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Performance Evaluation of SWAT-CN and SWAT-WB Hydrological Models for Estimation of Runoff in the Didessa Watershed, Abbay Basin, Ethiopia

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Abstract

Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. The Soil Water Assessment Tool is a watershed model widely used to predict water quantity and quality under varying land use and water use regimes. The objectives of this research were to test the performance evaluation of the SWAT-CN and SWAT-WB models for prediction of Runoff in the Didessa watershed. To determine the respective amounts of infiltration and surface runoff, SWAT uses the popular Curve Number method. Water balance models generally take the runoff generation processes in the assumption of saturation excess and in curve number method runoff generation processes in the assumption of infiltration excess. In order to use SWAT in monsoonal climates, the CN routine to predict runoff was substitute with a simple water balance routine in the code base. The calibrated and validated, SWAT-CN and SWAT-WB models performed well for simulation of monthly stream flow. Statistical model performance measures, coefficient of determination of 0.71 & 0.77 , the Nash–Sutcliffe simulation efficiency of 0.66 & 0.68, Index of volumetric fit of 0.96 & 0.88 and Percent bias -3.79 & -13.46, for calibration and 0.70 & 0.77, 0.68 & 0.69, 1.06 & 0.88 and 6.32 & 13.58 respectively for validation, both model indicated good performance of the model simulation on monthly time step. These results suggest that both SWAT can successful model saturation-excess and infiltration excess technique for runoff generation processes in the Didessa watershed. The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flow and soil erosion.

Keywords: Runoff; SWAT-CN; SWAT-WB; Didessa watershed

Introduction

All water-related engineering activities require an appropriate estimation of the runoff magnitude. In order to accurately determining the quantity of surface runoff that takes place in a river basin, an appropriate understanding of the complex relationships between rainfall and runoff processes, which depend upon many geomorphologic and climatic factors, is necessary. The simulation of time series of representative flow values need a model that is simple enough to be understand as well as to be use, yet complex enough to be representative of the system.

Establishing a rainfall-runoff relationship is the principal focus of hydrological modeling, from its simple form of unit hydrographs to rather complex models based on entirely dynamic flow equations. As the computing capabilities are increasing, the use of these models to simulate a watershed has become a standard. Models are generally used as useful in various areas of water resources development, among others in assessing the available resources, in studying the impacts of human interference in an area such as land use change, deforestation and other hydraulic structures as for instance dams and reservoirs (Moreda.F 1999).

In recent years, distributed watershed models have been used increasingly to implement alternative management planning in the areas of water resources allocation, flood control, land use and climate change impact assessments, as well as pollution control.

The Soil and Water Assessment Tool (SWAT) is a physical−based watershed−scale model that was developed to predict the impacts of land management practices over long periods of time on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land uses, and management conditions. SWAT model is a basin scale model where runoff is based on land use and soil type Surface runoff from daily rainfall is estimated in SWAT using SCS curve number method (Arnold, et al. 1998). SWAT has produced favorable model results when evaluated on watersheds with a range of conditions in the U.S (Lee.T 2011; Cibin, et al. 2014). And many other countries such as Iran (Monireh, et al. 2009), Malaysia (Milad.Jajarmizadeh 2012), Vietnam (Nguyen D. B 2010), 18 countries in West Africa (Schuol, et al. 2008). In Ethiopia Upper Abbay basin (Easton.Z.M, et al. 2011; Easton.Z.M, et al. 2010; White E. D. 2011; Setegn, Srinivasan and Dargahi 2008) etc. In addition, across many of these watersheds SWAT has shown flexibility model in simulating surface runoff.

One common method to determine the surface runoff generation in these models is the Natural

Resource Conservation Service Curve Number (CN) technique. This method was initially designed for determining runoff generation for engineering design purposes, but has since been adapted for use as implement in many temporal watershed models, including the USDA‘s Soil and Water Assessment Tool (SWAT).

White (2009) and Easton, et al. (2011) recently modified SWAT to more successful and effectively model hydrological processes in monsoonal climates like Ethiopia. This new version of SWAT, SWAT-Water Balance, calculates runoff volumes.

Therefore, the objective of this study was to compare and assess the suitability of two Runoff simulation models, namely SWAT-CN and SWAT-WB for simulating the hydrology of a major tributary of the lower Abbay River Basin, the Didessa Watershed. The performance of the two models was assessed with respect to their capacity to generate the monthly flow rate at the catchment outlet of the Didessa Watershed.

Methodology

The Didessa Watershed is geographically located between 36 ^{0} 02’ and 37 ^{0} 14’ East longitude, and between 7^0 43’ and 9^0 13’ North latitude (figure 1). It is situated in the south-west part of Abbay River Basin. The drainage area touches the three administrative zones of Oromia regional state of Ethiopia: Jimma Zones in the most upper and middle part, Illibabur Zone in the middle part and East/West Wellega in the lower part down to its confluence to the Abbay River.

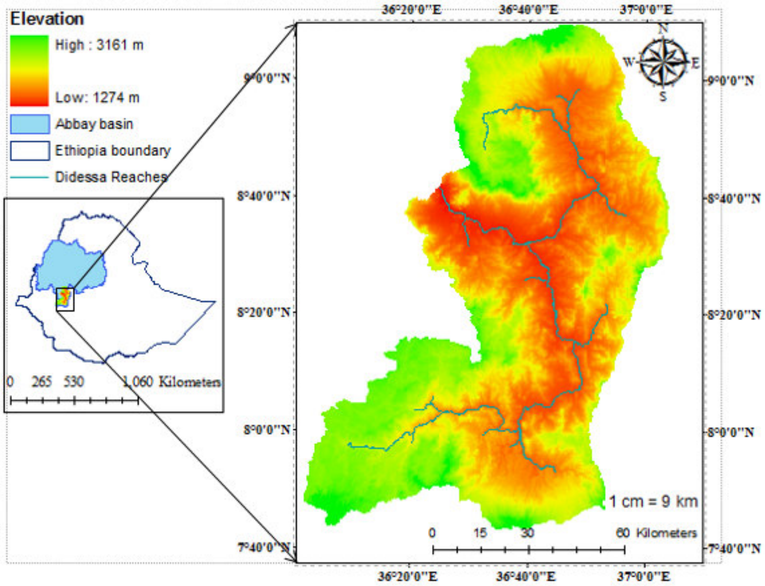

Figure 1. Location of Didessa Watershed

The study area has an annual rainfall ranging between 1509 mm to 2322 mm. The majority of the area characterized by a humid tropical climate with heavy rainfall and most of the total annual rainfall is received during one rainy season called kiremt. The maximum and minimum temperature varies between 21.1 – 36.5^{0}c and 7.9 - 16.8^{0}c, respectively. The altitude ranges between 1274m and excluding some top hills and mountains, which can go more than 3161m above sea level.

The Didessa River is the largest tributary of the Abbay River in terms of volume of water, contributing roughly a quarter of the total flow as measured at the Sudan border. Draining an area of nearly 27,000 square kilometers, the Didessa River originates from Mt. Vennio and Mt. Wache ranges which are located in the South Western part of watershed. Having a vast number of small and large tributaries the

Didessa sub-basin. Yebu, Urgessa, Temssa, Dabana, Indris, Anger and Tato rivers are some of the dozen tributaries of the Didessa River system. In the North East direction of the basin, the main tributary of Didessa River with the largest catchment area is Anger River (Muluneh.T and Mamo.W 2014). The catchment area at a gauging station near Arjo town is 9,981 km^2. Daily Didessa River flow data gauging station near Arjo town that was used in period from 1988-2008 G.C.

According to their texture, eight major and dominant soil types identified in the sub basins. The most dominant soil type is Haplic Alisols, Eutric Vetisols and Haplic Acrisols (63.85 %, 14.46 % and 11.18 % respectively). Small patches of soils present in the basin were Haplic Nitisols and Rhodic Nitisols (6.60 %, 2.96 %), and Eutric Regosols, Eutric Fluvisols, and Eutric Leptosols less than 1 % of area (BCEOM 1999). Didessa watershed with slope ranging from 0% to 103.98%, with a median and mean of 11.4% and 13.3 %.

Land use coverage indicated that Agriculture, Bush land, Forest, Grassland and Urban. Agriculture, Bush land and Forest (48.58 %, 29.94 % and 17.72 %) dominantly land use in Didessa sub basin. Grassland and

Urban also observed in some parts of the basin (BCEOM 2002).

Methodological Approach

In this research, Arc SWAT version 2009.93.7b used for SWAT2009 model, where the simulator is integrated with ArcGIS 9.3. The basic data sets required to develop an input database for SWAT2009 model are geographic, meteorological and hydrological data as well as other watershed data. Required geographic data includes DEM, soil, and land use and land cover etc. Hydrological data includes stream flow data. Meteorological data required include rainfall, temperature, and other related data.

Hydro-meteorological Data

The meteorological data required were daily precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity data for the 1988-2012 time spans. These data were obtained from Ethiopian National Meteorological Agency (NMA). If any of these data was not available, which is very likely, SWAT can generate data using weather generator. SWAT2009 includes the WXGEN weather generator model to generate climatic data or to fill in gaps in measured records. To generate the data, weather parameters were developed by using the weather parameter calculator WXGEN and dew point temperature calculator DEW02 that were downloaded from SWAT website. In this research, Jimma principal station used to weather generator. Daily Didessa River flow data gauging station near Arjo town which was used to calibrate and validate the two models. Were collected from ministry of water, Irrigation and energy, hydrology department the period from 1988-2008 G.C.

Spatial Data

Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. The watershed range from 1274 to 3161 meters above sea level. A 90 m by 90 m resolution DEM was obtained from MoWIE. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub-basin parameters such as slope gradient and the stream network characteristics such as flow direction and flow accumulation were derived from the DEM.

Soil Data

SWAT model requires different soil textural and physicochemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained mainly from the following sources; Abbay River basin Integrated Development Master Plan Project, The shape file which describes the distribution of soil in the Didessa watershed were obtained from the base line maps available at MOWIE at a scale of 1: 250,000. It was observed that eight major and dominant soil types identified in the sub basins.

Land Use/Land cover

Land use is one of the most important factors that affect surface runoff, erosion and evapotranspiration in a watershed. Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use map to SWAT land use databases in the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model. Hence the classified and use map and its attribute were adjusted to the SWAT model requirement format and database. Agricultural land use is the dominant land use in the Didessa River catchment. The LULC map and all datasets were obtained from MoWIE, 2002. This spatial database was derived from satellite imagery and field data collected and is the most current and detailed LULC data known to be available for the study watershed.

Model Setup

SWAT-CN and SWAT-WB Models Setup Soil and Water Assessment Tool–Curve Number and Water Balance, hydrological models, employed this study to simulate runoff. All of processes in SWAT-WB can be performed through the interface in Geographic Information System (GIS) for original SWAT. ArcSWAT 2009 interface with ArcGIS 9.3 used.

The model setup involved seven steps: (1) Watershed delineation (2) sub-basin discretization (3) HRU definition (4) Weather Data Definition (5) SWAT Simulation (6) sensitivity analysis, and (7) calibration and validation.

Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameters for Ethiopia. A watershed was separated into a number of sub-basins, for modeling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub-basins.

Sub-basin discretization

In the standard SWAT sub-basin, discretization was made based on the slope, soil and land use percentage thresholds. Sub-basins are divided into hydrologic response units (HRUs). HRU is the smallest unit in SWAT defined based on a unique combination of slope, soil type and land use. Using the SWAT Model Didessa watershed was divide in to 29 sub-basin and 236 HRUs determined by unique inter section of the LULC, slope and soil within the watershed.

Hydrological Response Units (HRUs)

The land area in a sub-basin was divided into HRUs. The HRU analysis tool in ArcSWAT helped to load land use, soil layers and slope map to the project. The delineated watershed by ArcSWAT and the prepared land use and soil layers were overlapped 100 %. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. Recommended thresholds of 10% for land cover also soil and 5% for the slope area were applied to limit the number of HRUs in each sub watershed. For this specific study a 10 % threshold value for land use, 10 % for soil and 5 % for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin.

Weather Data Definition

Meteorological records (precipitation, minimum and maximum temperature, relative humidity, solar radiation and wind speed) and location of Meteorological stations are prepared based on SWAT table format and integrated with the model using weather data input wizards. In both methods, Jimma Meteorological station data were used as weather generator.

Simulation

SWAT simulation run was carried out on the 1988-2012 climate data. The first two years taken for warm up period. The warm up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm up period differ from watershed to watershed. It is mainly depend on the objective of the study. The simulate output data imported to database and the simulation results were saved in different files of SWAT output format. The file that saved in table out Microsoft access format contains different SWAT parameters output. It is used for SWAT model calibration since most of the observations of the watershed's behavior are obtained by measuring these parameters.

Sensitivity analysis

The sensitivity analysis tool in SWAT2009 is used in ranking parameters based on their influence in governing flow or sediment. This is an important step in the modeling process as it helps in identifying the parameters to calibrate which otherwise will become very complex and computationally time consuming. After a thorough preprocessing of the required input for SWAT model, flow simulation was performed for sixteen years of recording periods starting from 1988 through 2003. The first two years of which was used as a warm up period and the simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool.

Calibration and Validation

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices. Once optimal parameter values were chosen via the manual routine, each calibrated models was then run over a new period. Stream flow data of five years from 2004 to 2008 were used for validation. The four statistical model performance measures used in calibration procedure were also used in validating stream flow both SWAT-CN and SWAT-WB models.

Model Performance Evaluation

The most widely used statistics reported for calibration and validation are $R^2$and NSE (Arnold J.G., et al. 2012). Four criteria were used for evaluation of SWAT-CN and SWAT-WB. NSE, R^2, IVF and PBIAS as model evaluation statistics. First, a visual comparison was made between the modeled and the observed hydrographs. Selected criteria used to evaluate the goodness-of-fit of each model approach are shown in Table 1.

Table 1 List of criteria used to compare predicted results versus observed measurements

No	**Criteria**	**Equation**	**Value for perfect fit**
1	Nash-Sutcliffe efficiency, NSE(Coefficient of efficiency)	$NSE = 1 - [\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}(O_i - \hat{O})^2}]$	1
2	Coefficient of determination, R^2 (The square of the Pearson's product moment correlation coefficient)	$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \hat{O})(S_i - \hat{S})}{\left[\sum_{i=1}^{n}(O_i - \hat{O})^2\right]^{0.5}\left[\sum_{i=1}^{n}(S_i - \hat{S})\right.}\right.$	1
3	Index of volumetric fit (IVF)	$\mathrm{IVF} = \frac{\sum_{i=1}^{n} Q_{i,obs}}{\sum_{i=1}^{n} Q_{i,sim}}$	1
4	Percent bias (PBIAS)	$PBIAS = [\frac{\sum_{i=1}^{n}(y_i{}^{obs} \quad y_i^{sim}) * (100)}{\sum_{i=1}^{n}(y_i^{obs})}]$	0

Where: (N) number of months, (O_i) Observed & (S_i) Simulated: (Ô) average of the observed value & (Ŝ) average of the simulated value.

Result and Discussion

Sensitivity Analysis

The model considered twenty-six flow parameters for sensitivity analysis from which twenty-one of them were found positive to be relatively sensitive with the category of sensitivity ranging from very high to small. Sensitivity analysis was run for the period 1988-2003.

SWAT-CN

The result of the analysis indicates that six parameters namely; Curve number (CN2), Maximum canopy index (CANMX), Threshold depth of water in the shallow aquifer required for return flow to occur (mm) (GWQMN), Soil Evaporation Compensation factor (ESCO), Maximum potential leaf area index at the end of time period (BLAI), and Soil Available Water Capacity (SOL_AWC) are the most crucial parameters for the Didessa watershed (Table 2).

Table 2. SWAT-CN most sensitive parameter

Parameter	**Description**	**Relative sensitivity value**	**Class**	**Rank**
CN2	SCS runoff curve number for moisture condition II	0.27	High	1
CANMX	Maximum canopy index	0.16	Medium	2
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.153	Medium	3
ESCO	Soil Evaporation Compensation factor	0.0967	Medium	4
BLAI	Maximum potential leaf area index at the end of time period	0.0832	Medium	5
SOL_AWC	Soil Available Water Capacity	0.0575	Medium	6

SWAT-WB

SWAT-WB flow sensitivity analysis was performed on model parameters. Seven parameters are found sensitive. Soil properties; depth from soil surface to bottom of layer (SOL_Z) in mm), available water capacity (SOL_AWC), and soil evaporation compensation factor (ESCO) were the high sensitive parameter in runoff production. Runoff generation was also found to be sensitive to groundwater parameters; the base flow alpha factor (ALPHA_BF) in days, and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) in mm. The base flow alpha factor (ALPHA_BF) in days was found to be the most sensitive parameter in sensitivity analysis. The crop parameters; maximum potential leaf area index (BLAI), and plant uptake compensation factor (EPCO) were high sensitive parameters in runoff production. Most sensitive parameters summarize in (table 3).

Table 3 SWAT-WB most sensitive parameter

Parameter	Description	Relative sensitivity value	Class	Rank
ALPHA_BF	Base flow alpha factor (days)	1.52	Vary High	1
SOL_Z	Depth from soil surface to bottom of layer (mm)	0.943	High	2
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.84	High	3
BLAI	Maximum potential leaf area index at the end of time period	0.801	High	4
SOL_AWC	Soil Available Water Capacity	0.483	High	5
ESCO	Soil Evaporation Compensation factor	0.367	High	6
EPCO	Plant uptake compensation factor	0.258	High	7

The model were developed using spatial data (DEM, land use, soil) and hydro-meteorological data. Model comparison was done initial finding parameters and the result presented in Table 4 below.

Table 4 SWAT-CN and SWAT-WB Model efficiency before calibration

Model	SWAT-CN	SWAT-WB
Coeff. det.(R^2)	0.47	0.37
N-S coeff. (ENS)	0.29	0.26
I. volumetric fit (IVF)	0.36	0.27
PBIAS	-70.74	-56.04

The SWAT-CN Model Calibration and Verification

The calibration and verification of the model are implemented by splitting the concurrent flow data series into calibration and verification periods (about two-thirds for calibration and one-third for verification) and the first two years of the simulation were used as a model warm-up in order to establish proper initial conditions. Statistical model efficiency criteria achieved the requirement of $R^2 > 0.6$ and ENS > 0.5 which is recommended by SWAT developer (Santhi, et al. 2001). Stream flow was calibrated until monthly $R^2 > 0.6$ and ENS > 0.5.

Model Calibration

After this initial findings parameter sensitivity analysis, model calibration and validation were done for Didessa watershed using SWAT-CN method. For 1990 to 2003 data used for calibration, 2004 to 2008 data used for validation and 1988 & 1989 data used to model initial condition. The most sensitive parameters controlling the High surface runoff in the watershed are the curve number (CN2), to reduce this high surface runoff was by decreased curve number (CN2) -10.3 % and increased Soil properties**;** Soil Available Water Capacity (AWC) and Soil Evaporation Compensation factor (ESCO) by +10 % and adjusted 0.4. The crop parameters; maximum potential leaf area index (BLAI) and Maximum canopy index (CANMX) increased by +20% and replaced by 2. Also groundwater parameters; to reduced high base flow Threshold depth of water in the shallow aquifer required for base flow to occur (GWQMN) replaced by 4500. Hence, reasonable results were obtained (Table 5 and Figure 2).

The performance efficiency values in both the calibration and validation phases prove that SWAT-CN predicted measured stream flow good for monthly stream flow time steps. As indicated in the table 5 blow, the monthly coefficient of determination value 0.71, the ENS value of 0.66 and Index of volumetric fit 0.96 and PBIAS -3.79 for the calibration period was respectively.

Table 5.SWAT-CN performance during the Calibration and verification periods

Model Performance	SWAT-CN Calibration	Validation
Coeff. det.(R^2)	0.71	0.70
N-S coeff. (ENS)	0.66	0.68
I. volumetric fit (IVF)	0.96	1.06
PBIAS	-3.79	6.32

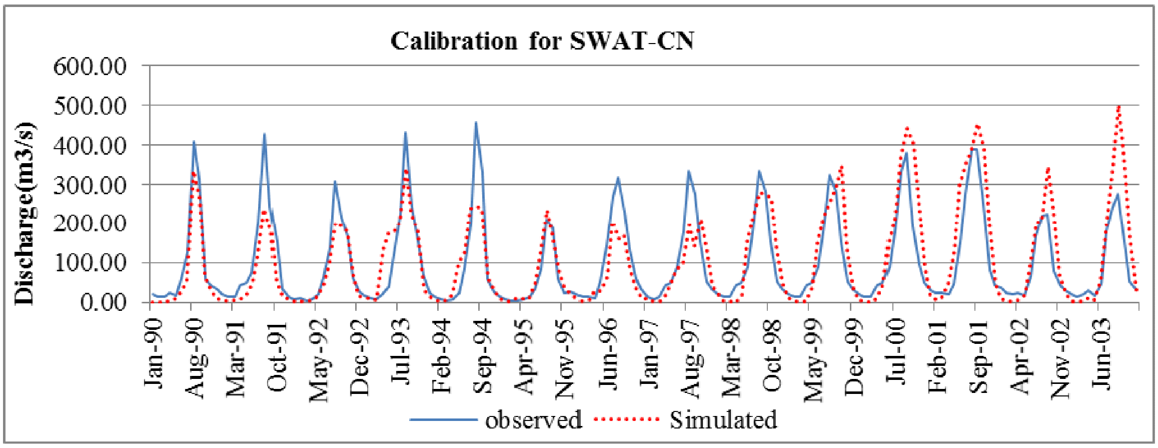

Figure 2. SWAT-CN model Observed and Simulated hydrograph during Calibration period

The above Figure clearly presents the graphical analysis of measured and simulated data that allows for identification of general trends in the data and differences between model simulations. The model-underestimated peak flow from the watershed in 1990 to 1998 years and over predicted in 1999 to 2003 years. The flow in the dry season, which is determined by the groundwater also under estimated in the period of 1990 to 1991 and 1998 to 2003 years.

This graphical interpretation together with the numerical analysis given in Table 5 gives a comprehensive measure of the agreement between measured and simulated data. Most models are on the condition with default values of the parameters. However, in this case initial values of the model parameters were described. The minimum and maximum acceptable values were provided based on the information of SWAT training manual, related pervious works and literatures. The manual calibrating was made by varying the values of the sensitive parameters within their allowable values. It was carried out repeatedly by changing one of the more sensitive parameters in the model and then observing the corresponding changes in the simulated flow. While performing the process, the models input parameters were adjusted, by means of the effective parameters, which were selected and ranked in the sensitivity analysis process. The best parameters obtained were compared to the predicted flows. Table 6 shown that the calibrated parameters are within range of the suggested values of SWAT.

Table 6. SWAT-CN finally calibrated flow parameter values

Parameter	Initial values	Lower and upper bounds	Fitted values
CN2	**	±25.0	-10.3%
CANMX	0	0.0 to 10.0	2
GWQMN	0	0.0 to 5000	4500
ESCO	0	0.0 to 1.0	0.4
SOL_AWC	**	±25.0	+10%
BLAI	**	±25.0	+20%

Where ** SWAT Default Initial values

Model Validation

It was found that the model has satisfactorily predictive capability with R^2, ENS, IVF and PBIAS values of 0.70, 0.68, 1.06 and 6.32 respectively. This showed the model parameters represent the processes occurring in the watershed to the best of their ability given available data and may be used to predict watershed response for various outputs. The model validation results for monthly flow (Figure 3) indicated the model-underestimated peak flow from the watershed in 2005 years. The flow in the dry season, which is determined by the groundwater also under estimated over all validation period. Generally, a good fit between measured and simulated output. Since the model performed as well in the validation period, as for the calibration period hence the set of optimized parameters listed in Table 6 during calibration process for Didessa watershed can be taken as the representative set of parameters for the watershed.

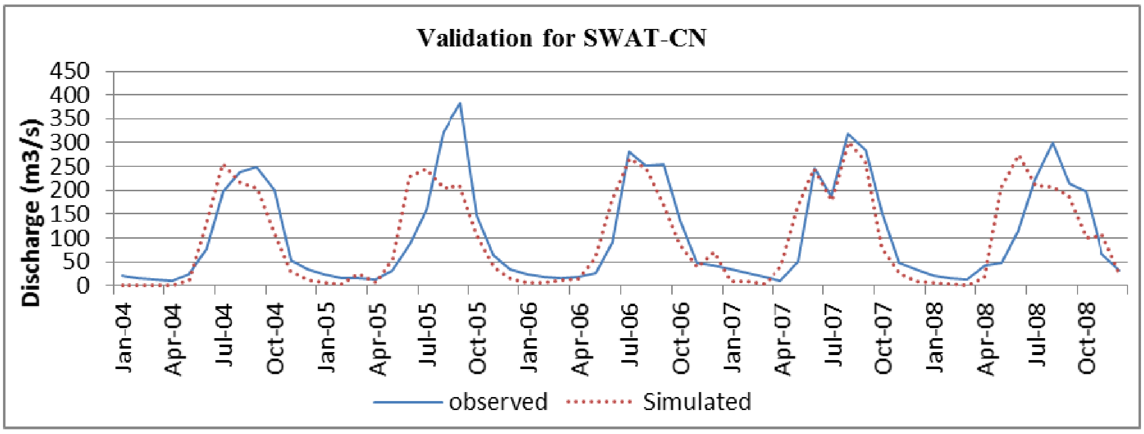

Figure 3 SWAT-CN Observed and Simulated hydrograph during validation period

The SWAT-WB Model Calibration and Verification

Result of sensitivity analysis was followed in model calibration which done on monthly basis. Runoff calibration for the study area was conducted similarly to SWAT-CN for the years 1988 to 2003. Data of previous two years respectively were used for warm up simulation. Calibration was performed manually until the predicted values meet with the observed monthly average. Similarly, model was done initial parameters in SWAT-WB model and the result presented in Table 4 above.

Model Calibration

The comparison of default simulation output with the observed value shows a clear difference between the simulation result and observed stream flow that necessitate model calibration. Base flow alpha factor (ALPHA_BF) and Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) replaced by 0.95 and 4500. Depth from soil surface to bottom of layer (SOL_Z) and Available water capacity of the soil layer (SOL_AWC) increased by 15% and 12% in order to reduce surface runoff, soil evaporation compensation factor (ESCO) was adjusted into 0.7 in attempt to decrease total flow. The crop parameters; maximum potential leaf area index (BLAI) increased by +20%, and plant uptake compensation factor (EPCO) replaced by 0.85. Parameters that affect the model result were adjusted in order for simulated output to meet the actual values as a result the objective functions (R^2,ENS, IVF and PBIAS) are improved. The topographic index map is created from DEM. As a result, 3.03123 and 19.6471 is the minimum and maximum topographic index for Didessa watershed respectively (figure 4). The effective depth coefficient (EDC) value was adjusted to be 0.050 to 0.831. This EDC value depends on topographic index of the soil, where areas that have a high topographic index (e.g, areas that produce a lot of runoff) have an EDC value approaching 0, and areas with a low topographic index (e.g, areas that do not produce a lot of runoff) have an EDC value approaching 1. The final adjusted parameter values presented in table 7.

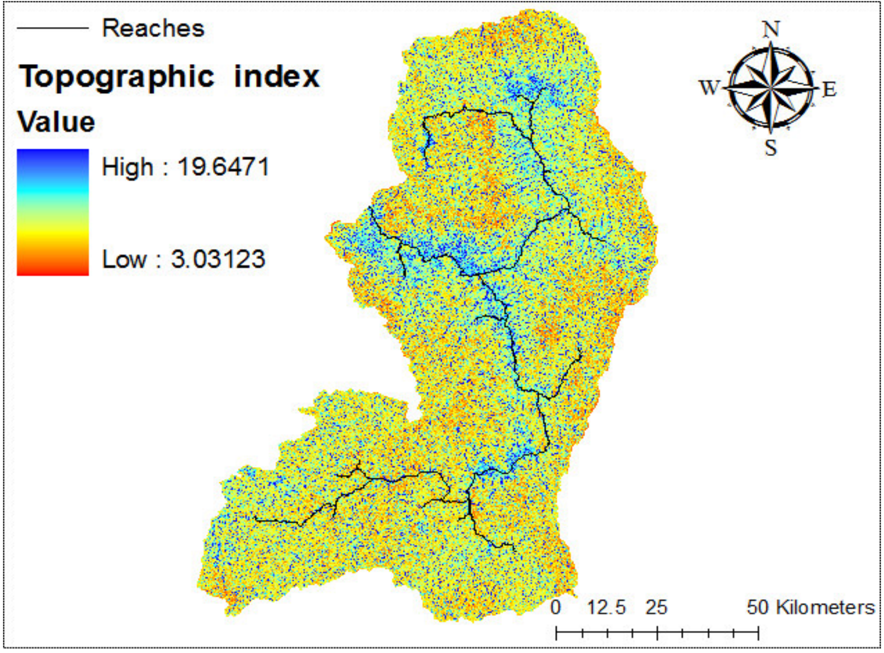

Figure 4. Topographic index for Didessa watershed

Table 1 SWAT-WB finally calibrated flow parameter values

Parameter	Initial values	Lower and upper bounds	Fitted values
ALPHA_BF	**	0.0 to 1.0	0.95
SOL_Z	**	±25.0	+15%
GWQMN	0	0.0 to 5000	4500
SOL_AWC	**	±25.0	+20%
BLAI	**	0 to 1	+20%
ESCO	0	0.0 to 1.0	0.7
EPCO	0	0.0 to 1.0	0.85
EDC	**	0.0 to 1.0	0.050 to 0.831

Where ** SWAT Default Initial values

The comparison of observed and calibrated flow for 14 years of simulation indicated that there were a good agreement between observed and calibrated flow yielding higher value of coefficient of determination (R^2) and Nash-Sutcliffe efficiency (ENS) than calibrated value of SWAT-CN. The model performance can be judged as satisfactory if R^2 is greater than 0.6 and ENS is greater than 0.5. The model goodness of fit and result on average of monthly surface runoff after calibration was shown in the table 8 and figure 5.

Table 2 SWAT-WB performance during the Calibration and verification periods

Model Performance	SWAT-WB Calibration	Validation
Coeff. det.(R^2)	0.77	0.77
N-S coeff. (ENS)	0.68	0.69
I. volumetric fit (IVF)	0.88	0.88
PBIAS	-13.46	-13.58

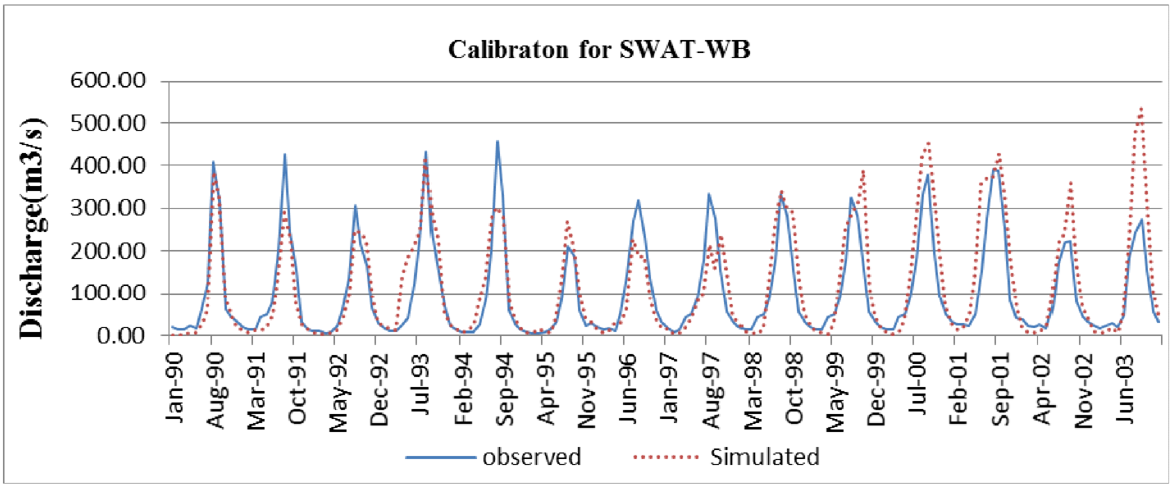

Figure 5. SWAT-WB model Observed and Simulated hydrograph during Calibration period

The above Figure 5 clearly presents the graphical analysis of measured and simulated data that allows for identification of general trends in the data and differences between model simulations. The model simulation underestimated peak flow from the watershed in 1991, 1992, 1994, 1996 and 1997 and over predicted in 1995, 1999 to 2003. The flow in the dry season, which is determined by the groundwater also under estimated in the period of 1990 to 1991 and 1998 to 2003.

Model Validation

Calibrated model efficiency was validated for the year 2004 to 2008 (one third of the entire flow data used for validation). It was found that the model has good predictive capability with R^2, ENS, IVF and PBIAS values of 0.77, 0.69, 0.88 and -13.58 respectively. The model validation results for monthly flow (Figure 6) indicated generally a good fit between measured and simulated output than SWAT-CN model. The model-underestimated peak flow from the watershed in 2005 and over predicted in 2004, 2006 and 2007. The flow in the dry season, which is determined by the groundwater also under estimated over all period.

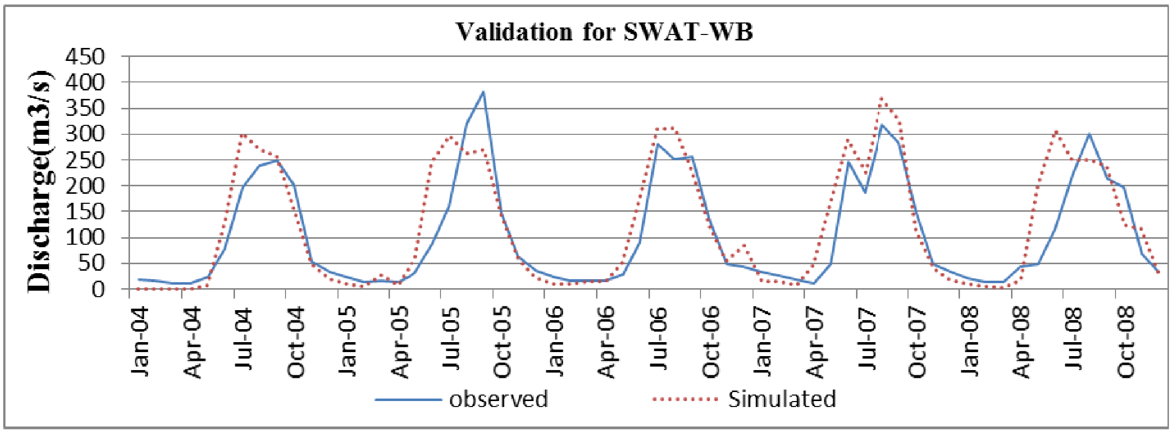

Figure 6 SWAT-WB Observed and Simulated hydrograph during validation period

Comparison of SWAT-CN and SWAT-WB approach

Model comparison was done initial findings parameter sensitivity analysis the result presented in Table 4 above. The initial parameter result shows that SWAT-WB (saturation excess) better output finding then SWAT-CN (infiltration excess).

After this initial findings parameter sensitivity analysis, model calibration and validation were done using SWAT-CN and SWAT-WB method (table 9). The SWAT-WB performance result is batter then SWAT-CN model applied in the Didessa watershed both in calibration (R^2=0.77 and NSE=0.68) and verification (R^2=0.77 & NSE=0.69) periods and has good hydrological fit.

The index of volumetric fit (IVF) and PBIAS the evaluation criteria SWAT-CN model present very good fit regarding the ratio between simulated and observed flow in calibration (IVF=0.96, PBIAS=-3.79) and verification (IVF=1.06, PBIAS=6.32) period. These results confirm the adequacy of both for modelling on the catchment.

Table 9 Overall model statistics for monthly stream flow in Didessa watershed

	SWAT-CN		**SWAT-WB**	
	Calibration	**Validation**	**Calibration**	**Validation**
R^2	0.71	0.70	0.77	0.77
NSE	0.66	0.68	0.68	0.69
IVF	0.96	1.06	0.88	0.88
PBIAS	-3.79	6.32	-13.46	-13.58

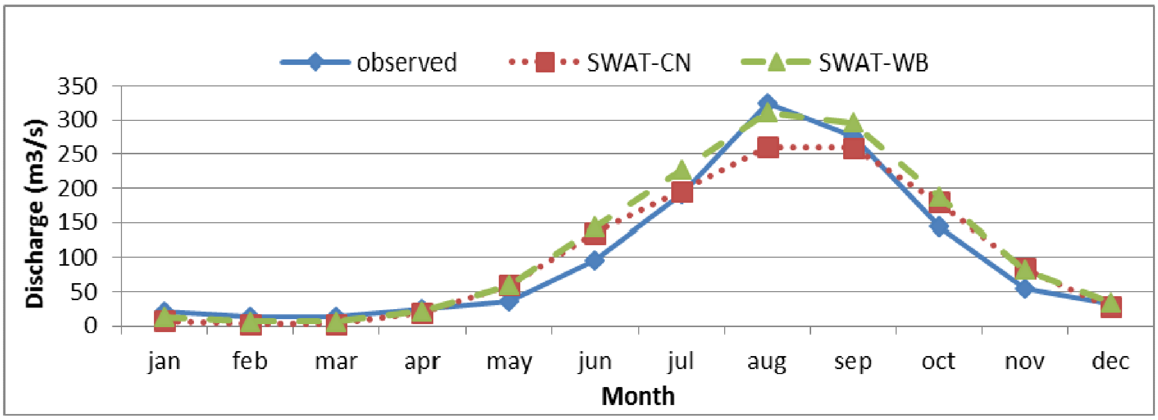

Figure 7. Observed and estimated hydrograph of SWAT-CN and SWAT-WB models in monthly annual flow

A comparison of monthly annual catchment stream flow for two models result obtained difference in peak flows. From figure 7, the majority of peak flows occur during the month of July to September, which is the rainy season in the Didessa catchment. Highest peak flows observed in august was 325 m^3/sec, SWAT-CN generated the same month was 260 m^3/sec and SWAT-WB produced 311 m^3/sec in the same month. On the other hand, dry average monthly flows occur during January to march. Observed 21 m^3/s, 15 m3/s and 15m^3/s, generated SWAT-CN was 8 m^3/s, 3 m3/s and 3 m^3/s and SWAT-WB was 13 m^3/s, 7m3/s and 7 m^3/s. In both peak and dry monthly annual average flows in Didessa catchment.

Conclusion and Recommendation

The performance and applicability of SWAT-CN and SWAT-WB models was successfully evaluated through sensitivity analysis, models calibration and validation. The result of sensitivity analysis indicated SWAT-CN and SWAT-WB models are curve number (CN2) and Base flow alpha factor (ALPHA_BF) were the most sensitive parameters.

The calibration and validation results of SWAT-CN and SWAT-WB models were driven by observed hydro-climatic, DEM, land use and soil data set show that both models was produce the monthly runoff with acceptable accuracy for Didessa watershed which was confirmed by various model efficiency measures. These results indicate that both SWAT model good performance rating in R^2, NSE, IVF and PBIAS. The model efficiency measures proved that hydrologic simulation with SWAT-WB and SWAT-CN in the Didessa watershed almost similar respond they have. However, for a more accurate hydrological modeling, a large effort will be required to improve the quality of available input data.

Further study is recommended that calibrated models can be used for further analysis of the effect of climate and land use changes as well as other different management scenarios apply on stream flows and soil erosion. Hence, the calibrated models using ungauged watersheds is required in order to check the transferability of the models and the performance of SWAT-WB and SWAT-CN for lower Abbay basin.

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