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REVIEW OF SOIL AND WATER ASSESSMENT TOOL (SWAT) APPLICATION IN SUB-SAHARAN AFRICAN COUNTRIES

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Abstract
Studies on Soil and Water Assessment Tool (SWAT) application in Sub-Saharan Africa were reviewed and evaluated mainly on basis of Nasch-Sutcliffe Model Efficiency (NSE). Most of the reviewed studies gave satisfactory results on performance while sensitive parameters were identified.The review studies highlighted lack of some input data which affected SWAT simulation in some catchments. Generally, the review observed that not much attention were given to crop parameters such as the leaf index. A better simulation will occur if crop parameters are taken into consideration as these will help in obtaining a better evapotranspiration, runoff and erosion simulation.

Keywords: Soil and Water Assessment Tool; hydrologic model; sub Saharan Africa

1. Introduction

The Soil and Water Assessment Tool (SWAT) is a physically based, spatially distributed, continuous time hydrological model (Arnold et al., 1998). Major modules in the model include hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, land management, stream routing, and pond/reservoir routing. The SWAT modelling tool simulates, among others, climate changes, hydrologic processes, land-use changes, water use management, water quality and water quantity assessments (Gassman et al., 2007). SWAT requiresa number of basin-specific input data encompassing different components such as weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, channel routing, and pond/reservoir routing. Weather inputs (i.e. precipitation, maximum and minimum temperature, relative humidity, wind speed, solar radiation) are required on a daily temporal resolution, although recent versions of the model allow hourly input files. SWAT is imbedded in several GIS interfaces (e.g. ArcGIS, Open Map, Grass, etc.) that allow to discretise a basin into sub-basins. Each sub-basin contains river reaches and one set of weather inputs. The sub-basin is further subdivided into hydrological response units that are identified on the basis of similar land use, soil type and slope classes. Over 600 peer-reviewed journal papers related to the SWAT model have been reported (Gassman et al., 2010). Besides its obvious advantage as a hydrologic modelling tool that includes modularity, computational efficiency, ability to predict long-term impacts as a continuous model, and abilityto use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance as one of the most widely adopted and applied hydrologicalmodels worldwide (Gassman et al., 2010). There are many rivers in the sub-Saharan Africa whichplay central role as sources for drinking water, irrigation and process water for industries for millions of people in the region. Demographic change, migration processes, land use, climate change impacts and major development projects are threatening the sustainability of the water resources in an international complicated context. As much as authors advocate the use of SWAT as a modelling tool, they have concerns on whether the reported methods and approaches, in fact, help achieve their reported goals. The purpose of this review, therefore, is to evaluate various models that have been reported in peer-reviewed journal papers in some Sub-Saharan African countries by looking at their used approaches and methods with respect to what they stated to achieve. In order to do so, the authors follow several fit-for-purpose (how useful is the model for its purpose), fit-to-observation (how well do the model outputs fit to field observations), and fit-to-reality (how well do the models represent the physical processes) evaluation criteria designed for measuring strength/weakness of the various SWAT models the journal papers were based on.

This study is aimed at critically reviewing SWAT research publications in the Sub-Saharan African countries. Specifically, the study has the following objectives which include the identification of the various parameters that affect hydrology in the area as well as to review SWAT performance based on Natch-Sutcliffe model efficiency (NSE) in the study area

2.0 Case Studies and Swat Applications

2.1 Sub-Saharan Africa (SSA)

Sub Saharan Africa (SSA) is used as a collective term that refers to African nations which lie South of the Sahara. The region makes up about 80% of theAfrican and 10% of the global population (Xie et al, 2012). It was estimated that the number of undernourished people in SSA in 2010 reached 239 million (FAO, 2010). Some of the major rivers in the Sub-Saharan Africa are, the Nile, the Zambezi, the Niger and the Congo. Victoria Falls is probably the most famous of water falls in the Sub-Saharan Africa and is located on the Zambezi River. The map of Africa showing Sub-Saharan Africais shown in figure 3.1

2.2 SWAT Application

(a)Jayakrishnan et al. (2005) modelled the hydrology of Sondu basin in Kenya using SWAT model and the watershed has an area of 3050km^2. The Natsh-Sutcliffe efficiency (NSE) coefficient of <0.1 was obtained and it was due to inadequate climatic and other SWAT input data. Only one rain gauge was used in the simulation and it was not represented.

(b)Mulungu and Munishi(2007), calibrated SWAT model for a 11000km^{2}Simiyu catchment in Tanzania by Latin-Hypercube-One factor At aTime was used for the sensitivity analysis and this was done for 16 parameters, the auto calibration was done with Shuffled complex evolution (SCE) algorithm. Total water yield and surface runoff fractions were within +1 or -1, while the base flow was 50%. An NSE of 0.4 was obtained by improving the spatial resolution of some SWAT inputs (soil and land use inputs).

(c) Xie et al. (2012), calibrated and evaluated a regional semi-distributed watershed model developed for sub-Saharan African countries using Gravity Recovery and Climate Experiment (GRACE) data, ten sub regions were modelled. The area of the region being modelled is 21 million km^2. The elevation of the region was obtained from Hydro SHEDS, The soil map gotten from Harmonized world soil database (HWSD), The land cover was obtained from Global Land Cover (GLC) 2000, Lakes and reservoir obtained from Global lake and wetland database (GLWD) while the climatic data was obtained from Surface meteorology and Solar Energy (SSE) Release 6.0, global precipitation climate project (GPCP) & Tropical Rainfall Measuring Mission (TRMM). The GRACE data used were obtained from CNES-GRGS (Centre National d;Etudes –Groupe de Recherches de GeodesieSpatiale). The data are provided as spherical harmonics as 10 day means. With regard to the performance of calibrated models in river discharges simulation, the highest values of weighed NSE coefficient obtained vary from -2.55 to 0.66 and are negative for five out of ten sub-region models (West Africa, Nile, Congo, Zambezi and Madagascar). The deterioration of its value is greater than 2 in models for all sub-regions other than West Africa, Nile, and Zambezi when the parameter set in the pareto frontier that most closely matches the simulation of GRACE TWS (TOTAL WATER STORAGE) variations was used. For the best fit solutions for river discharge simulation, 20% of stations have NSEs ≥0.7, 43% ≥0.4, and the NSEs at 64% of the stations used are positive. These percentages decrease from 20 to 6%, 43 to 17% and 64 to 30% if the models are run with the least fit solutions for river discharge simulation. More satisfactory model fits were obtained in simulation of TWS variations after the calibration. Overall, simulated and GRACE- based zonally averaged time series are in good agreement in sub-regions of West Africa, Volta, Chad, Nile, Eastern Africa, Zambezi and Madagascar during both calibration and validation periods. The means of the NSE coefficients for these sub-regional models range from 0.66 to 0.91. Larger discrepancies occurred in Congo and Horn of Africa. The largest discrepancies in TWS variation simulation (NSE coefficient ≤ 0) occurred in arid areas, where water storage amplitude is lower or equivalent to GRACE error (the Sahara, Somalia, Western Ethiopia, northwest Kenya, south Namibia and most of Southern Africa) and the equatorial humid area (notably in central Democratic Republic of the Congo).

(d) Schoul and Abbaspour(2006), used SUFI-2 for calibration and uncertainty analysis of SWAT model for a 4 million km^2 area in West Africa, including mainly the basins of river Niger, Volta and Senegal. The model was applied with a goal of quantifying the amount of global country-based available fresh water. Ten most sensitive parameters; CN2_GRAS, CN2_SAVA, SOL_AWC_SCL, ESCO, SURLAG, GWQMN, REVAPMN, RCHRG_DP, MSK_CO1, MSK_CO2 were included in the calibration procedure. NS of 64 stations were estimated for validation and calibration periods, most of the stations in the North have positive NS and many of them also gave NS higher than 0.7 but stations further downstream the River Niger are insufficiently simulated. The stations with a positive NS in the East are all tributaries to the River Niger having comparatively small watersheds. There was a wide range of quality in in the model fit ranging from very good fits in Couloumbou on River Gambia: $NS_{calib.}= 0.82$ and $NS_{valid.}=0.54$ to very poor fits in Malanville on River Niger: $NS_{calib.} = -1.16$ and $NS_{valid.} = -0.63$.

(e) Birhanu et al. (2007) modelled the WeruWeru catchment with an approximate drainage area of 101 km^2 and a mean annual precipitation between 1500mm and 3000mm using SWAT model at the foot slope of Mount Kilimanjaro in Nothern Tanzania, the water balance modelling was performed on an annual and monthly bases using spatial and temporal data. A statistical weather generator file was prepared for ten years to generate climatic data and fill in gaps in the measured records of climatic of climatic data. The rainfall-runoff modelling was based on a long term global water balance simulation for 15 years (1972-1986) and temporal calibration technique, R^2values of 82% and 59% were obtained during calibration and verification periods respectively. The predicted mean daily stream flow was found to be $1.92m^3/s$ exactly as observed during the water balance simulation. A total annual water yield of 597.1mm, observed total water yield was 597.2mm from which the annual surface flow was 155.8mm, with an observed surface flow of 158.8mm and that of base flow component was 441.4mm, with an observed base flow of 438.4mm. SWAT actual evapotranspiration of 536mm, potential evapotranspiration of 1274mm and lateral soil flow of 49mm.

(f) Koua et al 2014, SWAT was used to simulate water flow in large agricultural complex watershed in Buyo lake basin, West of Cote D'Ivore, 500 and 1000 runs were performed using SUFI2, there was a good correlation between the monthly observed and predicted river discharge.

(g) Dile and Srinivasan (2014) assessed the applicability of the National Centres for Environmental Predictions Climate Forecast System Reanalysis (CFSR) climate data in modelling the hydrology of data scarce Upper Blue Nile basin, Ethiopia. The DEM was obtained from the Consultative Group in International Agric. Res. (CGIAR) Consortium and has a resolution of 90m x 90m. The stream network, land use, and soil maps of the study area were collected from the Ethiopian Ministry of Water Resources. The soils physical and chemical properties were derived from the digital soil map of the world CD-ROM Africa sheet. The soil and water assessment tool was set up to compare the performance of CFSR weather with that of conventional weather in simulating observed streamflow at four river gauging stations in the Lake Tana basin- the upper part of the Upper Blue Nile basin. The conventional weather simulation performed satisfactorily with NSE ≥ 0.5 for three gauging stations, while the CFSR weather simulation performed satisfactorily for two. Both simulations gave minor differences in the water balance components in all but one watershed, much higher average annual rainfall was observed in the CFSR, this resulted in higher water balance components. Similar annual crop yields in the four administrative zones was observed in both weather simulations.

(h) Betrie et al. (2011): Used SWAT model for daily sediment yield simulations in the Upper Blue Nile under different Best Management Practice (BMP) scenarios. The scenarios are (1) maintaining existing conditions (2) introducing filter strips, and (3) applying stone bunds (parallel terraces) and (4) reforestation. The SWAT model simulation shows that the soil erosion extent varies from negligible erosion to over 150 t ha^{-1}. The observed average sediment yield at the outlet of the Upper Blue Nile was 131 x 10^6 tyr^{-1}. The SWAT model predicted 117 x $10^6 tyr^{-1}$ for scenario (1), existing conditions. This result is comparable with 140 x 10^6 tyr^{-1} estimated by NBCBN (2005) that included bed load as well. The bed load approximately accounts for 20 - 25% of the total load. Scenario (2), simulation of filter strips scenario resulted in reduction of total sediment yield to 66 x 10^6 tyr^{-1} form current conditions at El Diem, which is equal to 44% reduction. Scenario (3) applying stone bunds scenario caused a reduction in the total sediment yield to 70 x 10^6 tyr^{-1} from current conditions, which is equivalent to 41% reduction. The simulation for scenario (4) reforestation scenario showed the least reduction of sediment loads (104 x 10^6 tyr^{-1}) from current conditions, which is 11% reduction.

(i) VerbeetenandBarendregt (2007): Applied SWAT model in the evaluation of the impacts of climate change on hydrological services provided by dry forests and savannah ecosystems in Burkina Faso, West Africa. Erratic and intensive rainfall led to higher peaks in rainy season for preliminary result. This caused a decline of water availability and less groundwater recharge, there was an increase in sediment load under such climatic condition, this affected the water quality. Important metadata (geographic projection, accuracy, application scale) were missed by data sets and this affected the quality control and increased uncertainty in the input data sets. Problem posed by soil data set derived from FAO soil type also increased the uncertaintyof soil parameters considerably.

(j) Birhanu(2009) modelled the hydrology of the Kihansi river catchment in South Central Tanzania using SWAT model using distributed and lumped modelling approach. There were four upper sub-watersheds and ten sub-watersheds located downstream. Poor predictions were observed with the use ofcatchment characteristics, predicted flows tended to be higher with poor seasonal distributions. For bigger watersheds, the percentage deviation, the prediction efficiency, and the long-term water balance were found to be promising prior to optimizationhigher Pe (R^2) (>90%) indicate middle flows were better simulated in lumped modelling approach. The upper sub-watersheds (FSU1, FSU3,FSU4, and FSU5) were calibrated first, and the parameters in these sub watersheds were held constant while the lower sub-watersheds were calibrated. At the outlet of the watershed (NC3), the model captured 61% of the variance in calibration (1997-2001) and 37% in validation (2002-2004), this according to (Motovilov et al., 1999) is a satisfactory simulation. The improvement in performance efficiencies of sub watersheds FSU2, FSU7, and NC1 were partly associated to parameters of the upper sub watersheds at FSU1, FSU3, FSU4, and FSU5 and the sub basins between. Model parameters at the nested sub basins were fine-tuned manually for a better simulation at downstream watersheds. The outlet of three tested sub-watersheds (FSU2-L, NC1-L, and NC3-L) resulted to no marked difference in prediction efficiencies between distributed and lumped modelling systems. Optimised sets of parameters of a lumped model at NC3-L to each sub-watershed in distributed modelling system was used to justify the importance of distributed modelling, poor prediction efficiencies was observe and flows were over predicted with Dv(%) for the sub-watersheds (FSU1, FSU2, FSU3, FSU4, FSU5, FSU7 NC1, NC3, FSU2-L, NC1-L, and NC3-L) are 11.1, 6.6, 0.36, 96.3, 0.88, 13, -2.9, -5.3, 0, -0.11, and 16.3 respectively while the Pe(R^2)(%) are 69.6, 89, 91.7, 93.4, 91.2, 85, 97.5, 50, 90.6, 95 and 86.6 respectively, IVF(%) of the sub watersheds are, 89, 93, 99.6, 96.3, 99.1, 87, 103, 105, 100, 100 and 84 respectively and for NCE (%), 11, 62.6, 56.1, 33, 56.4, 14, 48, 60.4, 63.33, 21.1, and 41 respectively.

(k) Anderson et al.(2011), used SWAT model to model the Potential impacts of water harvesting and ecological sanitation on crop yield, evaporation and river flow regimes in the Thukela River basin, South Africa. Potential impacts of two strategies, *in situ* water harvesting (*in situ* WH) and fertilization with stored human urine (Ecosan) were explored to increase the water and nutrient availability in rain-fed smallholder agriculture in South Africas Thukela River basin with an area of 29,000km^2. Potential impacts on small holder maize yields, river flow regiments, plant transpiration, and soil and canopy evaporation during 1997-2006 were simulated using SWAT mode. The simulation showed that the impacts on maize yields are likely to be small with *in situ* WH having a median change of 0% the impact of Ecosan was significant with a median increase of 30%, these was caused by high nitrogen stress on crop growth, and low soil moisture enhancement with *in situ* WH. Yield increase of up to 40% within*sit* resulted occasionally as a result of the impacts varying significantly in space and time. Transpiration had median increase of 2.8%, 4.7mm $season^{-1}$ and soil and canopy evaporation had a median reduction of -1.7%, -4.5mm $season^{-1}$, this resulted in Ecosan significantly improving the productivity of the evaporative fluxes. For scenario A (in situ water harvesting), increases in yield of more than 5% are only obtained with runoff reductions of more than 80%. Yield was increased by in situ WH for smallholder fields (HRUs) and parameter sets in the 2003-2004 crop growing season than in any other season. There was dryness in 2003 with only 577mm of rain and this led to low soil moisture levels at the onset of the following season. Surface runoff was low in smallholder areas (simulated spatiotemporal median: 0-17mm a^{-1}, 95PPU). The spatiotemporal median increase in infiltration with in situWH was 0-7mm season $^{-1}$ (95ppu). Most of these leaves the soil as lateral flow or groundwater recharge, rather than transpiration. For scenario B (ecological sanitation), the median increase across space, time and parameter sets was statistically significant (p-value :< $22x10^{-16}$), amounting to 30%, equivalent to 0.2t ha^{-1}. On the basin scale. Some of the crops nutrient demands were met by the nutrients from Ecosan and the nutrient stress was significantly reduced (p-value: <2.2 x 10^{-16}) and increase maize yield. Scenario C (in situ water harvesting and ecological sanitation), there is no much improvement in yield with this scenario. There was an increased average yield of 30% relative to the baseline. For scenario D-F(unlimited nutrient and water supply), the simulations of unlimited nutrient and water supply reveal interesting maize yield dynamics in the basin.

(l) Ladokun et al. (2015) investigated the hydrokinetic energy potential of some selected rivers in the lower Niger River Basin in North Central Nigeria. MWSWAT, an interface of SWAT model and MapWindow GIS was employed for simulation to determine the hydrological parameters of the sub-basins and other computations were done using a spreadsheet package to estimate the instantaneous power density along the river reach. An estimated total theoretical resource of 826.7MW was obtained. River Moshi recorded highest discharge of 8315.78 m^3/secs, whileOshin has the lowest discharge of 1224.27m^3/secs. River Awun has the highest theoretical hydrokinetic potential of 257.5MW while Oshin has the lowest theoretical hydrokinetic potential of 20.9MW.

(m) Olotu et al. (2013) simulated Runoff and sediment load for reservoir sedimentation of river Ole Dam using SWAT and WEPP models by, Ole dam is a hydraulic structure on the river ole in Nigeria with 8.1 billion m^3 storage capacity. There is a reduction in reservoir capacity and this is as a result of sediment moving into the reservoir of the dam through the tributaries, and this has seriously complicated the water supply for potable and non-potable uses. Iteration was conducted using SWAT and WEPP model for a simulation period of 11 years (2000-2011) using both hydrological and meteorological data around the site. Maximum average sediment load value of $10.2*10^3$ton/ha with rainfall depth of 75.4mm and surface runoff of 34.2mm were generally observed in the month of September for the simulation period. Minimum simulated and observed sediment loads are $3.1*10^3$ton/ha and $2.8*10^3$/ha respectively through the tributaries to the reservoir and these were estimated in the month of March with the observed lowest rainfall depth of 19.7mm and runoff depth of 2.5mm. This shows that there is significant sediment load entrance into the reservoir from the two considered tributaries. There will be a complete silt up in the reservoir in the next 20 years, starting from 2043 if the sediment load remains unchecked.

(n) Kingston and Taylor (2010), used SWAT to explore the potential impacts of climate change on water resources in a humid, tropical catchment, the River Mitano in the Upper Nile Basin of Uganda. A Nash-Sutcliffe efficiency of -0.09 was observed after an initial runs, following adjustment of model parameters using 30-year-means of monthly observed and simulated discharges. This shows that the model performed poorly for the simulation. Using the autocalibration routine ParaSol, SUFI-2 and GLUE) in AVSWAT and SWAT-CUP resulted in non-satisfactory improvement of the hydrological model which can be attributed to some model observation divergences in the calibration period (1961-1990) which is too large to be resolved by autocalibration. Manual calibration was employed due to lack of success in autocalibration and this was done by manually adjusting the ten most sensitive parameters in the model. A more satisfactory fit between observed and simulated monthly river flow was obtained after manual calibration. There was a low Nash – Sutcliffe coefficient of 0.06 for the period 1961-1990, and high RMSE value of 8.65. Prescribed climate change scenarios for three River Mitano catchment show that temperature increases at a near-linear rate between scenarios, with a 6°C rise in global mean temperature resulting in increases between 7.2 and 9.5°C in monthly temperature over the catchment. The annual increase of precipitation was 6.7% from the baseline for the 6°C scenario. Increasing and decreasing linear trends in precipitation occur, most of which are within + or -9%of the baseline for the 6°C scenario. The impacts of prescribed increases in global mean temperature on the hydrological regime of the river Mitano comprise increases in mean annual river discharge up to 3°C scenario, followed by decreases for rises in global mean air temperature of 4 to 6°C. For the 0.5-3°C scenarios, small decreases in river discharge are projected during the first wet season (March-May) whereas large increases in discharge are projected during the wet season (October-December). From 0.5-2°C, these seasonal changes in discharge have a negligible influence on mean annual river discharge (<1% change from baseline) but for the 2.5 and 3°Cscenarios, increases in annual river discharge are >8% from baseline. For the 4-6°C scenarios, projected decreases in March-May river discharge are more substantial, eliminating the March-May seasonal peak so that the River Mitano flow regime shifts from bi modal to unimodal.

(o) Notter et al. (2012) modelled 43,000km^2Pangani Basin in Tanzania and Kenya, in which water provision as an ecosystem service was quantified in the study. SWAT model was used for the simulation and the Sequential Uncertainty Fitting ver. 2 (SUFI-2) was used for calibration and uncertainty assessment. Water provision is low in the watershed, (95%) prediction uncertainty, (95PPU) are available at 95%. 1.19-1.50ha (95PPU) of farmland on which a growing period with sufficient water of 3-6 months is reached at the 75% reliability level and this is suitable for the production of staple crops, as well as 0.19-0.51ha (95PPU) of farmland with a growing period of ≥ 6 months, suitable for the cultivation of cash crops. In the upper basin, Nash-Sutcliffe Efficiency (NSE) scores of ≥0.5 were achieved at 7 out of 8 gauges for calibration period and 4 out of 6 gauges for validation period. Averagely, P-factor at all stations for calibration period was 70% and R-factor was 0.61. For validation period, average P-factor was 66% and the average R-factor was 0.78. In the lower basin, NSE values of ≥0.5 were achieved at 4 of 8 gauges in calibration, and4 of 7 gauges in validation, the average P-factor in the lower basin for calibration was 73% and the average R-factor was 1.58, for validation, the average P-factor was 74% and the average R-factor was 1.66.

(p)Mwangi et al.(2015) evaluated the impact of conservation practices on water and sediment yield in 107km^{2}Saumua Watershed, Kenya using SWAT model. For sediment calibration, data on annual average erosion rates of the area was used, while measured three months sediment concentration data was used for validation. R^2 of 0.80 and 0.85 were obtained for calibration and validation periods respectively, Nash–Sutcliffe Efficiency of 0.74 and 0.81 were obtained for calibration and validation periods respectively while for PBIAS values of +5% or -5% and + 6% or -6% were obtained for calibration and validation periods respectively. For daily sediment simulations, satisfactory R^2 of 0.54 was obtained, Nash-Sutcliffe and PBIAS values were low and this was due to the short duration of measurement.

(q)Obieri et al.(2011) modelled the streamflow of NroMoru river catchment in EwasoNg'iro river basin, Kenya. The catchment covers an area of 172km^2. Sensitivity analysis and calibration of the SWAT model was carried out. The model was calibrated and validated for a three year period based on monthly flows. Correlation coefficient of about 0.7 was obtained, with NSE of 5% and D_v of 61.7%. There was satisfactory model performance after validation with coefficient of determination R^2 of 0.6, Nash-Sutcliffe (NSE) of 0.51 and a deviation volume (D_v) of 24.7%.

(r)Van Griensven (2012) reviewed some SWAT applications in the upper Nile Basin countries and some of his reviews are listed below.

- Mekonnen et al. (2009) developed a generic rainfall – runoff model better suited to Ethiopian catchments. They used a spectrum analysis method to extract the relationships between different temporal scales of available daily rainfall and runoff series that reflect the temporal and spatial scales of 25 discharges in two catchments in Ethiopia. This paper reported that frequencies in rainfall and stream discharge longer than 50 days had a sufficient coherence to warrant model calibration
- Setegn et al. (2009a) used SWAT to model the hydrological water balance of the Lake Tana Basin in Ethiopia with the objective of testing the performance of the SWAT model for stream flow prediction. These authors calibrated and validated on four tributaries of Lake Tana using SUFI-2, GLUE and ParaSOL algorithms. This paper reported that the SWAT model was more sensitive to HRU definition thresholds than to sub-basin discretization. Further, the paper reported that more than 60% of the observed river discharge falls within the 95% confidence bounds.
- Tiebe and Bewket (2011) assessed surface runoff generation and soil erosion rates for a small watershed in the Awash River basin of Ethiopia using the SWAT model. Comparing monthly predicted runoff against the measured values, the study demonstrates that distribution of observed and simulated runoff was quite uniform throughout the simulation period. The study presents a high correlation value of 0.831. It further reports a NSE of 0.789 to demonstrate that the model was able to generate monthly runoff close to the observed. They also used SWAT for hydrologic and soil erosion predictions for the Keleta watershed in central Ethiopia after calibrating the model against surface runoff that was obtained from flow separation techniques. The annual sediment yield varied between 1.57 and 7.57t ha^{-1} with a long-term average of 4.26t ha^{-1} yr^{-1}.
- Githui et al. (2009a) used monthly change fields of rainfall and temperature instead of mean annual perturbations to the historical time series or hypothetical scenarios for the 12709km^{2}Nzoia basin in Kenya, since the region has district wet and dry seasons. They used the MAGICC and scenario Generator (SCENGEN) from the climatic Research Unit (CRU) of the University of East Anglia to construct climatic change scenario based on IPCC A2 and B2 scenarios, for two selected 30yr periods: 2010-2039 centred on 2020 and 2040-2069 centred on 2050. Five GCMs (CCSR, CSIRO, ECHAM4, GFDL, and HADCM3) selected based on a correlation of greater than 0.7 between the observed and simulated rainfall and temperature and a small root-mean-square error were used in the study. Scenarios of future climate were obtained by adjusting the baseline observations by the difference for temperature or percentage change for rainfall between period averaged results for the GCM experiments (30 yr. period) and the simulated baseline period (1981-2000). All the scenarios indicated that temperature would increase in this region, with the 2050s experiencing much higher increases than the 2020s. While the models were consistent with respect to changes in both runoff and base flow, average stream flow seemed to increase with rainfall increase; relatively higher amounts were observed in the 2050s than in 2020s. All scenarios indicated higher probabilities to exceed the bank full discharge than the observed time series.

- Mango et al. (2011) developed the regional averages of temperature and precipitation projections from a set of 21 global models in the MMD (multi-model dataset) for the AIB scenario for East Africa. Based on the reported changes in temperature and precipitation, the hydrological model was run for minimum, median and maximum change scenarios. The mean for all projections is a 7% increase in annual precipitation by 2099, with projections ranging from -3% to 25%. Notable is the disproportionately nonlinear response of a large stream flow change that occurred by a small change in precipitation. A combined decrease in precipitation and an increase in temperature led to increased evapotranspiration and reduced runoff.
- Swallow et al. (2009) used SWAT model to estimate sediment yields and changes in sediment yield for the Yara and Nyando basins draining into the Lake Victoria from the Mau region in Kenya. A spatial analysis of trade-offs and synergies between sediment yield and agricultural production for the year 2005 was generated through a spatial overlay of results on sediment yields and value of agricultural production at the sub-basin level. The Yala and Nyando basins, measuring 4000km^2 and 3000km^2 respectively, have a mix of land tenure types. The authors noted the inability of the SWAT model to consider gully in the modified unified soil loss equation as a potential cause of underestimation of sediment yield especially for soil prone gully erosion.
- Setegn et al. (2010) used SEWAT to simulate the sediment yield simulations for the Anjeni, a small watershed (1.35km^2) in the northern highlands of Ethiopia using different slope classifications. The annual sediment yields were around 27.8 and 29.5t ha^{-1}. The paper showed that the results are highly sensitive to the size of the sub-basins. The obtained erosion parameters were used to model sediment transport in the Lake Tana basin in Ethiopia and gave annual sediment yields that varied spatially between 0 and 65t ha^{-1}.
- Muvundja et al. (2009) used an uncalibrated SWAT model to estimate flows and pollutant loads for the 127 streams draining to Lake Kivu; SWAT was used in a supporting role to other techniques that were used for the primary analysis; problems regarding the un-calibrated SWAT results are discussed.
- In analysing the impacts of land cover change on runoff for the Nzoia basin in Kenya, Githui et al. (2009b) used plausible ‘worst’ (scenario1) and ‘best’ (scenario 2) case scenarios. The emphasis was on reforestation and sustainable agriculture for the best-case scenario, and deforestation for the worst-case scenario. Using the CLUE-S model, and land cover scenarios were generated by using a baseline map as the dependent variable and location factors such as population, elevation, slope, distances to rivers and towns, and lithology in logistic regression.

Easton et al. (2010) simulated the hydrologic balance and sediment loss for the Blue Nile watershed that lies mainly in Ethiopia using SWAT-WB, a modified SWAT model that captures variable source area hydrologic phenomena. Predicted runoff losses (averaged across the entire sub basin) varied from as low as 13mm yr^{-1} for the entire Blue Nile basin to 44mm yr^{-1}. In Anjeni. Very large spatial variations in the computed erosion rates were reported (10% of the area contributes to 75% of the total sediment yield).

3 Reviewed Results and Discussion

3.1 Fit-to-observation

The sizes of the catchments reviewed varied from 101km^2 to 21,000,000km^2. Some authors used monthly data calibration, while some used daily data. There was not a fair basis for comparison as different areas reviewed have different climatic conditions, some areas have higher rainfall than others and this may cause an increase in runoff yield. Table 4.1 shows an overview of performance index (NSE) of the study.

Table 3.1: Overview of evaluation for performance Index (NSE)

Cases	**River**	**Area(Km^2)**	**Performance For Flow (NSE)**
Betrie et.al.(2011)	Upper blue Nile basin Ethiopia	184,560	(0.68)D, (0.82)M
Verbeeten&Barendregt, (2007)	Korsimoro, Burkinafaso	1,100	NA
Birhanu(2009)	Kihansi river catchment Tanzania	581	NA
Anderson et.al.(2011)	Thukela River basin, South Africa	29,000	NA
Ladokun et.al.(2015)	Lower River basin, Nigeria	48,600	NA
Olotu et.al.(2013)	Ole Dam, Nigeria	NA	(0.76)M
Kingston & Taylor (2010)	River Mitano catchment, Uganda	2,098	(0.06)M
Schoul&Abbaspour(2006)	Goulombou(River Gambia), Malanville (River Niger),	NA	(0.82)M (-1.16)M

Xie et.al.(2012)	West Africa Nile Congo Zambezi Madagascar Volta Horn of Africa East Africa South Africa	21,000,000	0.91-0.92 0.856-0.865 0.34-0.91 0.91-0.92 0.81-0.85 0.86-0.90 0.41-0.45 0.85-0.54 0.46-0.54
Taddele&Srinivassan(2013)	Lake Tana Basin, Ethiopia	15,000	Gilgel 0.87 Gumera 0.84 Rib -0.58 Megech 0.49
Birhanu et al.(2007)	Weruweru catchment, Tanzania	101	(82%)M
Obiero et al., (2011)	NaroMoru river catchment, Kenya	172	(0.01)D, (5%)M

In the review by van Griensven et al. (2012), some authors calibrated against monthly data while some authors calibrated against daily data, evaluation based on NSE is shown in table3.2

Table 3.2: Overview of evaluation for performance index (NSE)

Ethiopian cases	River	Area (km^2)	Performance for flow
Easton et al. (2010)	Anjeni	1.134	0.84 (D)
Setegn et al. (2010)	Anjeni	2134	0.89 (M)
Easton et al. (2010)	Gumera	1286	0.81 (D)
Setegn et al. (2009a)	Gumera	1286	0.61 (D)
White et al. (2011)	Gumera	1296	0.77 (D)
White et al. (2011)	Gumera	1296	0.64 (D)
Mekonnen et al. (2009)	Gumera	1286	0.84 (r2D)
Easton et al. (2010)	Ribb	1295	0.77 (D)
Setegn et al. (2009a)	Ribb	1295	0.55 (D)
Easton et al. (2010)	North Marawi	1658	0.75 (D)
Easton et al. (2010)	Jemma	5429	0.92 (M)
Easton et al. (2010)	Angar	4674	0.79 (M)
Easton et al. (2010)	Blue Nile@Kessie	65 385	0.53 (M)
Easton et al. (2010)	Abay Ethiopian@El Diem	174 000	0.87 (D)
Betrie et al. (2011)	Abay Ethiopian@El Diem	184 560	0.68(D), 0.82(M)
Easton et al. (2010)	Megesh		
Setegn et al. (2009b)	Lake Tana	15 096	
Setegn et al. (2009a)	Gilgel Abay		0.73 (D)
Mekonnen et al. (2009)	Gilgel Abay		0.84 (r2D)
Bitew and Gebremichael (2011)	Gilgel Abay	299	
Bitew and Gebremichael (2011)	Koga	1656	
Tibede et al. (2010)	Keleta	1060	0.789 (M)
Lake Victoria region			
Githui et al. (2009a)	Nzoia	12 709	0.71 (D) 0.76 (M)
Mango et al. (2011)	Mara-Nyangores RG	700	−0.53 (M)
Mango et al. (2011)	Mara-Nyangores RFE	700	0.43 (M)
Mulungu and Munishi (2007)	Simiyu-Ndagalu	5320	0.1373 (M)
Jayakrishnan et al. (2005)	Sondu	3050	−0.72 (D)
Kingston and Taylor (2010)	Mitano	2098	0.06 (M)–0.09 (D)
Swallow et al. (2009)	Nyando	4000	
	Yala	3000	
Ndomba et al. (2008)	Pangani	7280	0.54 (D)–0.65 (M)
Notter et al. (2012)	Pangani	43 000	

Source: van Griensven et al. (2012)

Using the classification as proposed by Moriasi et al. (2007), 15 catchment models were classified as very good, 2 as good, 6 as satisfactory, 3 as poor, and 5 studies did not report any NSE.

3.2 Parameter Values

So many parameters were reported in the papers reviewed, flow and sediment parameters were mostly reported.

4.0 Conclusions and Recommendations

Lack of data is a general problem in Sub-Saharan African countries, but SWAT model performed satisfactorily in the study area. There was lack of spatial distribution of the processes and this affected the spatial heterogeneity of the area. A method of validation for spatially distributed representation of the process is lacking in the model. There was not much report in crop parameters in the studies. A proper modelling of the land cover is important for obtaining correct evapotranspiration, runoff and erosion computations. It is recommended to try to evaluate the representatives of the distributed processes and parameters especially when land use studies are envisaged. A validation of the crop processes could be achieved through comparison with remote sensing data. For that reason, the model may not always be adequate for land use analysis studies

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