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Assessment of Water Balance of Deme Watershed, Omo-Gibe Basin, Ethiopia Using SWAT Model and ARC-GIS for Water Resources Management

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Abstract: To deal with water management issues, one must analyse and quantify the different elements of hydrologic processes taking place within the area of interest. Obviously, this analysis must be carried out on a watershed basis because all these process are taking place within individual micro watersheds. Only after understanding the spatial and temporal variation and the interaction of these hydrologic components one can scientifically formulate strategies for water conservation. To achieve this goal the choice and use of an appropriate watershed model is a must. All the thematic maps and attribute information of the watershed have been collected from various Government agencies. SWAT model has been set up for the Deme watershed by inputting the digital thematic maps, physical properties of soil and climatic parameters. Total area of the watershed corresponding to the outlet chosen at Deme watershed is 11284.35km^2 and its elevation varies from 1138 to 3269m. Calibration and validation of the model have been done by comparing the river flow prediction with the observed values. Nash Sutcliff Efficiency (NSE), coefficient of determination (R^2) and Percent bias (PBIAS) has given very high values for the calibration 0.75, 0.75 and -0.7% respectively and validation 0.73, 0.74 and 6.3% respectively. The calibrated model has been used to predict the important hydrologic processes. The water balance components of Deme watershed resulted PET 388.5mm, Evaporation and transpiration 293.8mm, Precipitation 1147.5mm, Average curve number 76.38, Surface runoff 189.7mm, Revap from shallow aquifer 7.7mm, Percolation to shallow aquifer 37.59mm, Lateral flow 624.33mm and Recharge to deep aquifer 0.28mm. The study has revealed that SWAT model can effectively be used in the simulation of river flow and for predicting the water balance of a watershed. Water balance information of the basin is of great use in planning water conservation, drainage and flood control.

Keywords: Deme, SWAT, Water Balance, Arc GIS, NSE, PBIAS and R2

1. Introduction

The most crucial element of programs for developing and managing water resources is understanding the water balance of a basin. Water balance equations can be used to quantify important hydrological processes. For many countries, managing water resources has been a severe problem [1]. The physical characteristics of the watershed, such as the watershed area, morphology, landuse landcover kinds, major stream length, soil type, slope, etc., have an impact on the components of the water balance of the watershed [2]. For any job involving the management of water resources, understanding the relationships between these parameters and various hydrological components is crucial [3]. The components of water balance of a basin is determined by climate, the physical characteristics of the watershed such as morphology, landuse and soil [4]. For any task involving the development of water resources, understanding the relationship between these physical factors and hydrological components is crucial [5]. Due to the complexity of the hydrologic processes, it is crucial to properly understand them, and watershed models are frequently utilized in this regard [6]. The majority of watershed models essentially mimic how precipitation changes into runoff, sediment outflow, and nutrient losses [7].

From various perspectives, managing water resources is extremely important, including for agricultural activity in irrigation, the development of water sectors for future scenario needs, the protection of water resources from various forms of pollution, and managing both the quality and quantity of water [8]. The properties of water resources, such as land use, land cover, soil conditions, rainfall, and surface runoff, are changing due to various climatic conditions and human activities [9]. First and foremost, various hydrological components and water balance, such as surface runoff, lateral flow, baseflow, precipitation, condensation, and evapotranspiration, must be examined and taken into consideration for successful water resource utilization [10]. Therefore, in order to assess the hydrologic response to climate and landcover variability and determine the water availability, an understanding of the link between these hydrological components and physical parameters is required [11]. In this study, SWAT was one of several integrated physically based distributed hydrological models. SWAT was chosen because it is an integrated, continuous-time, physically based, and long-term simulation at the scale of a river basin. The goal of the current study was to calibrate, sensitivity analyze, validate, and evaluate the SWAT model for studying the water balance components of the Deme watershed in Ethiopia's Omo-Gibe Basin.

2. Material and Methods

2.1. Description of the Study Area

The Deme watershed is one of the major watersheds in the Omo-Gibe basin, Ethiopia and contribute high amount of flow for Omo-Gibe river. It is found in the southern part of the country in Wolayita Zone, Sodo Zuria and Ofa Woreda. It is bordered between Wolayita, Gamo and Gofa Zone which covers an area of 11284.35km^2. Deme Watershed is situated between latitudes 06°10′N and 07°00′N and longitudes 37°00′E and 37°50′E.

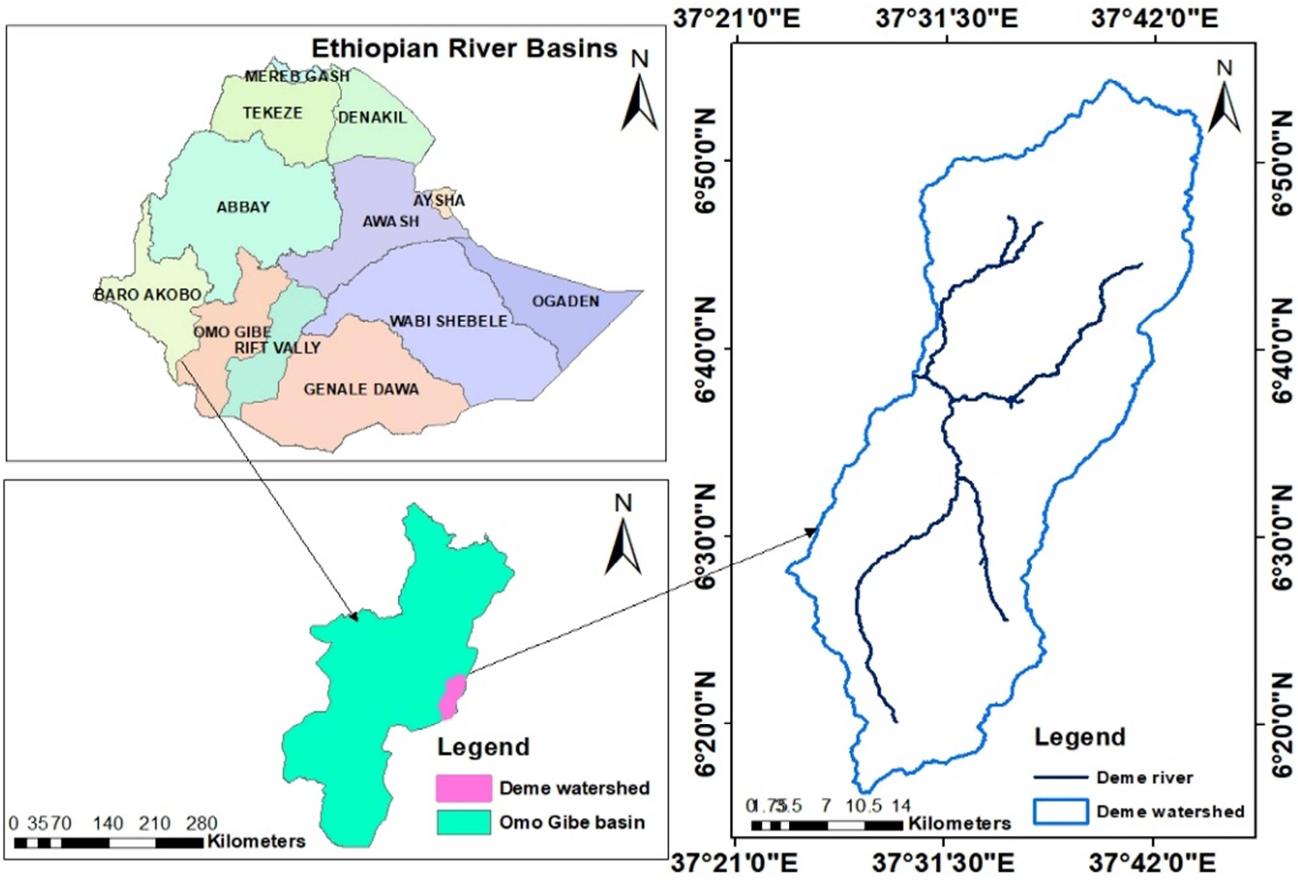

Figure 1. Location of the study area.

2.2. Frame Work of the Study

Following the choice of the hydrological model to be used in the study area, the precise data needed to run the model must be collected and prepared in the required format. For the SWAT model to simulate the hydrological processes in the research area, four types of data are required. The study makes use of soil maps, landuse maps, and hydro meteorological data.

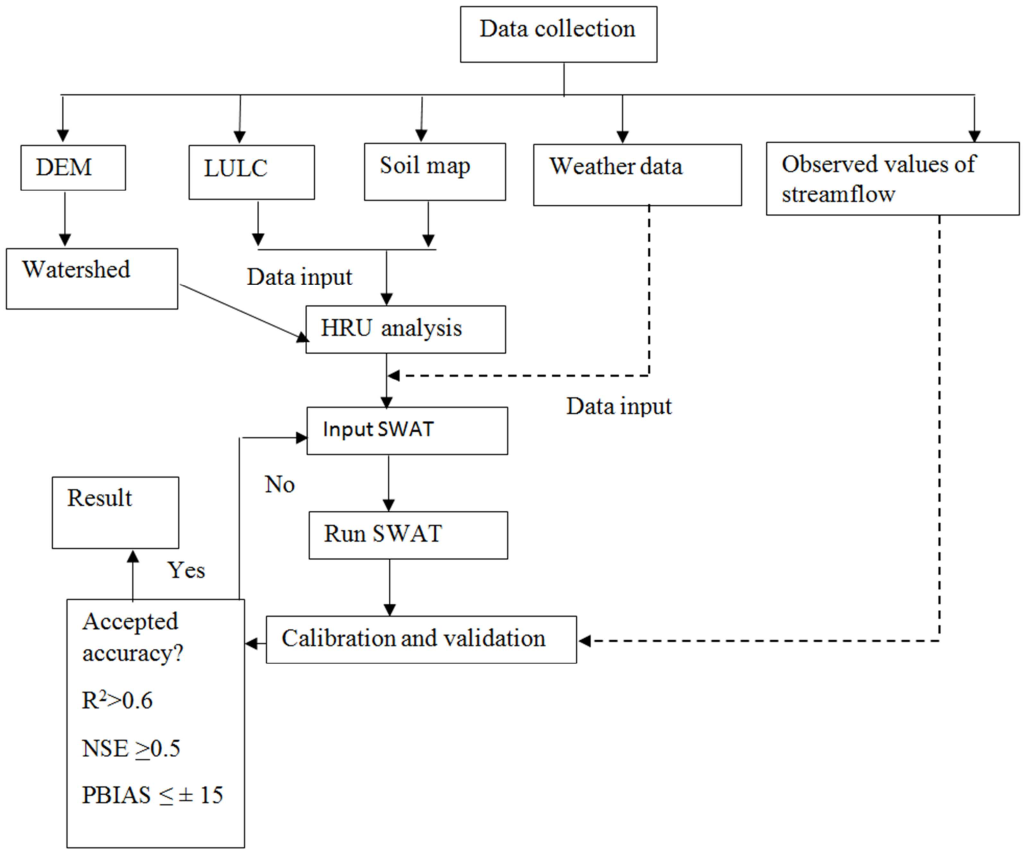

Figure 2. *General framework of the study.*

2.3. Input Data Sets for the Study

Data inputs on topography, climate, land use, and soil are required by SWAT. The model's pertinent input parameter values in this study were constructed utilizing data from a number of different databases. These databases contained information gleaned from maps of soils and land use as well as GIS data.

Table 1. *Collected data.*

Data	Location	Period of Records	Data Sources
Landuse landcover map	Deme	2021	Ministry of Water, Irrigation and Energy of Ethiopia, Department of Geology
Digital elevation model	Deme	2021	ALASKA satellite facility https://asf.alaska.edu/
Soil Map	Deme	2020	Food and Agriculture Organization (FAO)
Weather Data (precipitation, minimum/maximum temperatures, relative humidity, wind speed, and solar radiation)	Bele Areka Dara Malo Gessuba Morka Wolayita	1990-2019	Ethiopian National Meteorological Agency (NMA)
Streamflow data	Orotaalem	1990-2006	Ministry of Water, Irrigation and Energy of Ethiopia, Department of Hydrology

2.3.1. Digital Elevation Data

The SWAT-based hydrological simulation process uses digital elevation data. The DEM data was presented as raster files with attribute tables for the pixels, which were similar to images with pixels that include spatial coordinates and units. The watershed's boundaries, the reach network, and the computation of the sub-basin's surface properties all required the DEM. In order to define the HRU, the determined average slope grid was required. Since categorical variables are required by the HRU concept, the slopes were classified into classes. The slope and contours of the watershed are calculated using this DEM file, the base topographic input for the Arc SWAT model. The research area's DEM values range from 1138 to 3269m a.m.s.l see Figure 3.

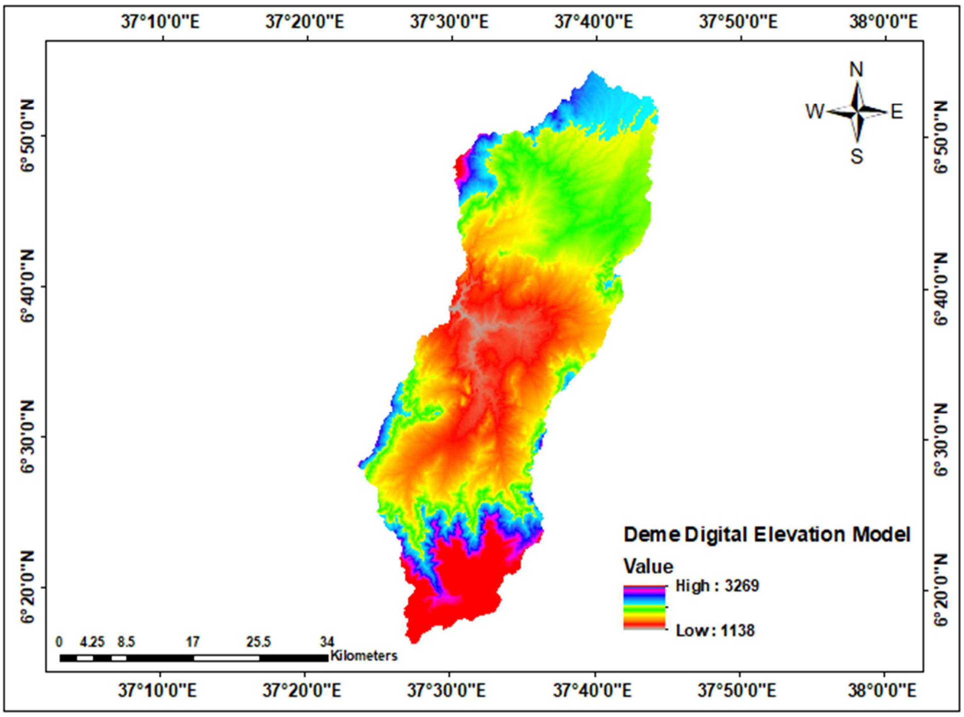

Figure 3. *Digital elevation model.*

2.3.2. Land Use Land Cover Map

Land use data is used as the form of separate GIS-layer (either vector or raster) reclassified using crops and land use types that are defined within the model databases. This procedure requires freely available land use raster data, river networks, road networks, etc. and pre-defined sub-basins for the watershed to be processed. Deme watershed are covered with Agricultural Land, grass land, shrub land, barren land, wet land, forest land and settlement land. The land use data is shown in Table 2 and Figure 4.

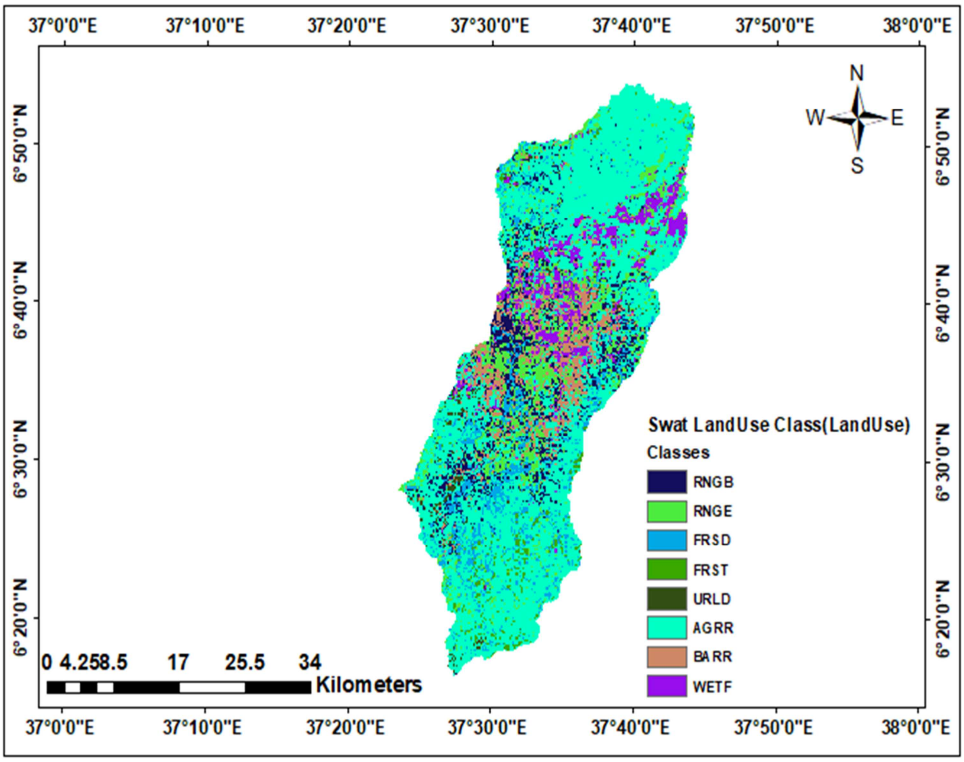

Figure 4. *Reclassified landuse landcover map.*

Table 2. *Land use classification with total area distribution.*

No	LULC Type	Area Coverage (Km^2)	Area in percent
1	Agricultural Land	713.45	55.55%
2	Grass Land	142.69	11.11%
3	Wood Land	104.28	8.12%
4	Shrub Land	109.29	8.51%
5	Barren Land	98.76	7.69%
6	Wet Land	79.37	6.18%
7	Forest Land	19.00	1.48%
8	Settlement Land	17.47	1.36%
	Total	1284.35km^2	100.00%

Table 3. *Reclassified Code of Landuse Landcover Map.*

No	LULC Type	Swat Code
1	Shrub Land	RNGB
2	Grass Land	RNGE
3	Wood Land	FRSD
4	Forest Land	FRST
5	Settlement Land	URLD
6	Agricultural Land	AGRR
7	Barren Land	BARR
8	Wet Land	WETF

2.3.3. Soil Map

Due to the SWAT code, the three primary soil types are identified on the soil map as Eutric Cambisoles, Eutric Nitosols, and Ochric Andosols. The SWAT model will use the unique identifier for the soil type included in the attribute table's soil map unit key column to learn more about hydraulic conductivity and other soil characteristics that affect hydrologic processes. For the SWAT model, various strata of each type of soil must have specific physicochemical and textural characteristics, such as soil texture, hydraulic conductivity, accessible water content, bulk density, and organic carbon content see Tables 4, 5 and Figure 5.

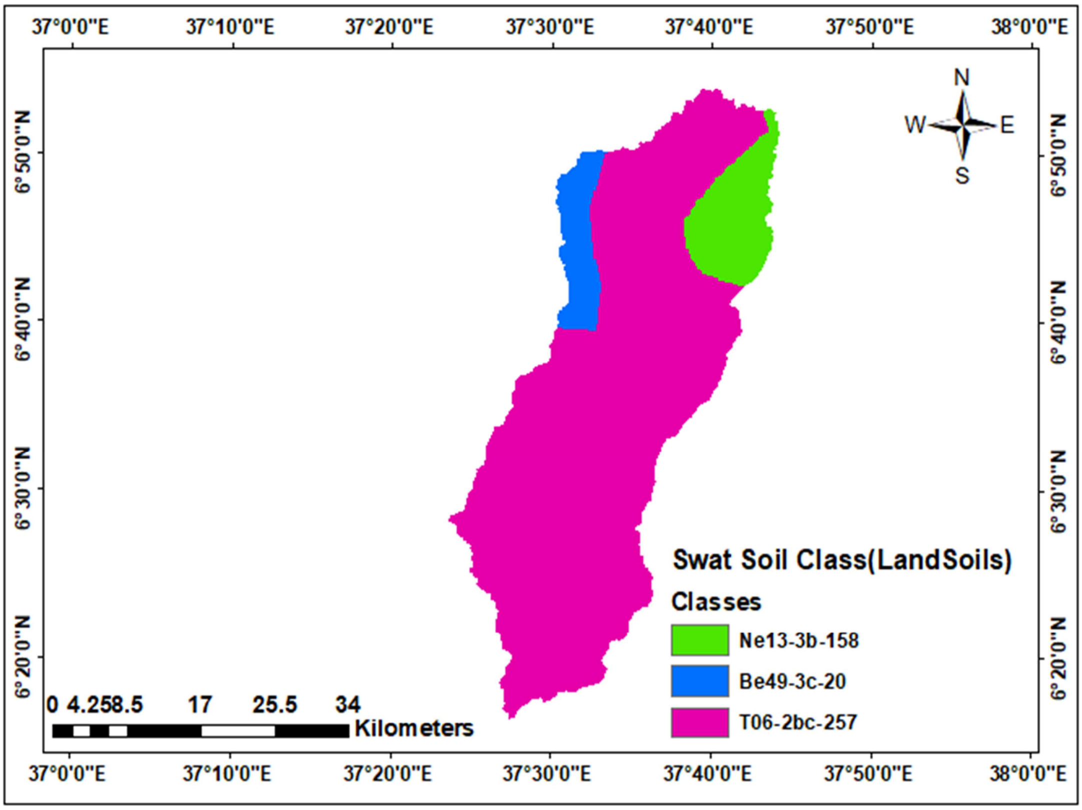

Figure 5. *Soil Map of Deme Watershed.*

Table 4. *Soil group classification of Deme watershed.*

No	Soil group name	Hydrologic soil group	Area (Km^2)	Percent area coverage
1	Eutric Cambisoles	B	119.05	9.27%
2	Eutric Nitosols	B	74.87	5.83%
3	Ochric Andosols	B	1090.41	84.90%
	Total	-	1284.35Km^2	100.00%

Table 5. *Reclassified Code of Soil Map.*

No	Soil group name	SWAT-Code
1	Eutric Camisoles	Ne13-3b-158
2	Eutric Nitosols	Be49-3c-20
3	Ochric Andosols	To6-2bc-257

One of the key elements influencing how a watershed reacts to its water balance is its soil composition. Soil with its physical and chemical qualities are needed as input files for SWAT. The Food and Agriculture Organization (FAO), which provides a shape-formatted digital soil map of the world, was used to create the soil map for the research region. http://www.fao.org/land-water/news-archive/news-detail/en/c/1026564/. The study basin's physical and chemical characteristics, including soil texture, accessible water content, bulk density, hydraulic conductivity, and organic carbon content, were taken into account using the raster soil map that the Food and Agriculture Organization provided (FAO). Using Arc GIS 10.4, a user soil database was created and added to the SWAT user soil databases in order to link the soil map with the SWAT model. In the study area, three main FAO/UNESCO soil classification systems were discovered. The soil map of the study area is shown above Figure 5.

2.3.4. Slope

The slope of the Deme watershed is calculated using a DEM with a resolution of 12.5m*12.5m. Along with the input parameters for land use and soil, the model also uses this slope to produce the hydrological response unit (HRU). Slope class is an option when defining a hydrological response unit in Arc SWAT. You have the option of selecting only one slope class or several slope classes. Multiple slope classes were chosen for this investigation, taking into account slope classes one 0-5%, class two 5-10%, class three 10-15%, class four 15-20%, and class five >20%. The slope categorization in the Deme watershed is shown in Table 6 and Figure 6 below.

Table 6. *Slope Area Contribution in the Deme Watershed.*

Slope Classes	Area Coverage (km^2)	Area coverage in Percent
0-5	421.03	33.15%
5-10	405.22	31.37%
10-15	184.74	14.30%
15-20	110.86	8.58%
>20	162.48	12.58%
	1284.35 km^2	100%

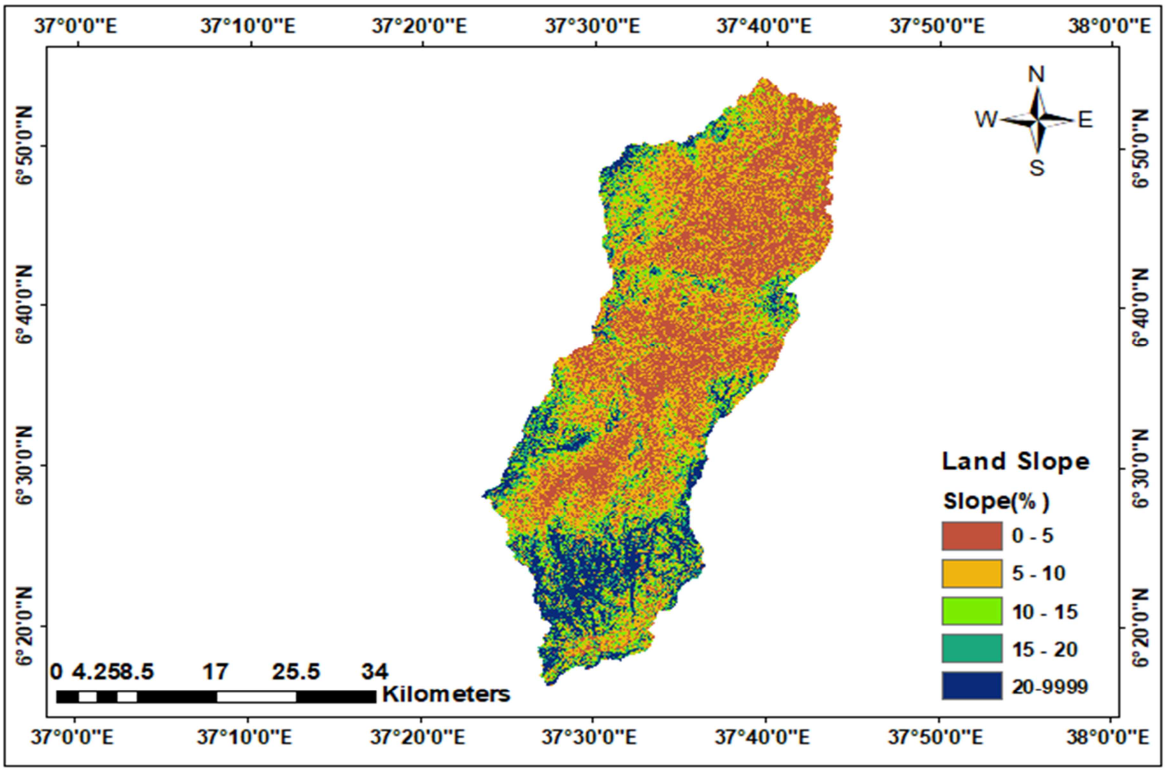

Figure 6. *Slope Map of Deme Watershed.*

2.3.5. Weather Data

SWAT needed daily climate and weather information that could be gleaned from measurable data sets or produced by a weather generator model. The model needs data on precipitation, minimum/maximum temperatures, relative humidity, wind speed, and solar radiation. From 1990 to 2018, meteorological data were gathered at the Bele, Areka, Dara Malo, Gessuba, and Wolayita stations.

2.3.6. Observed Value of Water Discharge

Observed value of water discharge (1989-2006) were collected from Orota alem stations and has been used for model calibrations and validations.

2.4. SWAT Model

A river basin or watershed size model is called SWAT, which stands for soil and water assessment tool. Jeff Arnold, a doctor, created it for the USDA Agricultural Research Service (ARS) [12]. SWAT was created to predict how land management methods in sizable, complicated watersheds with a range of soil types would affect water, sediment, and agricultural chemical outputs. In SWAT, a watershed is divided into several sub-watersheds, which are then further divided into hydrologic response units, which are made up of the same types of soils, landuses, and cover types. The input files needed to run the model were added using the geographic information system after HRU definition was finished.

The hydrological process simulated by the SWAT model is based on the balanced equation:

SWt = SW0 + ∑t i=l(Rday - Qsurf - Wseep - Ea - Qgw)

Where SWt is the humidity of the soil (mm), SW0 is the base humidity of the soil (mm), t is time (days), Rday is rainfall volume (mm), Qsurf is the value of surface runoff, Ea is the value of evapotranspiration (mm), Wseep is the value of seepage of water from the soil into deeper layers, Qgw is the value of underground runoff (mm).

Surface runoff is predicted by:

2.4.1. SWAT Setup

Arc SWAT extension of the SWAT version 2012 was used for setting up of the model. The ArcSWAT watershed delineator was used to delineate the watershed into sub-watersheds, slopes, drainage areas etc. using the DEM. The watershed was subdivided into several homogenous units (hydrologic response units or HRUs) having unique soil, slope and land use classes as input data. The input information for each sub-watershed was grouped into categories of weather, unique areas of land cover, soil, and management within the sub-basin. The loading and movement of runoff, sediment, nutrient and pesticide to the main channel in each sub-watershed were simulated considering the effect of several physical processes that influence the hydrology. Hydrographs were produced and subsequently, the water balance was estimated. The model performance statistics were evaluated and the availability of water within the catchment also assessed based on the water balance ratios.

2.4.2. Surface Runoff

The SWAT model presents two methods for estimating excess rainfall (runoff). The first one is the SCS curve number method, and the second method is the Green and Ampt infiltration equation (Arnold *et al.*, 2012). The curve number method was developed by the U.S Department of Agricultural Soil Conservation Service (SCS) in 1972. This method is based on empirical measurements of rainfall-runoff data for different soil types, land use, and land cover. The total daily runoff depth or daily excess rainfall (mm) based on the SCS method can be estimated from the following Equation 1.

Surface runoff is predicted by equations

$$Q_{surf} = \frac{(R_{day}-I_a)^2}{(R_{day}-I_a+S)} \tag{1}$$

Where Qsurf is the accumulated runoff or rainfall excess (mm H_2O), R-day is the rainfall depth for the day (mm H_2O), Ia is the initial abstractions which include surface storage, interception and infiltration before runoff (mm H_2O), and S is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management and slope, and temporally due to changes in soil water content. The retention parameter is defined in Equation 2.

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{2}$$

Where, CN- is the curve number for the day. The initial abstractions, Ia, is commonly approximated as 0.2S and Equation 1 becomes

$$Q_{surf} = \frac{(R_{day}-0.2S)^2}{(R_{day}+0.8S)} \tag{3}$$

2.4.3. Peak Runoff Rate

The peak surface runoff rate is the maximum volume flow rate passing a particular location during a storm event. It is an indicator of the erosive power of a storm and is used to predict sediment loss, SWAT calculates the peak runoff rate with a modified rational method.

The rational method is widely used in the design of ditches, channels, and storm water control systems. The rational method is based on the assumption that if a rainfall of intensity i begins at time t = 0 and continues indefinitely, the rate of runoff will increase until the time of concentration, $t = t_{conc}$, when the entire sub-watersheds area is contributing to flow at the outlet. The rational formula is

$$q_{peak} = \frac{C*i*Area}{3.6} \tag{4}$$

Where q_{peak} is the peak runoff rate (m^3/s), C is the runoff coefficient, i is the rainfall intensity (mm/hr), Area is the sub-basin area (km^2) and 3.6 is a unit conversion factor.

Equation 3 was modified to determine the peak runoff rate. The modified rational formula used to estimate peak flow rate is

$$Q_{peak} = \frac{\alpha tc * Q_{surf} * A}{3.6 * t_{conc}} \quad (5)$$

Where: Q_{peak} is the peak runoff rate (m^3/s), αtc is the fraction of daily rainfall that occurs during the time of concentration, Qsurf is the surface runoff (mm) given in equation 3, Area is the sub-basin area (km^2), t_{conc} is the time of concentration (hrs.).

The time of concentration is the amount of time from the beginning of a rainfall event until the entire sub-basin area is contributing to flow at the outlet. The time of concentration is calculated by summing the overland flow time (the time it takes for flow from the remotest point in the sub-basin to reach the channel) and the channel flow time (the time it takes for flow in the upstream channels to reach the outlet).

$$t_{conc} = t_{ov} + t_{ch} \quad (6)$$

Where t_{conc} is the time of concentration for a sub-basin (hr), t_{ov} is the time of concentration for overland flow (hr), and t_{ch} is the time of concentration for channel flow (hr).

2.4.4. Model Set-up

Understanding the hydrological cycle and estimating the hydrological parameters are vital for precise planning and effective use of the land and water resources. To assess whether the model is capable of accurately predicting streamflow, calibrate and validate it. With the help of a digital elevation model, land use information, and soil data, a SWAT model has been put up over the Deme watershed for this aim. The processed digital elevation model was used to estimate the flow direction, and from this model, flow accumulation was created by addressing each cell. This accumulation measures the contribution of each upstream cell to the flow through a certain cell. The outflows of the basin will be determined by segments of the flow network.

2.4.5. Watershed Delineation

The DEM's topography, contour, and slope are used to first define the watershed, then divide the basin into sub-watersheds. With the use of the Arc Map watershed delineation toolbox, sub-basin borders can be adjusted based on observed land use, soil types, and circulation patterns. The model uses contours and the slope of the watershed to calculate flow direction and accumulation following the creation of the DEM. The model creates a stream network in which each reach drains a sub-basin, all of which drain into a major reach, after flow direction and accumulation have been determined. Every reach has an outlet or node. The position of that outlet and flow network establishes and defines the lower boundary of the watershed basin. The watershed covered an area of 11284.35km^2. Figure 7 indicates the area delineated for the 17 sub-watersheds station of the Deme watershed after using the DEM (representing a small area). This study indicates that the resolution of the DEM affects the watershed delineation as well as flow network and sub basin alignment in SWAT models.

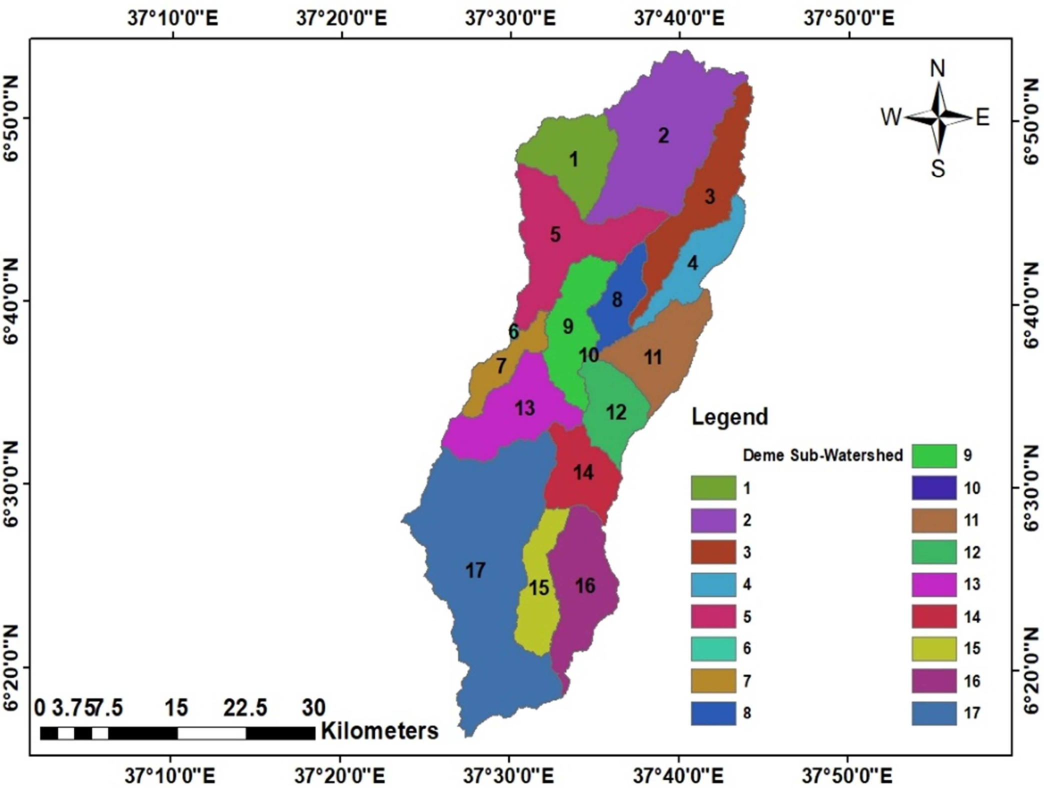

Figure 7. Sub-watershed of Deme watershed.

2.4.6. HRU Analysis

Three categorical variables soil type, slope, and land use were combined to create HRUs. The Slope Spatial Analysis tool in Arc Map 10.4 is used to determine the slope of a watershed from the digital elevation model (DEM). The tool converts the elevation into a slope projection using% slope using the DEM file as the input raster. The subsurface lateral water movement, flow buildup and routing, as well as sediment yield for each sub-basin, will all be filled in by this parameter in SWAT. Within our study area, the outcomes of this pre-processing stage produce finer scale diversity in slope parameters. Unique combinations of land use, soil type, and slope were used to develop the hydrologic response units. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. The land use, soil and slope map of Deme watershed were overlaid to produce a hydrologic response group by setting a threshold value of 5%, 5% and 10% for land use, soil and slope domination to which land use percentage over the sub basin, soil over the land use and slope class percentage over the land use respectively were adopted in these study during HRU definition. Those thresholds were selected by considering the effect of on the formulation of hydrologic response and for making the HRU formulation in a manageable amount.

2.5. Performance Evaluation of SWAT Model

Model calibration is the process of adjusting the model parameters to match the model output with the observed data with a limited range of deviation for better prediction of the SWAT model. Calibration is designed to reduce the uncertainty in the estimation process. Model calibration is started with the default parameters, and then the parameter values are adjusted more closely to match the model behavior for the watershed. For each calibration run and parameter change, the corresponding model performance statistics (R^2 and NSE) were calculated. For this study, this procedure continued until the acceptable recommended calibration values are achieved. The acceptable calibration values are $R^2 > 0.6$ and NSE> 0.65. In this study streamflow data and from the year 1991 up to 1999 (9 years).

Model validation is testing of calibrated model results with independent data set without any further adjustment [13]. Validation involves running SWAT CUP using parameters that were used during the calibration process, to see if the model is applicable outside the calibration period. In this study, the model performance measures used in the calibration procedure were used in validating too. In this study streamflow data from the year, 2000 up to 2006 (7 years). For this study, three methods were used: coefficient of determination (R^2), Nash-Sutcliffe Index (NSI) and Percent bias (PBIAS).

2.5.1. Coefficient of Determination (R^2)

Coefficient of determination (R^2) describes the percentage of the variance in calculated data experienced by the model. The most widely used criteria, for testing performance of a model is coefficient of determination R^2 as the following Equation

$$R^2 = \frac{\left[\Sigma(Q_{m,i}-\bar{Q}_m)*(Q_{s,i}-\bar{Q}_s)\right]^2}{\Sigma(Q_{m,i}-\bar{Q}_m)^2\,\Sigma(Q_{s,i}-\bar{Q}_s)^2} \quad (7)$$

Where $Q_{m,i}$= is the observed (measured) streamflow on the day i (m^3/s), $Q_{s,i}$= is the simulated streamflow on the day i (m^3/s), $\bar{Q}_m$= is the mean observed (measured) streamflow (m^3/s), $\bar{Q}_s$= is the mean simulated streamflow (m^3/s).

The general performance rating criteria developed by for calibration and validation of SWAT model are given in Table 7.

Table 7. *Performance rating for R^2.*

Performance rating	R^2
Very Good	$R^2 > 0.70$
Good	$0.60 < R^2 \leq 0.70$
Satisfactory	$0.50 < R^2 \leq 0.60$
Unsatisfactory	$R^2 < 0.50$

2.5.2. Nash-Sutcliffe Index (NSI)

NSI indicates how well the plot of observed versus simulated data fits the 1:1 line. NSI is computed as shown in Equation 8.

$$NSE = 1 - \frac{\sum_{i-0}^{n}(Q_{obs}-Q_{sim})^2}{\sum_{i=0}^{n}(Q_{obs}-Q_{sim})^2} \quad (8)$$

Where Q_{obs}= is the observed (measured) streamflow on day i (m^3/s), Q_{sim}= is the simulated streamflow on day i (m^3/s).

Performance ratings for NSI of this model are evaluated on different levels due to classification are given in Table 8.

Table 8. *Performance rating for NSI.*

Performance rating	NSI
Very Well	NSI > 0.65
Adequate	0.54< NSI <0.65
Satisfactory	NSI > 0.50

2.5.3. Percent Bias (PBIAS)

Whether the simulated data be larger or smaller than the observed data is measured by percent bias. The values of PBIAS of 0 indicate accurate model simulation. Positive values indicate model underestimated bias, and negative values indicate model overestimated bias. PBIAS is calculated with Equation 9.

$$PBIAS = \frac{\sum_{i=0}^{n}(Q_{obs}-Q_{sim})}{\sum_{i=0}^{n}(Q_{obs})} \quad (9)$$

Where: n is the number of observations during the simulation period, Q_{obs} is the Observed flow data, Q_{sim} is the simulated flow value with the respected time, and Q_{obs} are the arithmetic means of the observed and simulated values.

Table 9. *Performance rating for PBIAS.*

Performance rating	PBIAS
Very good	PBIAS<±10
Good	±10≤PBIAS<±15
Satisfactory	±15≤PBIAS<±25
Unsatisfactory	PBIAS≥±25

3. Results and Discussions

3.1. Sensitivity Analysis

To save time during calibration, sensitivity analysis for flow was completed before the model was calibrated. Since the SWAT model contains a number of factors to take into account, differentiating sensitive parameters allows us to focus solely on those parameters during calibration that have the most impact on the model output. Monthly checks were made to ensure that the model was appropriate for simulating streamflow from the Deme river watershed. The time period covered by the dataset was 1989 to 2006. The first two years of the simulation period were utilized to warm up the model. Data from 1991 to 1999 were utilized for calibration, while the remaining data were used for model validation.

The list of parameters adopted for the sensitivity analysis are stated in Table 10. Daily flow data was used from 1991 to 1999 for calibration of the model.

Table 10. *Sensitivity rankings of stream flow parameters in the Deme watershed.*

	Parameter Name	T-Stat	P-Value	Rank
1	V__SLSUBBSN.hru	-25.33397	0.00000	1
2	V__CANMX.hru	10.88819	0.00000	2
3	V__HRU_SLP.hru	9.62008	0.00000	3
4	R__CN2.mgt	7.674351	0.00000	4
5	R__SOL_K(..).sol	7.43827	0.00000	5
6	V__ALPHA_BNK.rte	7.37192	0.00000	6
7	V__ESCO.hru	-3.65565	0.00000	7
8	V__GW_REVAP.gw	3.53703	0.00044	8
9	V__ALPHA_BF.gw	2.99513	0.00288	9
10	V__GWQMN.gw	-2.52588	0.01186	10
11	V__REVAPMN.gw	-2.40451	0.01657	11
12	V__CH_K2.rte	-2.11017	0.03536	12
13	V__OV_N.hru	2.08021	0.03803	13
14	V__EPCO.hru	1.88421	0.06014	14
15	R__SOL_ALB(..).sol	1.52648	0.12755	15
16	V__RCHRG_DP.gw	-1.49500	0.13557	16
17	R__CH_N2.rte	1.33954	0.18103	17
18	V__GW_DELAY.gw	0.82846	0.40781	18
19	R__SOL_AWC(..).sol	0.56676	0.571142	19

3.2. Model Calibration and Validation of Flow

3.2.1. Model Calibration

The overall performance of the model for calibration has been evaluated with the Coefficient of determination (R^2), Nash Sutcliff Efficiency (NS) and Pbias; It resulted in 0.75, 0.75 and -0.7% values respectively. Figure 8 below shows the result of measured and simulated values of SWAT_CUP calibration.

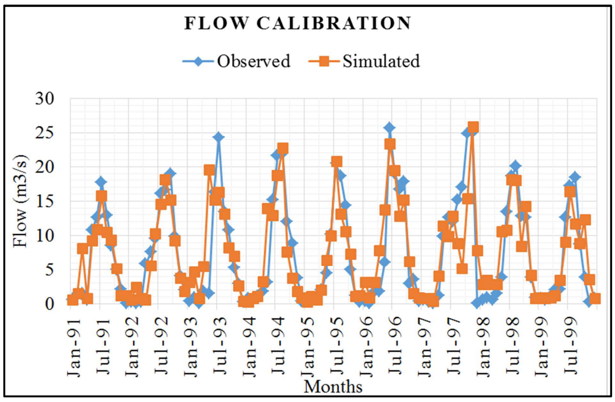

Figure 8. *Calibration results of monthly observed and simulated stream flow hydrograph.*

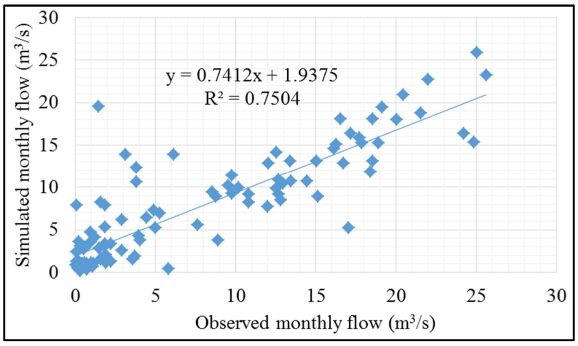

Figure 9. *Fit Line observed and simulated stream flow for calibration period.*

The plot of the measured and forecasted flow overlay of the monthly time step is shown in Figure 9 above. The graph reveals a minor under prediction at the year's peak flow phase in 1996, as well as a slight overestimation during the year's low flow period. The monthly observed and simulated calibration shows that the measure and simulated flow are generally in extremely excellent agreement.

Table 11. *Calibration statistics of observed and simulated streamflow.*

Monthly time step simulation	Average Flow (m^3/s)		Model Efficiency		
	Observed	Simulated	R^2	NSE	PBIAS
Calibration period (1991-1999)	7.28	7.33	0.75	0.75	-0.7%

3.2.2. Model Validation

Model validation is necessary to confirm the best fit calibration parameters and raise the user's degree of confidence. It was done for the entire year (2000-2006). The same parameters that were utilized and modified throughout the calibration procedure were used to compute this. Without additional adjusting, the parameters are used. Figure 10 performance statistics for the model show that R^2, NSE, and Pbias were, respectively, 0.74, 0.73, and 6.3%.

Table 12. *Validation statistics of observed and simulated streamflow.*

Monthly time step simulation	Average Flow (m³/s)		Model Efficiency		
	Observed	Simulated	R^2	NSE	PBIAS
Validation period (2000-2006)	6.27	5.87	0.74	0.73	6.3%

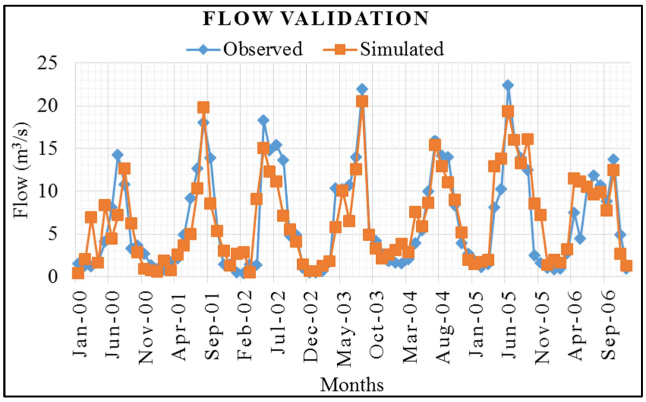

Figure 10. *Validation results of monthly observed and simulated stream flow hydrograph.*

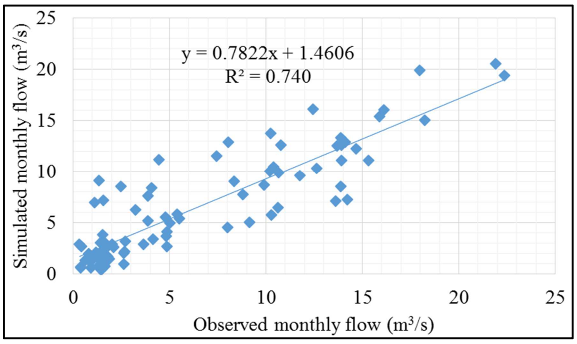

Figure 11. *Fit Line observed and simulated stream flow for validation period.*

The result indicated for calibrating and validating of simulated flow the hydrographs are well captured and the agreement between the measured and simulated value is generally good, which are verified by NSE, R^2 and PBIAS an acceptable result were obtained according to the model evaluation guideline [14].

3.3. Water Balance of Deme Watershed

The SWAT model was used to create the various Water Balancing Components. Rainfall, ET, Runoff, Baseflow, and Ground Water Recharge are the factors that were considered. The SWAT model also provided the distribution of landuse and landcover in the research area. Maps of soil, landuse, and landcover have also been published. The research area's soil classification is displayed on soil maps. We have two water balance equations for each watershed because the SWAT simulation was run individually for each watershed. The water balance equation is as follows:

$$P - Q - ET - \text{Base flow} \pm \Delta TWS - (\text{other components}) = 0 \quad (10)$$

Where;
P= Precipitation
Q= Runoff
E = Evapotranspiration
ΔTWS = change in terrestrial water storage And other components consist soil moisture, shallow and deep ground water storage, glacier and soil moisture.

Different components of the water balance of the Deme watershed has been determined using the calibrated and validated SWAT model. The most important water balance components considered are PET, Evaporation and transpiration, Precipitation, Average curve number, Surface runoff, Revap from shallow aquifer, Percolation to shallow aquifer, Lateral flow, Recharge to deep aquifer. The study revealed that a properly calibrated watershed model could be of great help in the watershed level water balance analysis. Figure 12 shows the quantified schematic representation of Hydrologic cycle. It is the hydrologic component output obtained from the SWAT model. The hydrologic cycle taking place in the land phase is explained by the Figure 12. Water present in each cycle component of the basin is expressed in mm. The water balance components of Deme watershed resulted PET 388.5mm, Evaporation and transpiration 293.8mm, Precipitation 1147.5mm, Average curve number 76.38, Surface runoff 189.7mm, Revap from shallow aquifer 7.7mm, Percolation to shallow aquifer 37.59mm, Lateral flow 624.33mm, Recharge to deep aquifer 0.28mm. The annual average precipitation of Deme sub-watersheds obtained for the period starting from 1991 to 2018 was 1147.5mm mm. Surface runoff, lateral flow and return flow ultimately contributes to the river flow and lost from the basin. Return flow or base flow is slower than lateral flow and surf ace runoff. The water that moves back to the atmosphere in the form of evaporation and transpiration and its value estimated at 293.8mm.

Table 13. *Monthly water balance component of Deme watershed.*

Month	Rain (mm)	Runoff (mm)	Water yield (mm)	ET (mm)
1	1.77	0.086	33.082	11.059
2	0.34	0.028	6.495	23.002
3	0.45	0.702	6.91	27.873
4	0.66	3.956	17.281	24.537
5	1.43	8.849	16.251	25.893
6	12.49	10.6	16.251	17.786

Month	Rain (mm)	Runoff (mm)	Water yield (mm)	ET (mm)
7	174.37	18.556	14.268	12.642
8	161.80	22.395	109.292	17.325
9	138.77	17.547	32.692	20.757
10	34.56	9.545	18.205	30.303
11	10.56	1.301	14.312	34.088
12	1.22	0.72	20.749	34.879

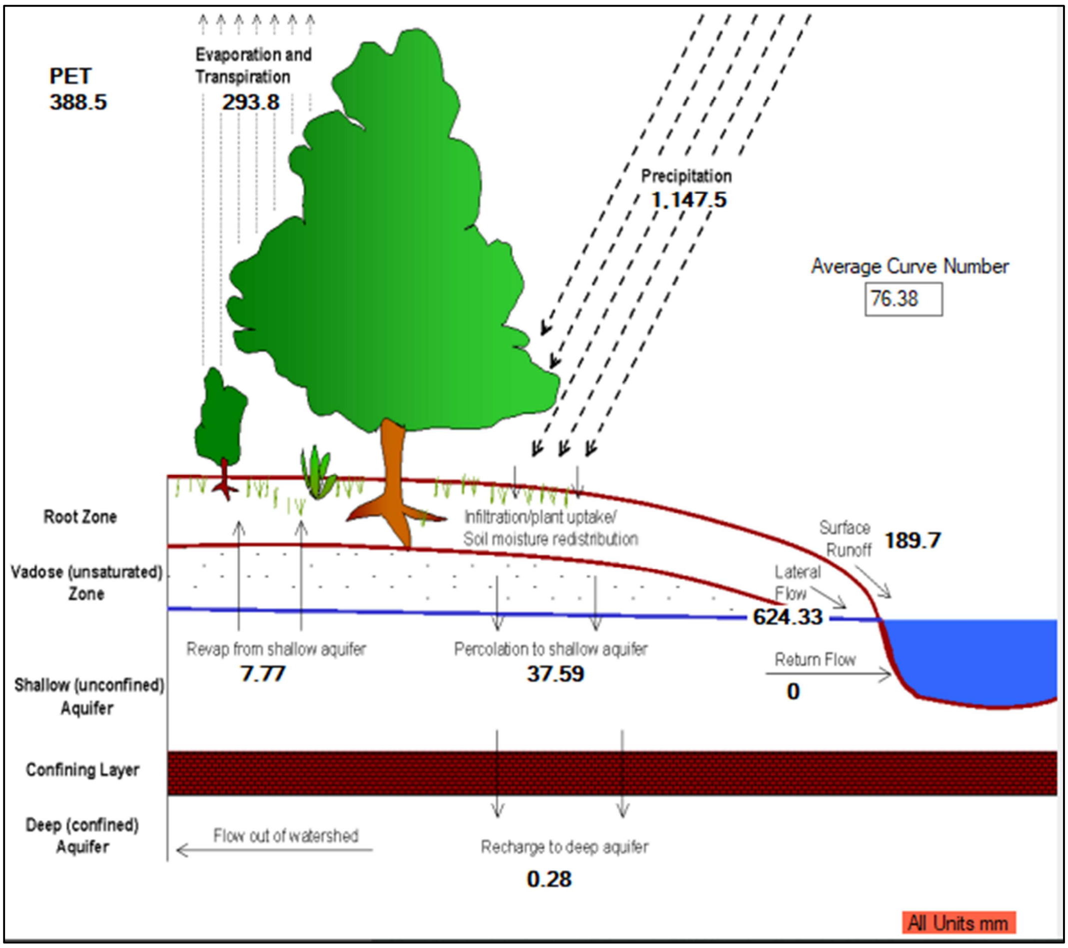

Figure 12. *Water balance of Deme watershed.*

4. Conclusion

Understandings on hydrological processes and develop suitable models for a watershed is the most important aspect in water resources development and management programmes. In the present study, Deme watershed of Deme river in Omo-Gibe basin, Ethiopia was selected for the assessment of water balance of a watershed using swat model for water resources management. Watershed based hydrologic simulation models are likely to be used for the assessment of the quantity and quality of water. The performance and applicability of SWAT model was successfully evaluated through sensitivity analysis, model calibration and validation. According to the result obtained from sensitivity analysis with measured discharge, subsurface flow parameters were found to be more sensitive to the stream flow of the watershed. Consequently, base flow was an important component of the hydrology of the study watershed, signifying the watershed is rich in ground water as a result of good recharge capacity. The stream flow simulation performance of the model for calibration and validation periods was evaluated using graphical and statistical methods. Nash Sutcliff Efficiency (NSE), coefficient of determination (R^2) and Percent bias (PBIAS) has given very high values for the calibration 0.75, 0.75 and -0.7% respectively and validation 0.73, 0.74 and 6.3% respectively. Model efficiency criteria were fulfilled the requirements of $R^2 > 0.6$, NSE > 0.5 and PBIAS ≤ ± 15, for both monthly flow calibration and validation periods. Accordingly, SWAT model was found to produce a reliable estimate of monthly runoff for Deme watershed. The water balance components of Deme watershed resulted PET 388.5mm, Evaporation and transpiration 293.8mm, Precipitation 1147.5mm, Average curve number 76.38, Surface runoff 189.7mm, Revap from shallow aquifer

7.7mm, Percolation to shallow aquifer 37.59mm, Lateral flow 624.33mm, Recharge to deep aquifer 0.28mm. However, the model was weaker for the simulation of monthly stream flow in both calibration and validation periods, particularly, the monthly peak events were underestimated and low flows were overestimated. Nevertheless, additional weather station on the upstream area may produce more accurate prediction on a daily time step. Overall, the simulated and measured discharge followed similar patterns and trend, thus, SWAT model can be used for hydrologic simulation of mountainous watershed with similar characteristics to Deme river watershed. However, for a more accurate modeling of hydrology, a large effort will be required to improve the quality of available input data. The study pointed out that SWAT model could be a promising tool to predict water balance for the sustainable management of water resource.

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