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Assessment of Sediment Inflow in Dire Dam Reservoir Using SWAT Model, Dire Catchment, Ethiopia

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Abstract: Soil erosion and associated sedimentation are a natural process caused by water, wind, and ice, several of human's activities such as deforestation, overgrazing, change in land use, and non-sustainable farming practice tends to accelerate soil erosion. This paper presents the runoff and sediment yield modeling of Dire watershed which is a drainage area of 76.058km^2. soil and water assessment tool (SWAT, Version 2012) integrating with ArcGIS (Version10.4) was used to simulate the streamflow and sediment yield of Dire watershed which located in the Awash river basin from 1990 to 2006. The model calibration and validation of streamflow and sediment yield were done using the SWAT_CUP software SUFI2 program. The streamflow data used for model calibration and validation was measured Beke gauge station from 1990 to 2006 but the sediment data use for both calibration and validation were generated using sediment rating curve. Time-series data from 1991 to 2000 were used for both streamflow and sediment calibration and a time series data from 2002 to 2006 was used for validation. Based on this data the model performance was evaluated by using the Coefficient of determination (R^2) and Nash Sutcliffe Efficiency (NSE). During Flow calibration and validation result the Coefficient of determination (R^2) and Nash Sutcliffe Efficiency (NSE) were 0.9, 0.84, 0.77, and 0.68 respectively. for sediment calibration and validation Coefficient of determination (R^2) and Nash Sutcliffe Efficiency (NSE) were 0.73, 0.66, 0.7, and 0.68 respectively. During the assessment of this study, the average annual sediment yield generated from dire watershed was 108.898 tone/year modeled and sub-basin 3, 2 and 7 were the most eroded sub-basin among 9 sub-basin with annual sediment yield180.534 tons/yr, 155.335, 137.066 tons/yr and 75.770 tons/yr and the average reservoir trap efficiency is 96.27%, the reservoir life expectancy of the Dire dam was 31 years.

Keywords: Dire Watershed, Sediment Yield, Reservoir Sedimentation, Reservoir Life Expectancy, SWAT Model, SWAT_CUP, SUFI2

1. Introduction

Erosion and sedimentation embody the process of erosion, transportation, and deposition of solid particles often called sediment. These natural processes have been active throughout geological time and have presented the landscape of our world. Today, erosion transport and sedimentation can cause severe engineering and environmental problems. Today's worldwide yearly mean loss of reservoir storage capacity due to sedimentation is already higher than the increased capacity by the addition of a new reservoir of irrigation, drinking water, and hydropower. depending upon such a problem it is commonly accepted that about 1-2% of the worldwide reservoir capacity is lost annually [1]. Approximately 40% of the world's fertile soil is excessively degraded as a result of erosion [2]. Soil erosion in Ethiopia as a whole has reached the highest level and increasing under the combined pressure of increasing population and deforestation. Soil erosion and sedimentation may be regarded as it undermines both current and future agricultural production, long-term use of water resources dependent on reservoir and dams. Based on different studies soil erosion is one of the serious problems in Ethiopia's highland area that increased sedimentation of reservoir and lakes due to the fact that either the upstream sediment supply is never considered or underestimated mainly due to lack of different data [3] The amount of soil erosion generated from Ethiopian highland was estimated at 130 tons per hectare year for cropland area and 35 tons per hectare year [4].

The main objective of this study is to assess the amount of sediment inflow in Dire dam reservoir using the SWAT model and this research tries to address the following specific objective: -

a) To predict surface runoff and sediment yield from Dire watershed to Dire reservoir.
b) To identify the most susceptible erodible sub-basin area and the corresponding best management scenarios in Dire Dam watershed.
c) To estimate reservoir life due to sedimentation inflow.

2. Description of the Study Area

The Dire Dam is located in Berek Woreda in Oromia National regional state Ethiopia. The dam site and reservoir area are located on the perennial Legeddadi stream and within Dire-Sokoru kebele about 40km north_east of Addis Ababa-Dessie highway. Geographically the dam is located at 9° 46' 73.58" Northing and 38° 56' 49" Easting at an altitude of 2675m above mean sea level. The watershed area is cover 76.058km^2.

The area is characterized by moderate weather with average annual maximum Temperatures ranging from 22°C-24°C while the average annual minimum temperature is ranging from 8°C-10°C and the mean annual rainfall of the watershed area is 1200mm. The Dire sekoru watershed is comprising different land use land cover that exists surrounding the reservoir area. The mainland use type that exists in the catchment area is characterized by high cultivated land (hill slope cultivation and valley cultivation), forest mixed, barren land build area, and waterbody (Reservoir) along the reservoir area.

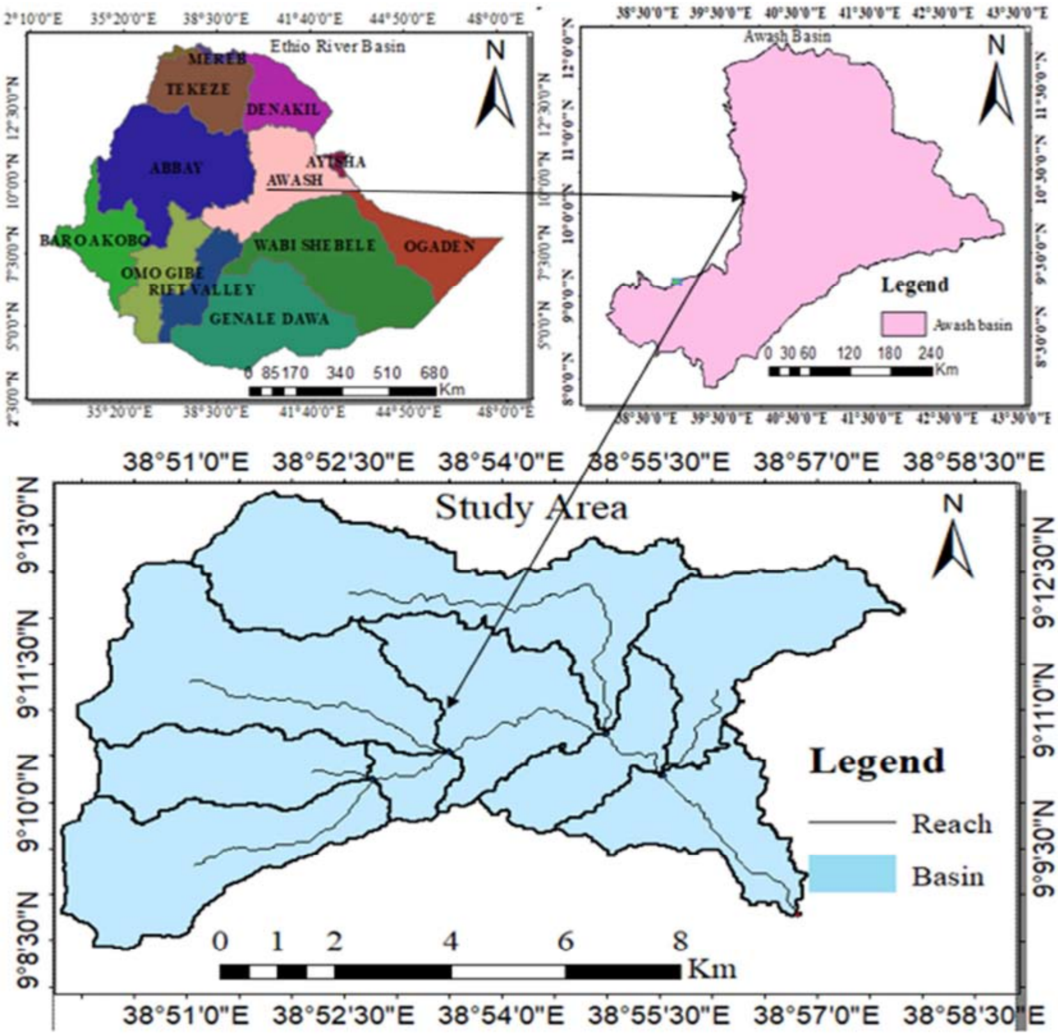

Figure 1. *Location of the study area.*

3. Material and Methods

During this study, a physical based SWAT model was used for the assessment of streamflow and sediment yield in the dire watershed. For the satellite image classification, Arc GIS 10.4 was used for land use land cover classification of the study area. the performance of the model was evaluated through sensitive analysis, calibration, and validation using the coefficient of determination (R^2) and Nash Sutcliffe coefficient (NSE).

3.1. Description of the SWAT Model

The Soil and Water Assessment Tool (SWAT) is the physical-based numerical model, continuous-time model, and A watershed-scale numerical model for the simulation of water, sediment, nutrient, and pesticide movement in surface and subsurface systems. The SWAT model aids in the prediction of the impact of climate and vegetative change, reservoir management, groundwater withdrawals, water transfer, land-use change, and watershed management practices on water sediment and chemical dynamics in complex watershed systems [5]. SWAT can be also to analyze the watershed by subdividing the area into the homogeneous part and analyzes the behavior of each part before examining how each part interacts with the watershed as the whole. SWAT uses a daily and monthly time step, continuous for 1 to 100years [6].

3.2. SWAT Model Component

The hydrology component of the SWAT model is based on the water-balance equation [5]. The water balance in the SWAT models relates to soil water, surface runoff, interception, daily amount precipitation, evapotranspiration, percolation, lateral subsurface flow, return flow or base flow, and transmission losses, [7]. The second component is the routing phase of the hydrological cycle in which the water is routed in the channel network of the watershed, carrying the sediment, nutrients, and pesticides in the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the following water balance equation [8].

$$Swt=Swo+\sum(Rdav-Qsur-Ea-Wseep-Qgw) \quad (1)$$

Where Swt is the final soil water content (mm), Swo is the initial soil water content for a day (mm), t is days (days), Rday is the day precipitation (mm), Qsur is the surface runoff (mm) Ea is evapotranspiration (mm), Wseep is seepage from the bottom soil layer (mm) and Qgw is the groundwater flow on a day (mm).

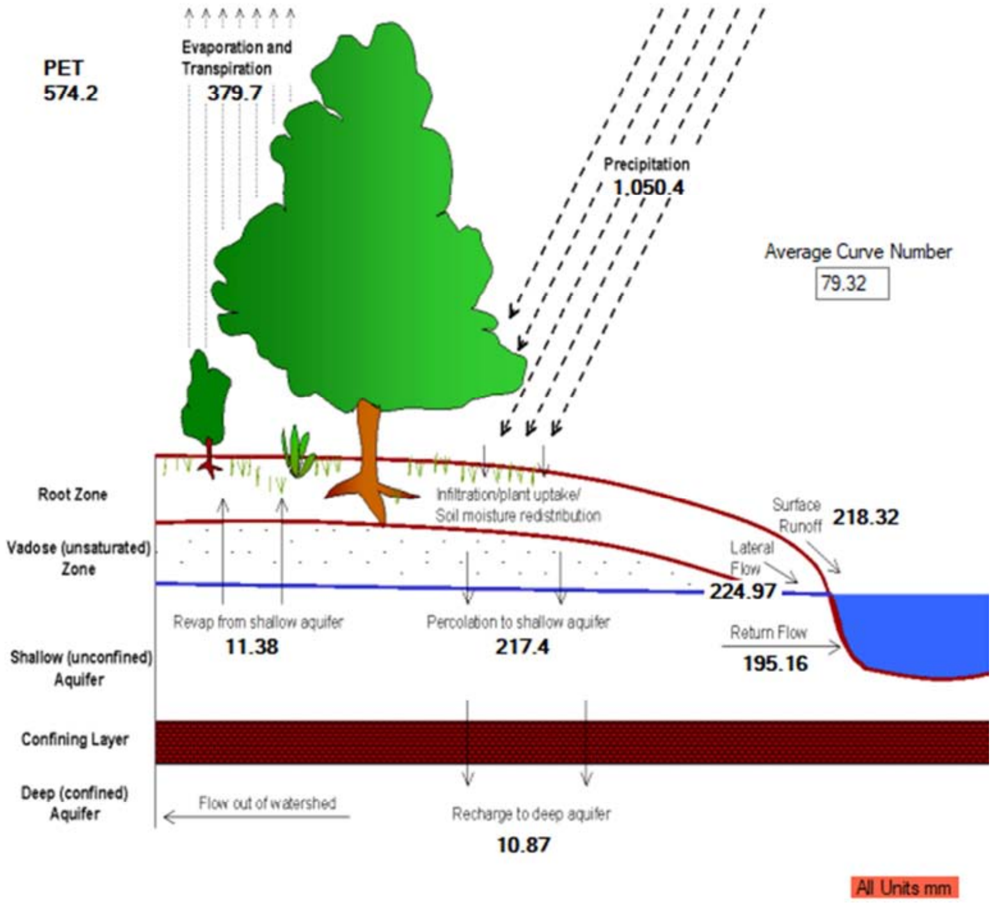

Figure 2. *SWAT hydrological consideration from Arc SWAT model output.*

3.3. SCS Curve Number (Surface Runoff)

The SCS runoff equation is an empirical model that come into common use in the 1950s. I t was the product of more than 20 years of studies involving rainfall-runoff relationships from the small rural watershed [9].

$$Qsur=\frac{(Rday-Ia)^2}{Rday-Ia+S} \quad (2)$$

Where Qsur is the accumulated runoff or rainfall excess

(mmH_2O), Rday is rainfall depth for the day (mmH_2O), Ia is the initial abstraction which includes surface storage, interception, and infiltration before runoff (mmH_2O), and S is the retention parameter (mmH_2O),

The retention parameter varies spatially due to change in soils, land uses, management, and slopes and temporally due to change in soil water content. The retention parameter is defended as

$$S=25.4*(\frac{1000}{CN}-10) \quad (3)$$

Where CN is the curve number for a day. The initial abstraction, Ia is commonly approximated as 0.2*S the accumulated surface runoff equation becomes.

$$Qsur=\frac{(Rday-0.2S)^2}{(Rday+0.8S)} \quad (4)$$

when runoff only occurs when Rday is greater than Ia. Therefore, there is some amount of rainfall Ia (initial abstraction before ponding) for which no runoff will occur (i.e., runoff is zero) [10].

The amount of sediment yield in the watershed area and for each sub-basil is estimated by using Modified Universal Soil Loss Equation (MUSLE) which is given by as follows.

$$Sed=11.8\,(Qsurf*qpeak*Ahru)^{0.56}*K_{USLE}*C_{USLE}*P_{USLE}*L_{SUSLE}*CFRG \quad (5)$$

Where: -Sed-is the sediment yield on a given day (metric tons), Qsurf-is a surface runoff volume (mm/ha), Qpeak is a peak runoff rate (m^3/sec), Ahru is the area of the HRU (Ha), K_{USLE} IS The USLE soil erodibility factor, C_{USLE} is USLE Cover and management factor, P_{USLE} IS THE USLE support practice factor, L_{LSUSLE} is the USLE topographic factor, CFRG is the coarse fragment factor.

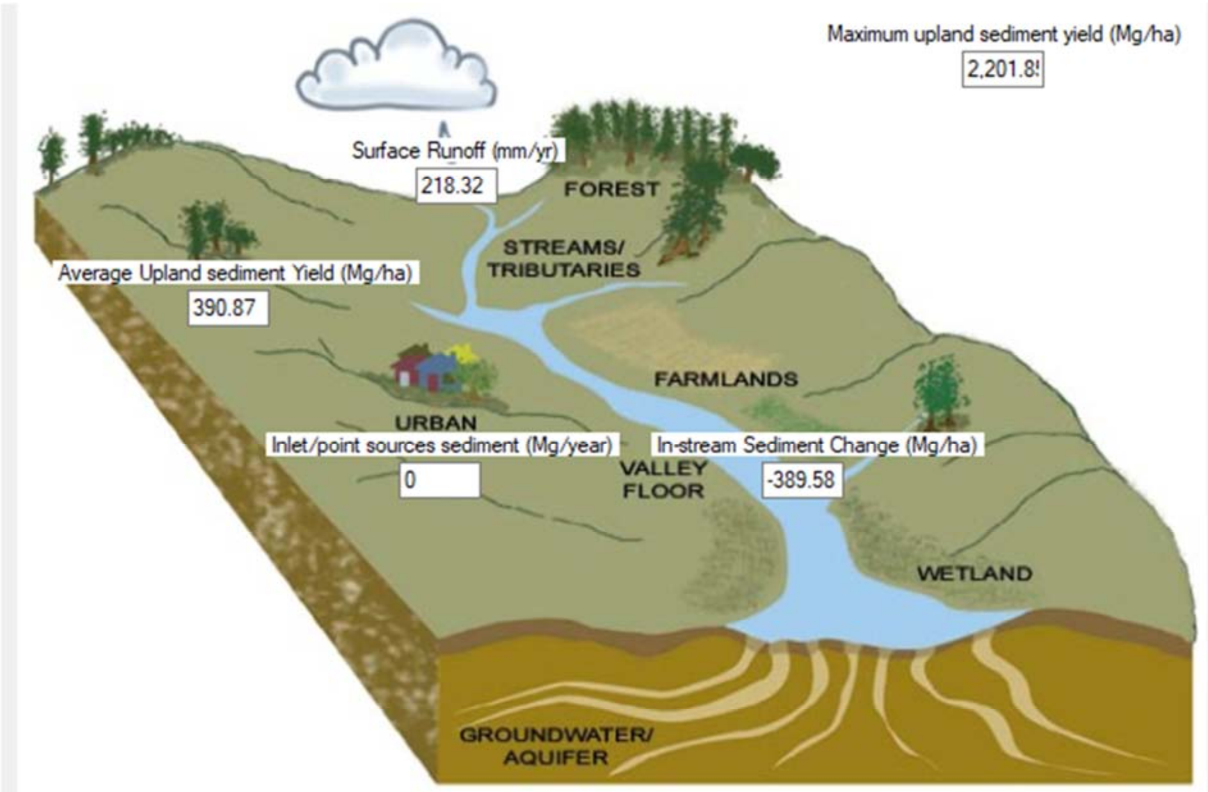

Figure 3. *Sediment concentration in the study area from the SWAT model output.*

3.4. Model Input

3.4.1. Digital Elevation Model (DEM) Data

Digital Elevation Model (DEM) is one of the main inputs for the calibration and validation of the SWAT model. The resolution of the Digital Elevation Model (DEM) is the most critical input parameter when developing a SWAT model [7]. The Digital Elevation Model (DEM) of the study area is collected from the Ministry of Water Resource, Irrigation, and Electricity of the Ethiopia GIS department. The DEM of the Dire watershed area was extracted from this with the spatial resolution of 30mx30m by using Arc-GIS Arc hydro tools.

3.4.2. Land Use and Land Cover Data

Land-use/ land-cover data also a major significant effect on the hydrological modeling of surface runoff and sedimentation. For this study, the land-use/land-cover data is obtained from USGS (the United States Geological Survey) Landsat database with the spatial resolution of 1km, which distinguishes land use land cover class. After processing this USGS Landsat image in Arc-GIS, This Landsat image is classified by using supervised classification in ArcGIS software. based on this supervised classification the land-use/land-cover of the Dire watershed study area is contained agricultural land, forest mixed, barren land, water body, and buildup area. The land use of the study area was projected to WGS1984 UTM Zone37N using the raster projection in Arc-Map before it was imported to Arc-SWAT.

Table 1. *LULC type and Area Coverage in Dire watershed (model output).*

Land-use/land-cover	SWAT Code	Area coverage (ha)	% of area coverage over the whole watershed
Agricultural land	AGRL	4105.6554	53.98
Forest Mixed	FRST	1405.5216	18.48
Build up Area	URBN	1963.7994	0.91
Waterbody	WATR	68.8827	0.81
Barren land	BARN	61.9761	25.82

3.4.3. Soil Data

In addition to DEM data, soil data is another spatial input data required for the modeling of streamflow and sedimentation in the SWAT model. The soil map of the Awash basin is obtained from the Ministry of Water, Irrigation, and Electricity GIS department (MOWRIE). Which projected to WGS1984 UTM Zone37N using the raster projection in ArcMap before it's used in as input of the Arc SWAT model. The soil of Ethiopia is not available in the SWAT database. So, to generate the soil type of the study area we should be edit and giving Arc SWAT database coding and represent it in the lookup table as shown Table 4 below.

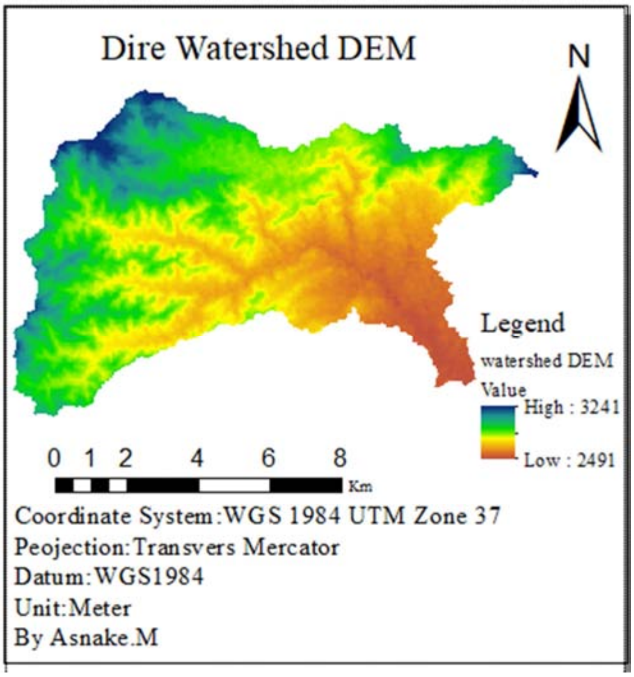

Figure 4. *Study area DEM map.*

Table 2. *Soil type and area coverage in Dire watershed (Model output).*

Soil type	SWAT Code	Area Coverage (ha)	% of area coverage over the whole watershed
Orthic solonchakes	Orthic solonchakes	2192.6111	28.83
Calcic Xerosoils	Calcic Xerosoils	869.5059	11.43
Cromic Luvisoils	Cromic Luvisoils	4015.2137	52.79
Pellic Soils	Pellic Soils	454.5417	5.98
Leptosoils	Leptosoils	73.964	0.97

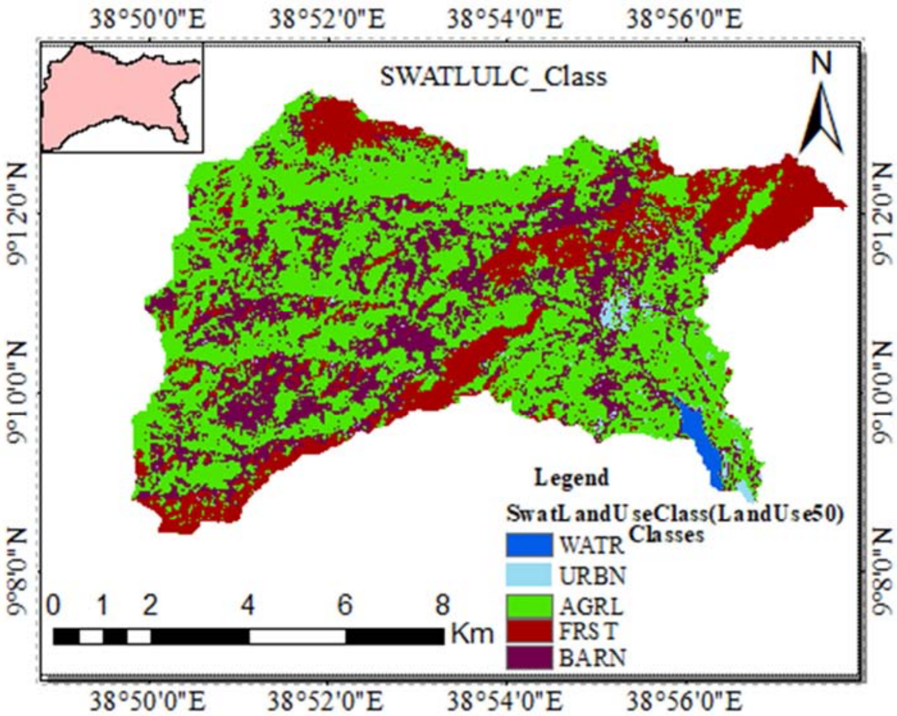

Figure 5. *Study area LULC classification map.*

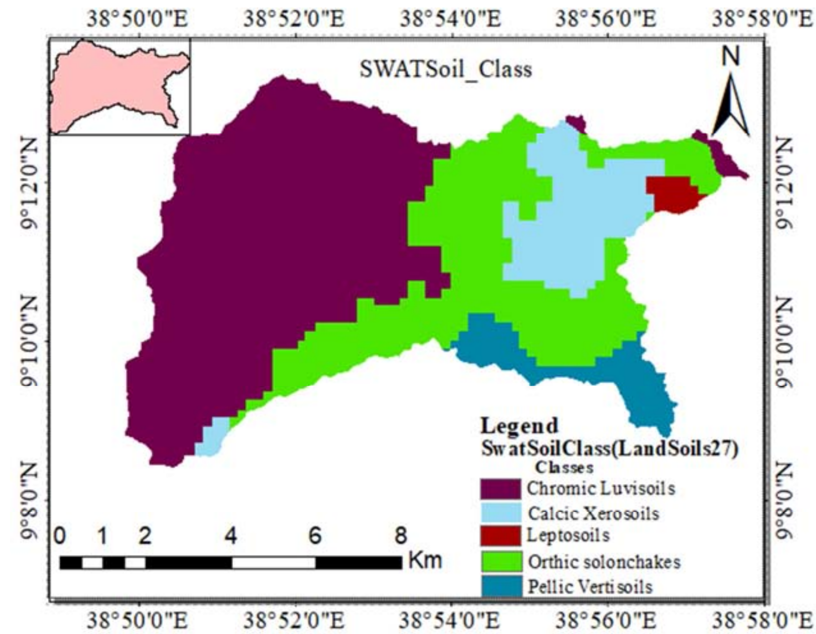

Figure 6. *Study area Soil classification map.*

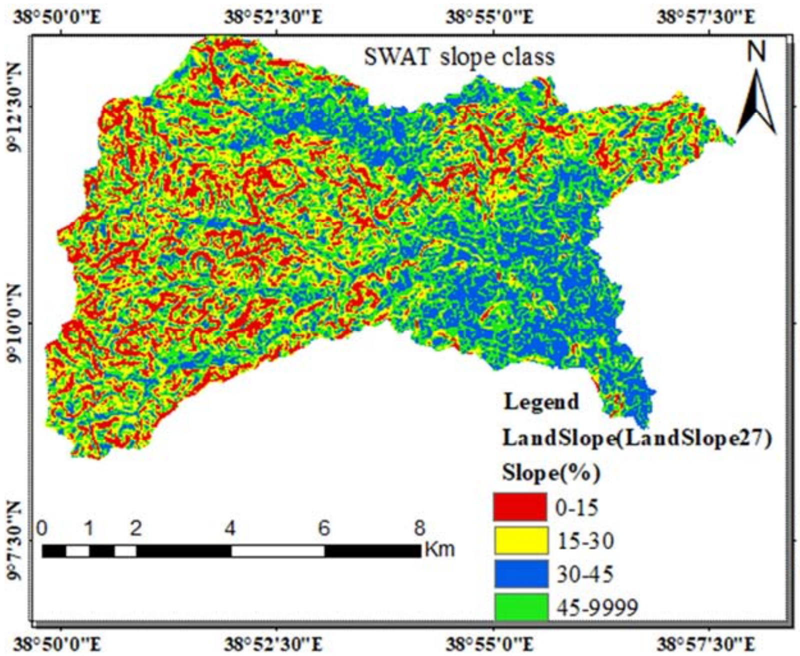

Figure 7. *Study area Slope classification map.*

3.4.4. Streamflow and Sediment Data

SWAT model simulates streamflow and sediment yield transport at a catchment scale, on a continuous, daily time step [5]. The observed streamflow data were collected from the Ethiopian Ministry of Water, Irrigation, and Energy bureau hydrology department from 1990-2006. The streamflow data which is observed from 1990-2000 was used for model calibration and the remaining streamflow data from 2002-2006 was used for model validation. The monthly observed sediment data also observed in the Kessem river Beke gauge station. This sediment data was taken from Ethiopian Ministry of Water Irrigation and Energy (EMOWIE) hydrological department for the year 11-Nov-1992 up to 9-Sep-2007 with three times of recording time.

In the limitation of the sediment data, the sediment data used for model calibration and validation is generated using the sediment rating curve. The sediment rating curve giving the sediment load concentration (qs) in tones/day concerning daily discharge (Q) in m^3/sec can be expressed in mathematical equation: -

$$qs=kQ^n \quad (6)$$

taking a log in both sides, logqs=logk+nlogQ and this equation is a similar linear regression equation.

$$Yi=aXi+b \quad (7)$$

where Yi is the independent variable, in this case, sediment discharge, xi is an independent variable measured discharge value, b is the intercept and a is the slope of the graph. In a mathematical solution, the value of a and b is determined by using the following equation.

$$a=\frac{\sum Y.\sum\sum X2-\sum X\sum XY}{N\sum\sum X2-(\sum X)2},\ b=\frac{N\sum Y\sum XY-\sum X\sum Y}{N\sum X2-(\sum X)2}$$

This linear regression method is used for estimating the unknown intercept (b) and slope (a) from the observed sediment and discharge data [11].

The sediment data which collected from MOWR were in concentration basis it converted into tone per day using the following equation

$$Qs=0.0864*C*Q \quad (8)$$

Where Qs is total sediment in tone per day, C is total sediment concentration (mg/l) and Q is daily mean water discharge in m3/sec.

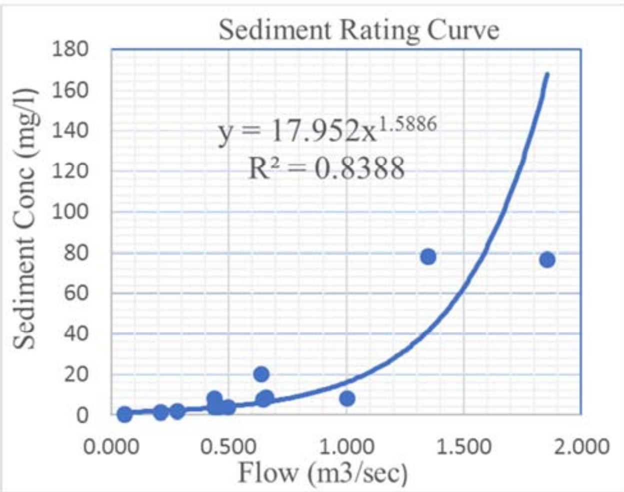

Figure 8. *Sediment rating curve.*

3.5. Method of Data Analysis

Hydrological studies require extensive analysis of meteorological, hydrological, and spatial data to represent the actual processes taking place on the environment and better estimation of quantities out of it. The daily observed of rainfall, maximum and minimum temperature, relative humidity, solar radiation, wind speed, and solar radiation area recorded from five stations such as Addis Ababa bole airport station (1990-2006), Sendafa station (1990-2006), Inttoto station (1990-2006) and Dire gidib station (2000-2006) is obtained from Ethiopian National meteorology Agency.

Filling Missing Data

Due to the absence of observer or instrumental failure data records occasionally are incomplete. In such cases, one can estimate the missing data by using the nearest station rainfall [11]. For any hydrological model study; checking the availability, quality, consistency, and homogeneity of hydro-meteorological data is necessary. Besides this, any engineering studies of water resources development and management depend heavily on these meteorological and hydrological data [12]. Rainfall data are an important input to hydrological designs, weather measured storm event data or synthetic data. Therefore, to determine whether the data collected meet these criteria, we need to have an efficient screening procedure. A number of methods have been proposed for estimating missing record rainfall data by one of the following methods.

1. Normal Ratio Method

If the annual precipitations vary considerably by more than 10%, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighboring stations by the ratios of normal annual precipitations

$$Px=\frac{Px}{Nx}\left(\frac{P1}{N1}+\frac{P2}{N2}+\frac{P3}{N3}+\frac{P4}{N4}+\text{----}\frac{Pn}{Nn}\right) \quad (9)$$

Where Px is the missing precipitation records

Nx=Annual-average precipitation at a gauge with missing values

N1, N2, N3…. Nm=Annual average precipitation at the neighboring gauge.

2. Simple Average Methods

According to this method, the missing rainfall Px of a station X is computed by the simple arithmetic average of rainfall at nearby stations determined by the following form.

$$Px=\sum\frac{Pi}{Ni}.=\frac{1}{N}.(P1+P2+P3+P4\text{--}+Pn) \quad (10)$$

Where n is the number of index station

Px is precipitation at X station

The above method is used only under the following condition. The normal annual rainfall of the missing station is within 10% of the normal annual rainfall of the station. In this study, the rainfall missing data is fill by using both the simple average and normal ratio method.

3.6. Model Efficiency

There are a large number of performance criteria used by different researchers to quantitatively measure the accuracy, efficiency, and reliability of their models. It is difficult to select one criterion as a benchmark standard and some criteria are only applied to certain specific problems. Generally, they are grouped into graphical and numerical performance indicators [13]. For this study, the numerical performance measures are selected for the SWAT model analysis. From the numerical performance indicators such as coefficient of determination (R2), and Nash Sutcliffe efficiency (NSE), were selected to check the model performance for this study.

1. Coefficient of Determination (R^2)

The coefficient of determination R^2 is defined as the squared value of the coefficient of correlation according to Bravaispearson. It calculated as

$$R^2=\frac{\sum_{i=1}^{n}(Qmi-Qm))(Qsi-Qsm)}{\sum_{i=1}^{n}(Qmi-Qm)^\wedge 2*\sum_{i=1}^{n}Qsi-Qsm)^\wedge 2} \quad (11)$$

Where Qmi is the measured value, Qm is the average measured value, Qsi is the simulated value, and Qsm is the average simulated. The coefficient of determination (R^2) describes the degree of linearity between observed and simulated model input or output value. The correlation coefficients which range from 0 to 1 is an index of the degree of the linear relationship between observed and simulated data. If R^2=0, no linear relationship exists. If R^2=1, a perfect positive linear relationship exists and less error variance between the observed and simulated value. Generally, the value of coefficients of determination (R^2) is greater than 0.5 are considered acceptable.

2. Nash and Sutcliffe Efficiency (ENS)

The ENS is proposed by Nash and Sutcliffe Efficiency (1970) is defined as one minus of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as:

$$ENS=1-\frac{\sum_{i=1}^{n}(Qmi-Qsi)^2}{\sum_{i=1}^{n}(Qmi-Qm)^2} \quad (12)$$

Where: -Qsi is the simulated value, Qmi is the measured value, and n is the total number of observations.

NSE ranges between -∞ and 1.0 (1 inclusive), with NSE=1 being the optimal value. The value between 0.0 to 1.0 is generally viewed as the acceptable level of performance, whereas a value less than 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

Table 3. *Recommended Model performance parameter range.*

Coefficient	Value	Descriptions
R^2	NSE, $R^2 < 0.5$	Unsatisfactory
	$0.5< R^2 \leq 0.65$ $0.5<NSE \leq 0.65$	Satisfactory
NSE	$0.65< R^2 \leq 0.75$ $0.65<NSE \leq 0.75$	Good
	$0.75<R^2 \leq 1.00$ $0.75<NSE \leq 1.00$	Very good

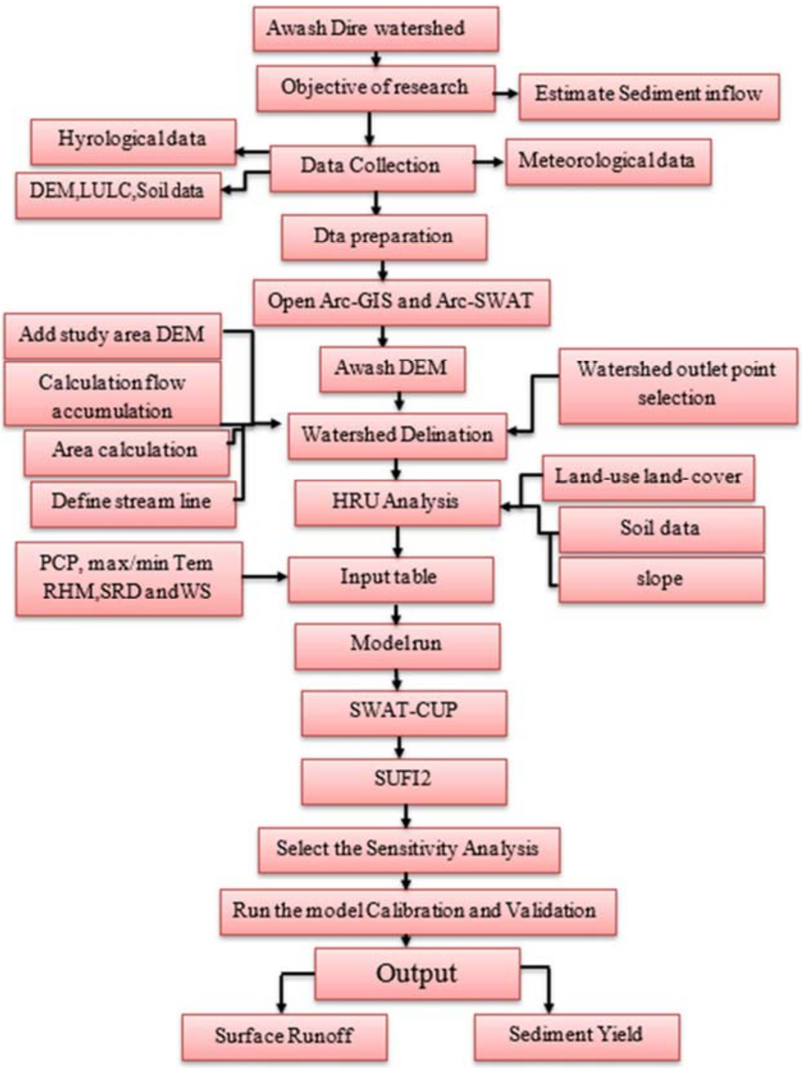

Figure 9. *General framework of the study.*

4. Result and Discussion

4.1. Land Cover Classification

Accuracy Assessment

The land use land cover of the study area is classified based on satellite images obtained from the United States Geological Survey (USGS). The processing and analysis of the satellite image are done by using ArcGIS software. the land use land cover of the study area is classified under five main classes by using supervised classification such as Waterbody, Buildup area, Agricultural area, forested mixed, and Barren land. after classified, the land use land covers the accuracy assessment of image classification was done based on the observed ground truth data to minimize error caused during land cover classification. The accuracy was performed for the 2006 satellite image. This is because during the downloading of satellite images from USGS Earth explorer the last verified satellite data was available for 2006 the accuracy of image classification was checked with the accuracy matrix using a total of 150 random points is selected. This accuracy assessment was done by using the land use land cover map of the study area, ground-truth point, and Google Earth. The average percentage image accuracy assessment of the Dire watershed is 92.59%. the result of this land use land cover classification could be considered as good agreement. Generally, the overall accuracy of the land cover classification is as shown in the following error matrix is given as Table 4.

Table 4. *Accuracy Assessment of LULC classification.*

Predicted	Truth1	Truth20	Truth39	Truth6	Truth60	Class Name	Percentage
1	8	0	0	0	0	Waterbody	89.09%
6	0	45	2	0	0	Buildup Area	62.65%
20	0	2	38	1	1	Agricultural Area	73.33%
39	0	3	0	11	0	Forest Mixed	83.33%
60	1	0	2	0	48	Barren Land	71.98%
Sum	9	50	42	12	49	162	150
	Average Accuracy Percentage						92.59%

4.2. Model Calibration and Validation

Streamflow Modeling

The sensitivity of the simulated flow of Dire watershed was performed using monthly observed data which recorded Beke gauge station. For the identification of the most sensitive parameter, 20 flow parameters were selected and checked as shown Table 5 ten sensitive parameters were selected based on P-Value and t-test and the calibration was done using the SWAT model interface Sequential Uncertainty Fitting program (SUFI2). The streamflow calibration and validation

The SWAT model simulation used for both streamflow and sediment calibration and validation was done by using Monthly observed data from the year 1990 to 2006. flow calibration was performed for the period of 10 years from January 1st, 1991 to December 31st, 2000, and year. from January 1st, 2002 to December 31st, 2006 were used for flow validation. During the flow calibration, and validation the first year 1990, 2001 was considered as a warm-up period respectively.

Table 5. *Flow parameter and its range.*

Sn	Parameter Name	Description of Parameter	Range	Calibrated value	Sensitivity	Significance
1	R__CN2.mgt	SCS runoff curve number	-0.2-0.2	-0.187	1	high
2	R__USLE_K(..).sol	USLE equation soil erodibility (K) factor.	-0.25-0.25	-0.111	2	high
3	R__SOL_K(..).sol	Saturated hydraulic conductivity	-0.2-0.2	-0.111	3	high
4	V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur	0-500	391.25	4	high
5	V_SLSOL.hru	Slope length for lateral subsurface flow	10-150	58.125	5	medium
6	R__EPCO.hru	Plant uptake compensation factor	0-1	0.3825	6	medium
7	V__SLSUBBSN.hru	Average slope length	10-150	20.017	7	medium
8	R__SOL_Z(..).sol	Depth from the soil surface to bottom of the layer	-0.25-0.25	0.011	8	small
9	V__ESCO.hru	Soil evaporation compensation factor	0-1	0.2525	9	small
10	V_RCHRG_DP	Deep aquifer percolation fraction	0-1	0.8725	10	small

Table 6. *Summary of calibrated and validated performance criteria of streamflow.*

Sn	Performance criteria	Calibration (1991_2000)	Validation (2002_2006)
1	Coefficient of determination (R^2)	0.90	0.73
2	Nash Sutcliffe Efficiency (NSE)	0.84	0.68

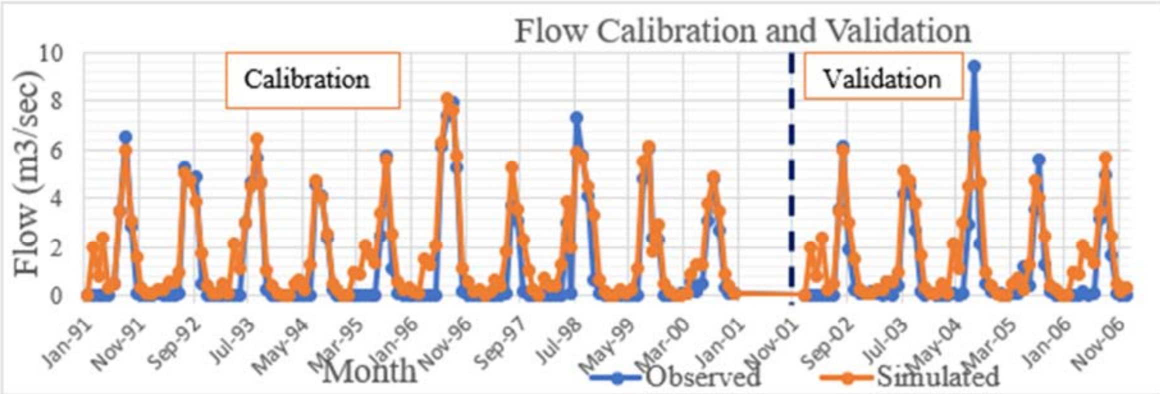

Figure 10. *Time series of observed vs. simulated flow (monthly) calibration period (1991–2000) and Validation period (2002-2006).*

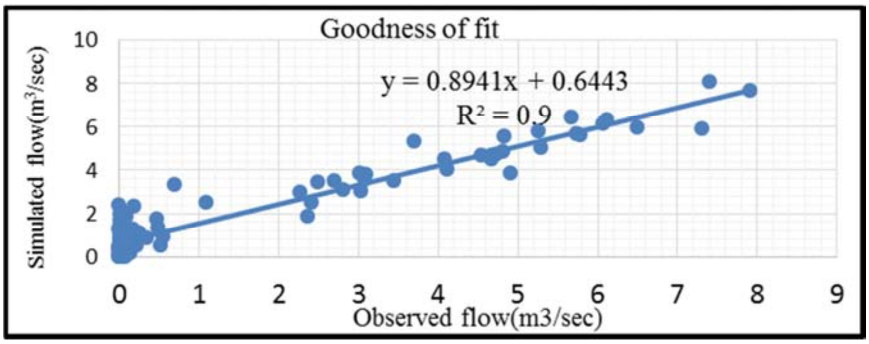

Figure 11. *Goodness of fit for Flow calibration.*

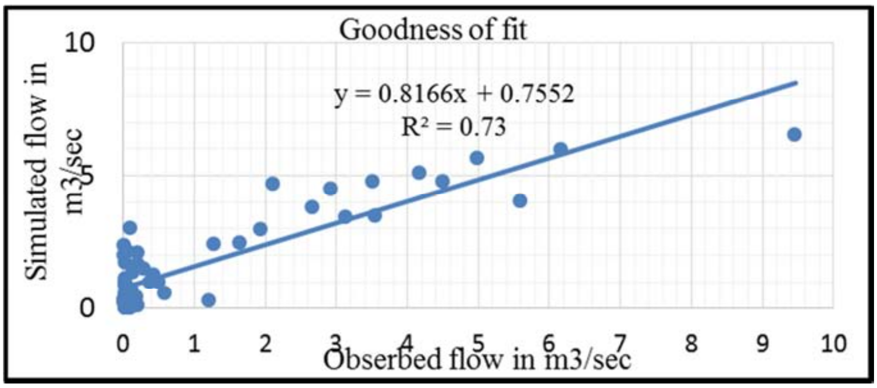

Figure 12. *Goodness of fit for Flow Validation.*

Sediment Yield Modeling

The parameter used for sediment calibration and validation was done using Monthly data generated by the sediment rating curve corresponding to daily streamflow data which recorded from the Kessem river in Beke gauge station from 1990 _2006. Sediment calibration was performed for the period of 10 years from January 1st, 1991 to December 31st, 2000, and years from January 1st, 2002 to December 31st, 2006 were used for Sediment validation. During the Sediment calibration, and validation the first year 1990, 2001 was considered as a warm-up period respectively. The sensitive sediment parameter used for sediment calibration and validation with their range value is as shown below Table 7.

Table 7. *Sediment parameter and its ranges.*

Sn	Parameter Name	Description of Parameter	Range	Calibrated value	Sensitivity	Significance
1	R__CN2.mgt	SCS runoff curve number	-0.2-0.2	-0.187	1	high
2	R__USLE_K(..).sol	USLE equation soil erodibility (K) factor.	-0.2-0.2	-0.1111	2	high
3	R_USLE_P.mgt	USLE equation support practice	-0.2-0.2	-0.183	3	high
4	V_USLE_C. plant	min value of USLE_C factor applicable to the land cover/plant	0.001-0.5	0.336	4	medium
5	V_LAT_SED.hru	sediment concentration in lateral flow and groundwater flow	0-5000	1762.5	5	small
6	V_SPEXP.bsn	Exponential re-entrainment parameter	1-1.5	1.016	6	small

Table 8. *Summary of calibrated and validated performance criteria of Sediment.*

Sn	Performance criteria	Calibration (1991_2000)	Validation (2002_2006)
1	Coefficient of determination (R^2)	0.77	0.7
2	Nash Sutcliffe Efficiency (NSE)	0.66	0.68

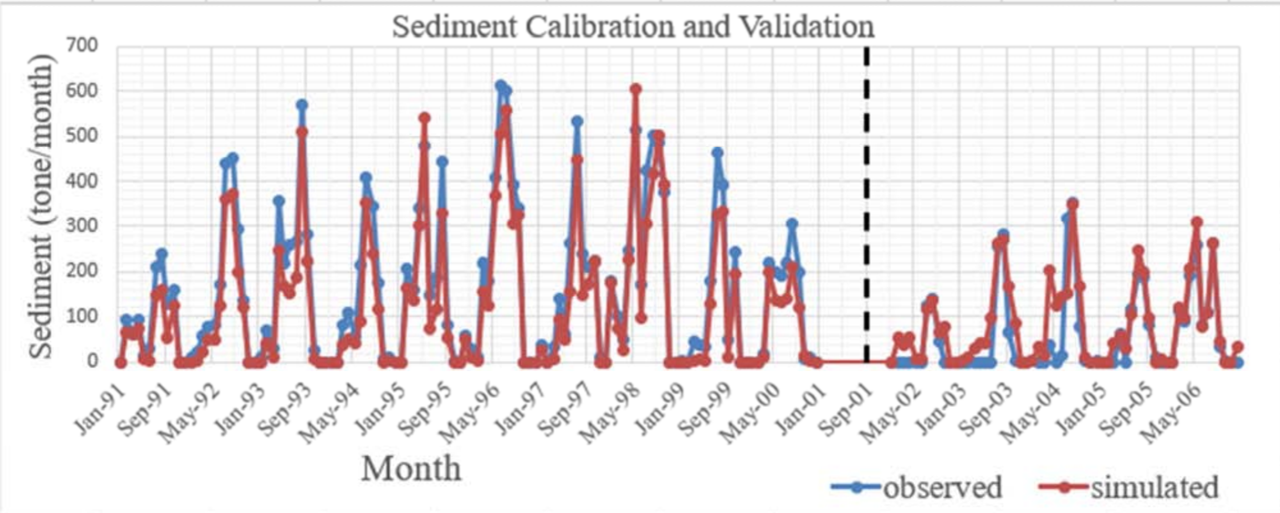

Figure 13. *Time series of observed vs. sediment (monthly) calibration period (1991–2000) and Validation period (2002-2006).*

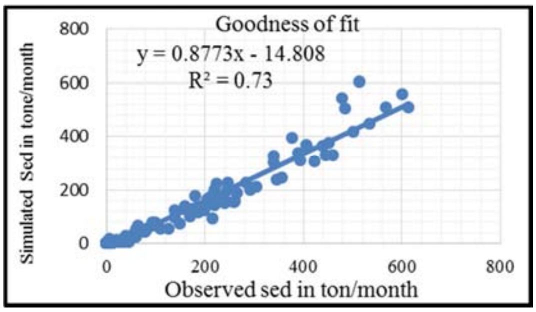

Figure 14. *Goodness of fit for sediment calibration.*

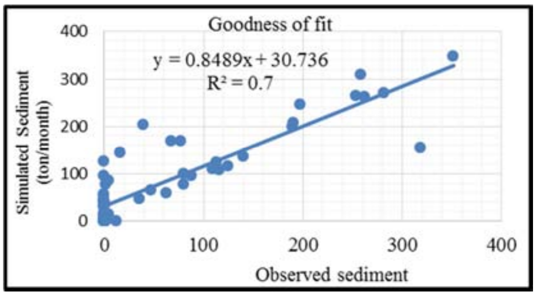

Figure 15. *Goodness of fit for sediment Validation.*

4.3. The sediment of Sub-basin and Sensitive Area

After delineating and reclassify the study area using ArcGIS interface Arc SWAT, the Dire watershed contains 9 sub-basin and four specific sub-basins as shown below Table 8 and Figure 18 Dire Sekoru (Subbasin9, Subbasin4), and Dire Kaki stream (Subbasin5) enter into Dire reservoir with a common course. The other sub-basin Dire Buru Maru (Subbasin1, Subbasin2, Subbasin6, Subbasin7) and Dire Tenkeli Woreli (Subbasin8) also flow several distances before entering into Dire reservoir.

The total average sediment which transported from the whole watershed area is 108.89t/yr. From the Arc SWAT output, the maximum sediment load is eroded from Subbasin3, Subbasin2, Subbasin7, and Subbasin4 are about 180.534 tons/yr, 155.335, 137.066 tons/yr and 75.770 tons/yr respectively. each sub-basin contains different Hydrological response units (HRU) such as land use land cover, soil type, and different slope class. In the case of These, the amount of sediment which eroded from each sub-basin is different and not equal. Those variations of sedimentation indicate that different amount of hydrological Response unit (HRU) generates a different amount of sediment. In this study, the watershed contains 9 sub-basin and 219 hydrological response units (HRU). Out of these nine sub-basins, sub-basin number three (HRU 37 to 48) generates the maximum amount of sediment as compared to other sub-basin results which generated 180.534 tons/yr and the minimum sediment load also generated from sub-basin number 5 to generate 10.029 tons/year.

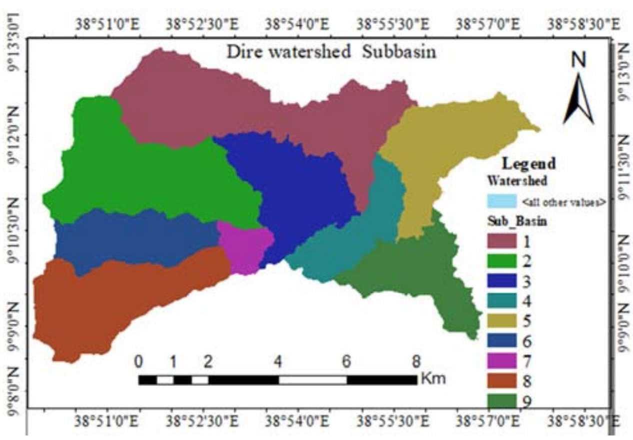

Figure 16. *Study area Sub basin map.*

Table 9. *Dire sub-basin and specific sub-basin Name.*

Sub-basin	Specific Sub-basin Name	Sub-basin	Specific Sub-basin Name
1	Dire Buru Maru	6	Dire Buru Maru
2	Dire Buru Maru	7	Dire Buru Maru
3	Dire Sekoru	8	Dire Tenkeli Woreli
4	Dire Sekoru	9	Dire Sekoru
5	Dire Kiki		

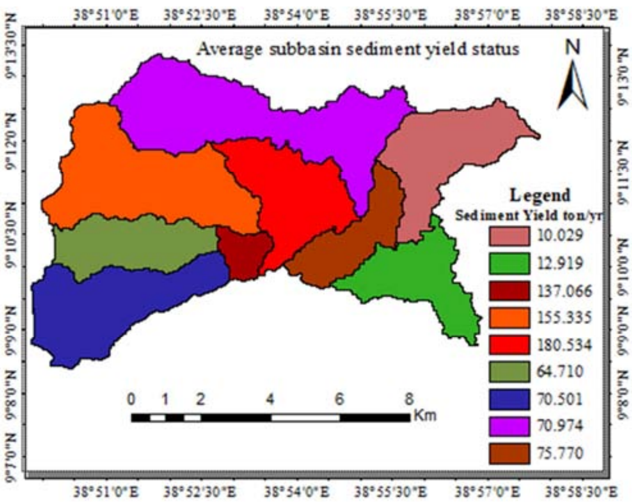

Figure 17. *Total sub basin sediment deposition in tone/yr.*

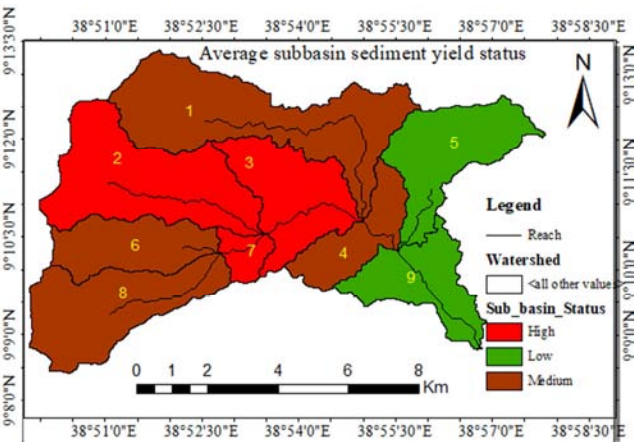

Figure 18. *Sediment deposition status for Dire watershed.*

4.4. Best Sediment Management Scenario Development and Analysis

Depending on the Arc SWAT watershed delineation Dire watershed contains 9 subbasin and 5 LULC class with 53.98% of agricultural land, 18.48% of forest mixed, 25.82 barren lands, 0.91% of urban area and 0.81% of waterbody. According to the spatial variability of sediment yield level was identified in section 4.3 and the BMP scenario were developed. The BMP used in this study were identified using SWAT model simulation result. During this study four different scenarios (filter strip at 3m and 5m width, terracing, grassed waterway and 50% of barren land change to forest) were developed and comparing according to the effectiveness of sediment yield reduction. The baseline or the original scenario (S1) was performed for the assessment of streamflow and sediment yield simulation and validation of Dire watershed. Each baseline simulation was run the same simulation period, without any sediment reduction management scenario inputs. In scenario2 filter strip were placed in the selected critical subbasin, all soil and all slopes. The effect of this filter strip in a critical subbasin simulated in SWAT model by modifying a filter strip width (FILTERW) at 3m and 5m spacing was checked the change of sediment yield from the baseline existing condition. Terracing were applied in scenario3 by changing the terracing SWAT parameter value TERR_P, TERR_SLSUBBSN file in (.hru), and (.mgt) SWAT input file database. In scenario5 50% of the barren land changed into forest land also modifying in SWAT land use update file database. Based on the assessment of this BMP terracing (S2), grassed waterways (S4) and 50% of the barren land changed to forest land (S5) were the most BMP to reduced sediment yield in Dire watershed.

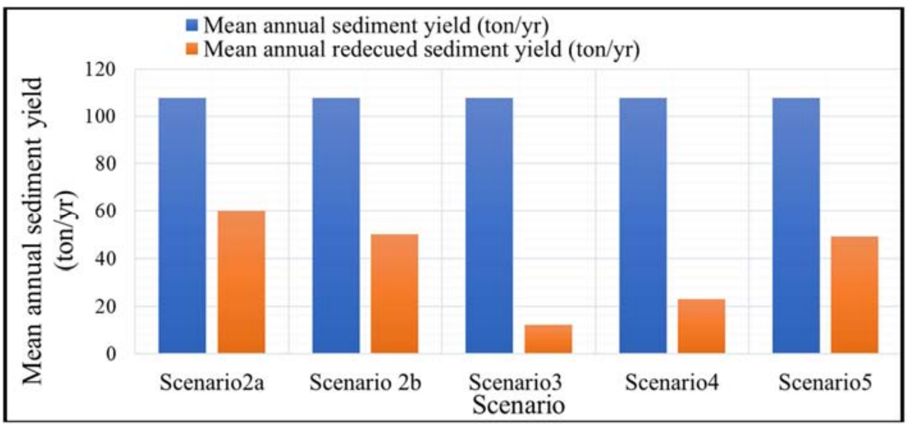

Figure 19. *Percentage comparison reduced sediment yield due to all scenarios.*

Table 10. *Reduced mean annual sediment yield due to applied all scenario for critical subbasin.*

subbasin	Reduced mean annual sediment yield (ton/yr)					
	Baseline (S1)	Filter strip (3m) (S2a)	Filter strip (5m) (S2b)	Terracing (S3)	Grassed waterways (S4)	Reduced sediment yields due to 50% BARN to FRST (S5)
1	70.97	39.54	32.85	7.92	15.10	33.94
2	155.33	86.54	71.89	17.31	32.45	71.06
3	180.53	100.75	83.75	20.42	38.28	82.18
4	75.77	42.78	35.72	9.46	17.98	36.68
6	64.71	36.05	29.95	7.21	13.52	29.22
7	137.07	76.36	63.44	15.27	28.64	61.25
8	70.50	39.28	32.63	7.86	14.73	31.08

Table 11. *Mean annual sediment yield and percentage of reduction for each scenario.*

Scenario	Scenario1	Scenario2		Scenario3	Scenario4	Scenario5
BMP	Baseline	Filter strip (3m)	Filter strip (5m)	Terracing	Grassed waterways	Reduced sediment yields due to 50% BARN to FRST
Mean annual reduced sediment yield (t/yr)	-	47.66	57.81	95.634	84.88	58.498
mean % of reduced from baseline	-	44.17	53.58	88.86	78.6	54.084

4.5. Method of Estimating Reservoir Life Expectancy and Trap Efficiency

4.5.1. Trap Efficiency

The reservoir will normally trap all of the inflowing coarse sediment until the reservoir is nearly full and reached its sediment storage capacity [14]. The trap efficiency depends primarily upon the fall velocity of various sediment particles; flow rate and velocity of the reservoir [15]. as well as the reservoir size, the reservoir sediment trap efficiency tends to decrease over time as sediment fills the reservoir. However, the trap efficiency also decreases temporarily during floods as inflow velocity increase through the reservoir. So, the trap efficiency (?) is the percentage of total inflow sediment load that is trapped within a reservoir over a stated period to total sediment flowing in the catchment area. Methods for estimating reservoir trap efficiency are emphatically based upon measured sediment deposits in a large number of reservoirs. The commonly used studies are those G. Brune and A. Churchill presented by Strand (1974). Brune presents a set of envelope curves as shown the following figure20 shows the percentage of sediment trapped (the relationship between the volume of sediment trapped and the volume of total sediment inflow) versus the capacity inflow ratio [16]. In addition to Brune [1], [17] showing the relation between reservoir storage capacity, water inflow, and TE; have been conducted by Brune, (1953) is the most widely used method for estimating sediment retention in reservoirs [16]. Brune curves were drawn based on data from 44 normal ponded reservoirs in the United States. Brune, curve plotted the TE against reservoir C/I. and the graph is composed of three curves, one median and two envelop.

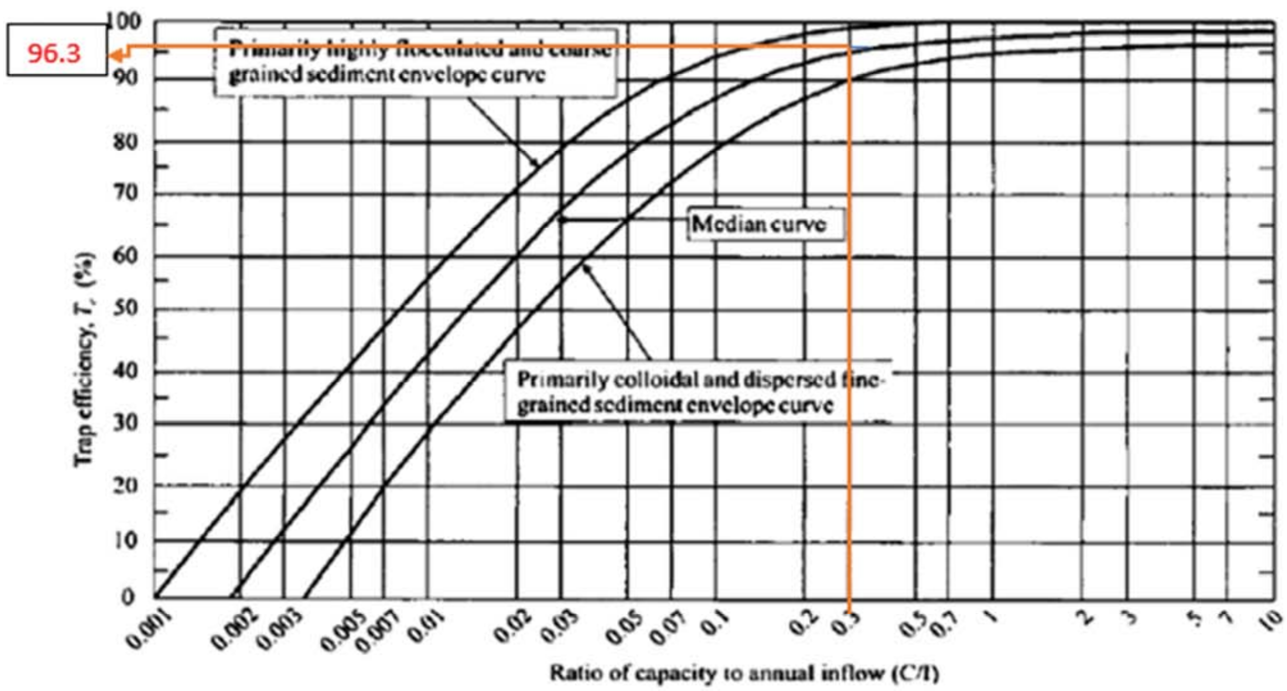

Figure 20. *Trap efficiency related to capacity/annual inflow (C/I) ratio by Brune (1953).*

Table 12. *Equation used for the Trap efficiency Prediction based on C/I ratio for different textures.*

Type of curve	C/I>1	1<C/I>0.02	C/I<0.02
Upper curve (Sand-Gravel)	100	100-(0.485|ln(C/I)|$^{2.99}$)	124-(6.59|ln(C/I)|$^{1.52}$
Median curve (Mixture)	97	97-(1.275|ln(C/I)|$^{2.47}$	128-(11.51|ln(C/I)|$^{1.304}$
Lower Curve (Clay-Silt)	94	94-(3.38|ln(C/I) |$^{1.92}$	94-(3.38|ln(C/I)|$^{1.92}$

According to [18], the initial storage capacity of the Dire dam was 19 Mm^3 and the annual surface runoff which generated dire watershed and Arc SWAT simulation results are 69.48Mm^3. Based on Brune, (1953), the capacity inflow ratio (C/I) is 0.2754 from Table 11, this C/I ratio is lies between 1 and 0.02 and in the median curve (Mixture) and from the following Figure, the trap efficiency in Dire dam reservoir is 96.270%.

4.5.2. Specific Unit Weight of Deposited Sediment

The deposition of the sediment in the reservoir is determined in terms of weight per time (t/day). To get the volume of deposited sediment, the conversion of this unit has to be made. Several factors influence the value of the unit weight of the sediment deposited in a reservoir. The most pronounced effects are the water that the reservoir is operated, the texture and size of sediment particles, the compactness of consolidation rate, the action of density currents, and the effect of the vegetation in the reservoir headwater area is the main influence in sediment particle. The estimation of the sediment unit weight or apparent specific weight is carried out by the following equations:

$$\gamma i = Wc\ Pc + Wm\ Pm + Ws\ Ps \quad (13)$$

$$\gamma T = \gamma i + 0.4343K \left\{\frac{T}{T-1}(lnT) - 1\right\} \quad (14)$$

$$K = Kc\ Pc + Km\ Pm + KS\ PS \quad (15)$$

where, $\gamma_{i\text{ is the}}$ initial unit weight ($t/_m{}^3$), Wc, Wm, Ws is a coefficient of clay, silt and sand respectively which obtained from Table 12, Kc, Km, Ks is a corresponding coefficient, Pc, Pm, Ps is the percentage of clay, silt, and sand respectively based on incoming sediment, γT is the unit weight after T years ($t/m^{3)}$, T is a time of compaction (year), K is a constant which depends upon the size of the sediment and the type of reservoir operation.

According to awash soil survey Bibiso, (2017) report, the composition of sediment in the awash basin, sand (0.02-0.2mm), silt (0.002-0.02mm, clay (<0.002mm) with average percentage composition of 23%, 35%, and 42% respectively. Based on the distribution of sediment in the reservoir is type I (Sediment always submerged or nearly submerged). The coefficients (K) and initial unit weight are estimated as 0.1286 and 0.924 tone/m^3. Based on this result the average unit weight deposited sediment at 25yr, 50yr, and 75yr is 1.055 tone/m^3, 1.091 tone/m^3, and 1.13 tone/m^3 respectively.

4.5.3. Reservoir Life Expectancy

The expectancy of a reservoir is the expected time at which the reservoir will be filled with sediments. The period up to which the reservoir can serve the defined purpose is called usable life, the period after which the cost of operating the reservoir exceeds the additional benefits expected from its continuation is called economic life, the design life is generally the useful life, full life period is that when no capacity is available in the reservoir for the useful purpose [19]. Its determination requires the storage compacity or volume of the reservoir, (VR) the mean annual incoming total sediment discharge (Qt) in weight per year, the sediment size distribution, the trap efficiency of the reservoir (TR), mass density of the deposited sediment ($\Delta\rho$) and the dry specific weight of sediment deposits γmd. After transforming the incoming mean annual sediment discharge into the volume of sediment trapped in the reservoir, the life expectancy T_E is given by

$$T_E = \frac{VR * \gamma md}{\sum TRi * \Delta\rho i * Qt} \quad (16)$$

The probability of occurrence of one or sever events that may fill the reservoir before the expected life duration must be considered [20].

The life expectancy of Dire reservoir which is estimated using trap efficiency is as shown below Figure 21 and Table 13.

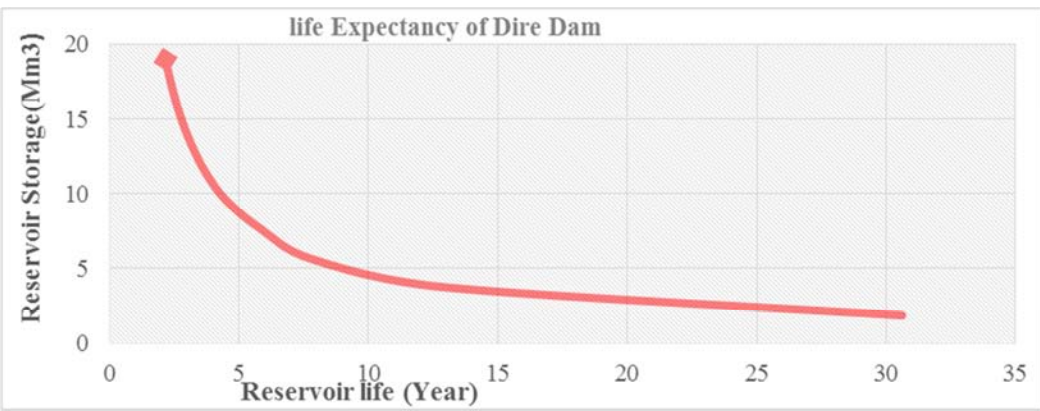

Figure 21. *The life expectancy of Dire Dam reservoir.*

Table 13. *Coefficients for use in metric units, transformed from the original value of Lara and Pemberton.*

Type of operation of the reservoir	Clay		Silt		Sand	
	Wc	Kc	Wm	Km	Wc	Kc
1	0.416	0.2563	1.121	0.0913	1.55	0.00
2	0.561	0.1346	1.137	0.0288	1.55	0.00
3	0.641	0.00	1.153	0.00	1.55	0.00
4	0.961	0.00	1.169	0.00	1.55	0.00

Table 14. *The life expectancy of Dire Dam Reservoir.*

Cpacity in %	Capacity volume	C/I ratio	Trap efficiency in %	Annual sed trapedin Mm3	Average annual sed trap in Mm3	Useful life of Reservoir
100	19	0.27346	94.75	0.380	0.360	2.160
90	17.1	0.24611	94.06	0.342	0.322	2.418
80	15.2	0.21877	93.42	0.304	0.284	2.739
70	13.3	0.19142	92.5	0.266	0.246	3.161
60	11.4	0.16408	91.49	0.228	0.209	3.729
50	9.5	0.13673	90.02	0.190	0.171	4.548
40	7.6	0.10938	86.75	0.152	0.132	5.899
30	5.7	0.08204	87.94	0.114	0.100	7.759
20	3.8	0.05469	79.3	0.076	0.060	12.906
10	1.9	0.02735	66.85	0.038	0.025	30.619

From the above graph the gradual sediment deposition for both live and dead storage, the reservoir is reduced until the dead storage is completely filled with sediment. According to the Empirical area reduction method, (Figure 21), the Dire Dam reservoir will have useful life is 31 year for the estimated Average annual sediment load is 1826.017 tone from the output of SWAT model using the simulation of 1990 to 2006, trap efficiency of 96.27% and average deposit density of 1.13tone/m^3. The reservoir storage capacity will be lost at an average rate of 0.4035% per year.

5. Conclusion

In this study, the SWAT model was used to simulate runoff and sediment yield from Dire watershed. The model runs on a monthly time step and makes it possible to divide a basin into nine natural sub-watersheds. The objective of this study was to estimate the amount of sediment yield from Dire watershed to the Dire reservoir using the SWAT model. The model performance evolution during monthly streamflow calibration and validation period at the outlet indicated that R^2=0.90 NS=0.84 and R^2=0.770, NS=0.68 respectively. At the same time, the model performance evaluation during monthly sediment yield calibration and validation period indicated that R2=0.73, NS=0.66, and R^2=0.70 NSE=0.68 respectively. This model performance coefficient indicates a good agreement between the observed and simulated value of surface runoff and sediment yield in Dire watershed.

The total annual sediment load transported into the reservoir is 1633.49 ton/year and annual average specific sediment yield into the reservoir is 108.89ton/yr. The spatial and temporal variation of sediment yield is analyzed and the sediment inflow into the reservoir varies from time to time. Sub-basin, 3, 2 and 7 respectively, produce more sediment when compared to the other sub-basin, this is due to the fact that they are agricultural areas and in addition, the soil around these areas contains silt materials and the catchments have relatively having steeper slopes from the lower slopes. On the other hand, sub-basin 1, 4, 5, 6, 8, and 9 produce the low sediment among the total 9 sub-basins.

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