (1992-1999)	Hombole	0.72	0.69	0.81	0.76	0.48	12.29
		Metehara	0.86	0.93	0.80	0.79	0.46	-12.4
		Awash	0.77	0.93	0.79	0.78	0.45	-4.24
	Validation (2000-2006)	Hombole	0.63	0.84	0.8	0.78	0.46	-8.55
		Metehara	0.77	0.91	0.8	0.76	0.45	-9.3
		Awash	0.73	0.92	0.82	0.8	0.46	2.99
Sediment yield	Calibration (1990-1999)	Hombole	0.56	0.76	0.82	0.79	0.44	14.3
		Metehara	0.85	0.93	0.8	0.79	0.46	-13.3
		Awash	0.86	0.52	0.78	0.77	0.48	8.41
	Validation (2000-2006)	Hombole	0.54	0.84	0.78	0.77	0.48	0.1
		Metehara	0.65	0.73	0.77	0.8	0.46	-11.3
		Awash	0.77	0.68	0.81	0.79	0.46	12.8

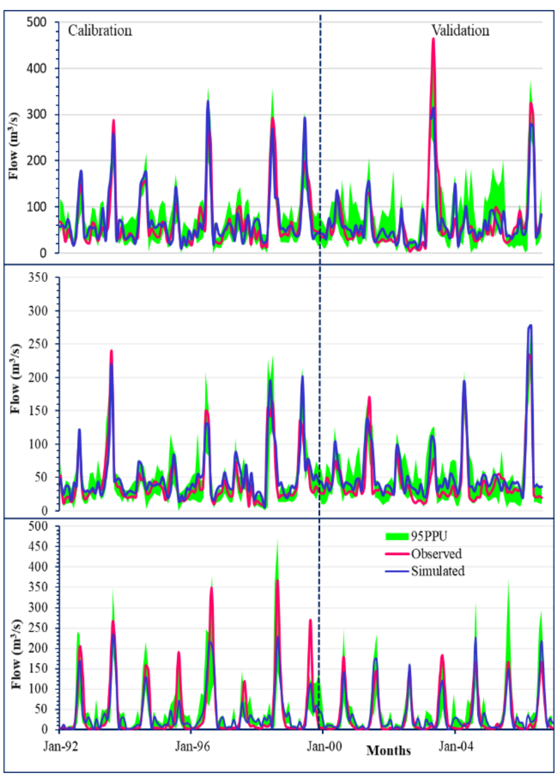

Figure 4. Monthly calibrated and validated flow results at Awash (top), Metehra (middle) and Hombole (bottom) gauging station.

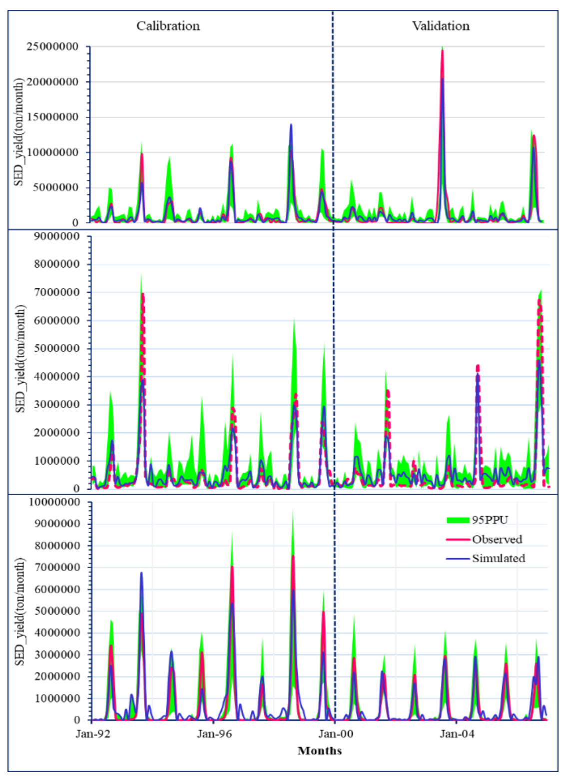

Figure 5. Monthly calibrated and validated sediment yield results at Awash (top), Metehra (middle) and Hombole (bottom) gauging station.

Spatial and temporal variability of sediment yield

a. Spatial variability

Following the successful calibration and validation of the flow and sediment yield, SWAT was run for 22 years (1992-2014) to get average annual sediment yield with sub-watershed level. In figure 6, the sediment outflow from each sub-watershed displayed. Accordingly, the variability of sediment yield for the entire sub-watershed has identified, and the predicted value ranges from 0.2 to 30.4 tons/ha/year with an average of 7.23 tons/ha/year (Figure 6). The sediment source map generated by using the average annual sediment yield from each sub-watershed based on erosion potential or sediment yield (ton/ha/year) (Figure 6). After simulation and calibration have performed, two sub-watersheds identified as very high sediment sources, seven sub-basins categorized as high sediment sources, nine sub-watersheds as moderately sediment sources, 17 sub-watersheds with low erosion and the remaining 34 sub-watersheds were shallow erosion-prone areas (Figure 6). These are an indicator of sustainable watershed management to control sedimentation (Anton et al., 2016), increasing the life span of reservoirs (Ezugwu, 2013).

For sediment yield rate, 11% (covering 12.7% of the total watershed area) of the sub-watershed is a critical source area and contributing 15-30.4 ton/ha/yr relatively higher; 13% of the sub-watersheds (covering 17.95% of the total watershed area) contribute relatively moderate (10-15tons /ha/yr), and the sub-watersheds covering 69.3% of the total area are contributing 0-10 ton/ha/year (Figure 6). Ranking of sub-watersheds based on their sediment yield rate (ton/ha/year) shows 19 sub-watersheds, which have a contribution of greater than 10 tons/ha/year, were identified (Figure 6).

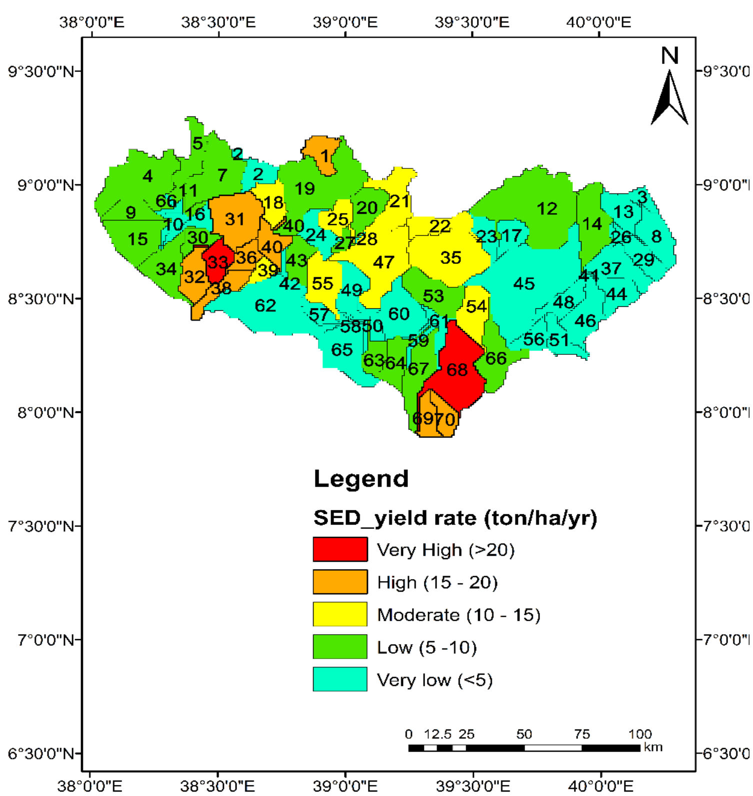

Figure 6. Variability of sediment yield in the proposed Middle Awash Dam watershed

As shown in table 7, sub-watersheds dominantly covered with agricultural land, grassland, shrublands and sparsely populated forest lands are the primary sources of sediment yield. Moreover, these sub-watersheds dominantly covered with Vertisols and Chromic Luvisols soil types (Figure 2). These indicated that these types of soil are the source of sedimentation. According to Virmani et al. (1994), Vertisols, Cambisols, and Luvisols can be affected by critical erosion problems. Among the 19 sub-watersheds ranked based on their sediment yield contributions, eight sub-watersheds have a slope greater than 5%, which is relatively steeper (Table 7).

Table 7. First 19 selected prioritized sub-watersheds based on sediment contribution.

Sub basin	Area (km^2)	SWAT Dominant Land use		Mean slope	SED yield (ton/ha/yr)
		Land use type	coverage		
33	228.97	Agricultural and Range brush	90%	4.80%	30.05
68	739.45	Agricultural, and Range brush	92%	5.90%	20.48
36	163.37	Agricultural & sparse forest	100%	3.80%	19.77
32	299.8	Agricultural & Range brush	82%	5.60%	18.78
1	230.71	Agricultural, Range grass and Range brush	90%	6.90%	16.68
38	223.32	Range brush, Agricultural & sparse forest	88%	5.60%	16.62
69	171.05	Range brush, Agricultural & sparse forest	85%	7.30%	15.49
31	523.52	Range brush, Agricultural & sparse forest	100%	6.40%	15.47
40	225.06	Range brush, Agricultural & sparse forest	100%	3.10%	15.42
54	293.68	Agricultural & Range brush	100%	4.40%	13.78
18	228.09	Range brush, Agricultural & sparse forest	91%	4.80%	13.73
70	165.53	Range brush, Agricultural & sparse forest	74%	8.90%	12.9
55	339.73	Agricultural & Range brush	94%	3.10%	12.63
22	246.76	Agricultural & Range brush	97%	3.30%	12.09
39	139.92	Range brush, Agricultural & sparse forest	100%	3.70%	11.59
25	181.6	Range brush, Agricultural & sparse forest	100%	6.80%	11.82
35	723.79	Agricultural & Range brush	97%	4.40%	10.46
47	718.14	Agricultural & Range brush	96%	2.70%	10.18
21	396.21	Range brush, Agricultural & Wood land	100%	2.90%	10.01

When a seasonal and robust rainfall is associated with high intensity and high volume, such soils may be subjected to initiation to erosion. The most upstream sub-watersheds contribute most of the annual sediment yield. This upstream watershed sediment source is due to the frequent and intensive precipitation and runoff generated than the lower sub-watersheds (Figure 7).

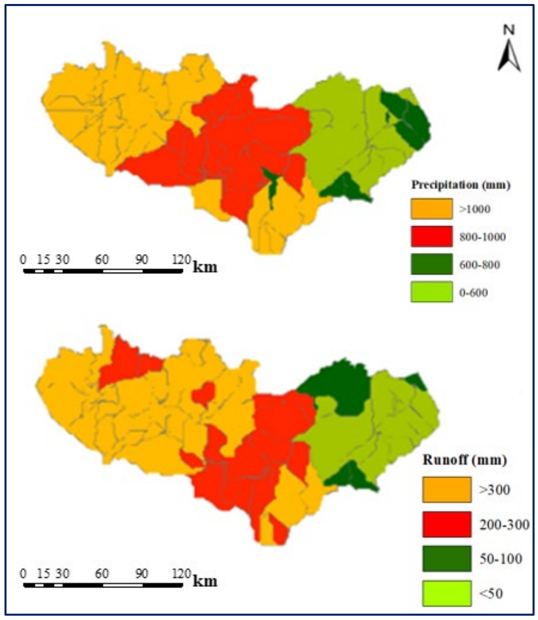

Figure 7. Spatial distribution of precipitation with the corresponding generated runoff.

b. Temporal variability

As the average monthly sediment yield graph estimated by the model (Figure 8), the sediment yield in each year increased during the months of high precipitation events. About 70.8% of the total annual sediment yield has occurred during July, August and September. The above temporal variability of sediment indicates surface runoff which is higher during July, August and September. In this study watershed, during these months' runoff was higher due to relatively higher precipitation occurrence. Likewise, in a monthly case, the watershed's annual sediment yields positively correlated with runoff and precipitation. For example, the maximum surface runoff occurred in 1996 and 2007, leading to maximum sediment yield with a mean annual rainfall of the year, which is relatively maximum. On the other hand, in 2002, relatively minimum precipitation was predicted and generated a relatively minimum runoff magnitude (114.27mm). This developed a proportionally minimum annual sediment yield of 6.4 tons/ha/year (Figure 8).

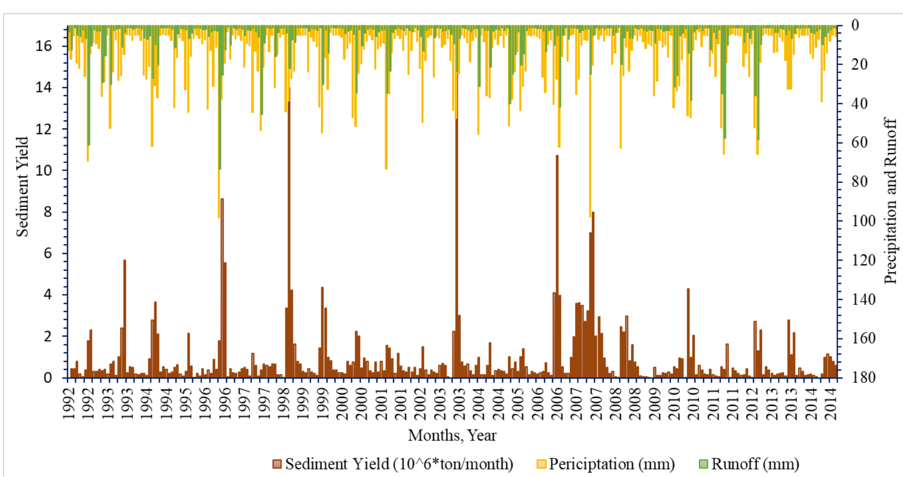

Figure 8. Monthly sediment yields potential variability and relation with Precipitation and runoff.

Conclusions

In this study, sediment yield characterization and identification of critical source areas attempted for the proposed Middle Awash Dam watershed. The entire watershed was subdivided into 70 sub-watersheds spatially linked by stream networks that take part in sediment source contribution. Multi-site calibration technique was applied. During calibration of flow, curve number was the first sensitive parameter. Similarly, the linear re-entrainment parameter for channel sediment routing was the most sensitive sediment parameter. The performance of the SWAT model was a perfect prediction ability. The watershed's average annual sediment yields informed that the watershed needs considerable management, about 30.65% of the total watershed area identified as a critical sediment source area. The majority of the required source area is relatively steeper in slope and dominantly covered with agricultural land, grassland and bushlands. The most upstream sub-watersheds are somewhat the source of sediment due to high runoff generated from high seasonal rainfall from July to September. In general, the model's performance has a strong predictive capability for the modelling of the hydrological process of the proposed Middle Awash Dam watershed for multi-site sediment yield calibration.

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