Rainfall - Runoff Modeling: A Comparative Analyses: Semi Distributed HBV Light and SWAT Models in Geba Catchment, Upper Tekeze Basin, Ethiopia

Abebe Temesgen Ayalew
Hydraulic and Water Resources Engineering Faculty, Arbaminch Water Technology Institute, Arbaminch, Ethiopia

Email address: teabeman@gmail.com

To cite this article: Abebe Temesgen Ayalew. Rainfall - Runoff Modeling: A Comparative Analyses: Semi Distributed HBV Light and SWAT Models in Geba Catchment, Upper Tekeze Basin, Ethiopia. American Journal of Science, Engineering and Technology. Vol. 4, No. 2, 2019, pp. 34-40. doi: 10.11648/j.ajset.20190402.12

Received: July 13, 2019; Accepted: August 6, 2019; Published: August 16, 2019

Abstract: This study was conducted to identify the best hydrological models in simulating the discharge in a comparative approach /SWAT and HBV light/ at Geba cathment and identifying of models which represent realistic simulation at sub basin scale. The various modelling procedure (i.e input data, sensitivity analysis, calibration, validation and uncertainty assessment) were employed to test the models performance. The results shows that K2, MAXBAS, BETA are more sensitive than other model parameters in HBV light model and CN2, GWQMNN and SOL_AWC are more sensitive parameters in case of SWAT. The calibration results of HBV light and SWAT as evaluated by ENS, R2 and PBIAS are 0.70, 0.71 and 0.73, 0.81, -11% respectively. Moreover, an ENS, R2 and PBIAS of 0.71, 0.72 and 0.72, 0.72, 4.1% were obtained during validation Period for HBV light and SWAT models respectively. From the uncertainity plot for HBV light most of the simulated flow are inside the 95PPU with high predictive uncertainity band in Monte Carlo Simulation as comparsion with the SWAT CUP uncertainity analysis by SUFI 2 and from the uncertainity plot in SWAT model most of the simulated hydrograph is outside the upper and lower band and less predictive uncertainity. These mentioned results depicted that both models are well reasonably simulated the discharge of Geba catchment and from uncertainity and identifiability of parameter applying HBV light model could be effective in simulation of runoff for sustainable water resources management in the watershed run off.

Keywords: Flow Simulation, Comparative Analysis, HBV Light, SWAT, Uncertainty, Geba Cathment

1. Introduction

Developing the basic relationships between the different hydrologic systems like rainfall, runoff, soil moisture, ground water level and land use land cover are crucial for effective and sustainable water resources planning and management activities with the support of hydrological models [3].

Models are generally used as utility or supporting tools in various areas of water resources development, in assessing the available water resources in different areas for studying the impacts of human interference in an area such as land use change, deforestation and other hydraulics structures such as dams and reservoirs [11].

Lack of data is one of the main limitations for hydrological modeling. However, it is often used as a justification for over simplifying, poorly performing models [8]. If we want to enhance our understanding of hydrological systems, it is important to fully exploit the information contained in the available data, and to learn from model deficiencies [4].

In order to model rainfall-runoff process, a variety of hydrological models have been applied [7]. But the applications of models are different due to the fact that catchments are heterogeneous; In this regard comparative studies in modeling would enable to identify suitable model for understanding hydrological processes better and prediction of environmental changes. Moreover, in data scarce region e.g. Tekeze basin and understanding of catchment behavior and impact assessment are crucial from the perspective of sustainable water resources development point of view. Thus, this research will be conducted in the Geba cathment of upper Tekeze sub basin with the aim of identifying better model in predicting discharge in terms of model conceptualization, parameterization and capturing the
response mode of the daily hydrographs during the wet and dry seasons.

2. Materials and Methods

2.1. Description of Study Area

The Geba watershed drains the north-eastern part of the Tekeze River Basin and is located in northern Ethiopia, Tigray Regional State. This research focuses on the upper part of the watershed which covers about 2437.52 km². The study area is bounded between latitudes 13°16' and 14°16' North and longitudes 38°38' and 39°49' East. There is a considerable variation in altitudes over the basin with a maximum altitude of 3298.45 m a.s.l., a minimum altitude of 1747.04 m a.s.l and an average altitude of 2000 m a.s.l. [6]. The topography of the basin is highly controlled by erosion features and geological structures. Sharp cliffs and steep slopes occurs along the major rivers. [2]

2.2. Data Collection

The metrological and hydrological data required for this study were collected from Ethiopian national meterological agency (NMA) and ministry of water irrigation and electricity (MoWIE). Metrological data from 1992-2012, flow data from 2002-2012 were collected and DEM (Digital elevation model of 30*30) was collected from Ethiopian mapping agency. Soil map and LULC is obtained from MoWIE.

2.3. Data Analysis

In this study station average and normal ratio method were used to complete missing data of all stations. Double mass curve was used to check the homogeneity and consistency of rainfall as well for adjustment of inconsistent data. The Penman-Monteith method is recommended as the sole method for determining reference evapotranspiration (ET0) when the standard meteorological variables including air temperature, relative humidity and sunshine hours data are
available [10]. However, those data are not available in all stations in this study area. So, Potential evapotranspiration was calculated by using Hargreaves method since most of the stations have maximum and minimum temperature in all stations.

2.3.1. Model Sensitivity Analysis
Sensitivity analysis was applied manually by changing the value of one model parameter at a time for SWAT model through SWAT CUP and Monte Carlo Simulation for HBV light model. That is the value of each model parameter was increased and decreased up to 60% by 20% interval and those having steep slopes are considered as most sensitive while those having moderate to gentle slopes are less sensitive.

2.3.2. Model Calibration
It was performed manually by trial and error from 2002 to 2012 by changing one model parameter at a time until the model simulated stream flow match with observed stream flow.

2.3.3. Model Performance
For this study the model performance was evaluated by $E_{NS}$, $R^2$ and PBIAS for HBV light and SWAT models respectively for the calibration and validation period.

2.3.4. Uncertainty Analysis for Both Models
Due to errors in different condition either in input data, model performance or parameter selection the model commonly affected by uncertainty. For this study Monte carlo simulation procedure [9] and SWAT CUP through SUFI 2 [1] was used for HBV light and SWAT model respectively.

3. Results and Discussion

3.1. Model Development HBV Light

3.1.1. Sensitivity Analysis
For Geba catchment the most sensitive parameters are K2, MAXBAS and BETA where as the rest model parameters are less sensitive or insensitive through out the simulation period.

And from the below the dominant process for the HBV light model is subsurface or ground water dominance since as compared to others its K2 (storage or recession coefficient at box 2) is sensitive through out the objective functions.

3.1.2. Calibration and Validation
Eight years (from January 1, 2002 to December 31, 2009) which includes one years of warm up, (from January 1, 2002 to December 31, 2003). And for the validation from January 2010-Dec 2012 the model performance of Geba watershed by HBV light model are satisfactory with objective functions like $E_{NS}$ and $R^2$ greater than 0.60 and $Reff = 0.7145$, $NSE = 0.707$ and $Reff = 0.71$, $NSE = 0.71$ for the calibration and validation period.

3.1.3. Scatter plot during calibration period in the Geba catchment.
Figure 7. Observed and simulated hydrographs during validation period.

Figure 8. Scatter plot during validation period in the Geba cathment.

Table 1. Model parameter values for HBV light.

| Parameter | unit | Valid range   | Optimized parameter value for calibration |
|-----------|------|---------------|-------------------------------------------|
| FC        | mm   | (0,inf)       | 850                                       |
| LP        |      | [0,1]         | 0.8                                       |
| BETA      |      | (0,inf)       | 0.85                                      |
| PERC      | mm/∆t| [0,inf)       | 60                                        |
| UZL       | mm   | [0,inf)       | 50                                        |
| K0        | 1/∆t | [0,1]         | 0.85                                      |
| K1        | 1/∆t | [0,1]         | 0.55                                      |
| K2        | 1/∆t | [0,1]         | 0.65                                      |
| MAXBAS    | ∆t   | [1,100]       | 1                                         |
| Cet       | 1/C  | [0,1]         | 0.01                                      |
| PCALT     | %/100m| (-inf,inf)   | 24                                        |
| TCALT     | °C/100m| (-inf,inf) | 0.9                                       |
| P_snow    | m    | (-inf,inf)   | 10.5                                      |
| T_snow    | m    | (-inf,inf)   | 12.5                                      |

3.1.3. Uncertainty Analysis HBV Light Model

For this study Monte carlo simulation procedure was used to assess the uncertainty analysis in HBV light model.

a) 150000 model parameter run was produced
b) After selecting model run just select objective function $Reff > 0.6$
c) Upper and lower bound was adopted

In similar way to SWAT model the dotty plot for HBV light model is carried by considering the objective function to the crosponding parameter value.

These results indicate a large equifinality of parameters and many unconstrained parameters. [9] stated the concept of equininity concept in different cathment and he got large equininity and unconstrained parameters.

Figure 9. Dotty plot for model parameters.

Figure 10. Uncertainty analysis in HBV light model.

As it is shown in figure 10 most part of the simulated hydrograph lays inside the uncertainty range or interval. In this study only parameter uncertainty is considered. Therefore the result of simulated flow is reliable. and researcher found that the simulation result lays outside the uncertainty range as [10] stated clearly for uncertainty analysis in muger cathment abay basin, Ethiopia.

3.2. SWAT Model Development

3.2.1. Sensitivity Analysis

Land use and antecedent soil water conditions (CN2) was the most sensitive of all followed by the ground water determinant parameters for flow in the watershed (GWQMN) and The soil properties of the watershed (SOL_AWC).

The other ground water parameters which flow was sensitive were delay time for aquifer recharge (GW_DELAY) and soil layer depth from soil surface to bottom of the layer (SOL_Z) and the rest parameters are insensitive to runoff simulation.

Since land use and antecedent soil water conditions (CN2) was the most sensitive of the model parameters the identification of parameter should be surface dominance in case of SWAT model.

Note: the t Stat provides a measure of sensitivity (larger absolute values are more sensitive); the p value determines the significance of the sensitivity (a value close to zero has more significance); “R_” and “V_” means relative change and a replacement to the initial parameter values, respectively; and RS- Relative sensitivity values of model
parameters have a value Small to Negligible when $0 \leq RS < 0.05$, Medium: $0.05 \leq RS < 0.2$, High: $0.02 \leq RS < 1.0$ Very High: $RS \geq 1.0$.

### 3.2.2. Calibration and Validation

Eight years (from January 1, 2002 to December 31, 2009) which includes one years of warm up, (from January 1, 2002 to December 31, 2003) during calibration. For the validation time period from January 1, 2010 to December 31, 2012, the statistical values in monthly time base of $R^2$, NSE, RSR and PBIAS are 0.81, 0.73, 0.52,-11% and 0.72, 0.72, 0.53, -11% for calibration and validation respectively The model was calibrated automatically by changing the parameters itself iteratively 1500 times. After adjustment the result of the model test shows that the $R^2$, NSE, RSR and PBIAS of 89.60%, 86.36%, 36.76 and -8.16% respectively. Therefore the objective functions were satisfied.

#### Table 2. Recommended and finally fitted parameter values of flow calibration.

| Parameters    | Effect of parameter when its value increase | Recommended range | Fitted value |
|---------------|-------------------------------------------|-------------------|--------------|
| ALPHA_BF      | Increase the ground water flow response to changes in recharge | 0-1              | 0.67         |
| CN2           | Increase surface runoff                   | 35-98            | 87.29        |
| GWQMN         | Decrease base flow                         | 0-5000           | 650          |
| ESCO          | Decrease evaporation                       | 0-1              | 0.55         |
| SOL_AWC      | Increase ground water recharge             | 0-1              | 0.95         |
| CANMAX        | Increase the canopy water trapping and storage | 0-10            |              |
| REVAPMN       | Decrease the actual amount of water moving in to the soil zone in response to water deficiencies | 0-500           | 445          |
| GWREVAP       | Decrease base flow by increasing water transfer from shallow aquifer to root zone | 0.02-0.2        | 0.05         |
| SOL_Z         | Depth from soil surface to bottom of layer | 0-3500           | 1715         |
| SOL_K         | Saturated hydraulic conductivity           | 0-2000           | 1500         |
| GW_DELAY      | Ground water delay time                    | 0-500            | 265          |

![Figure 12](Observed and simulated flow hydrographs during calibration period.)

Figure 12. Observed and simulated flow hydrographs during calibration period.

![Figure 13](Scatter plot during calibration period in the Geba catchment.)

Figure 13. Scatter plot during calibration period in the Geba catchment.

![Figure 14](Observed and simulated flow hydrographs during validation period.)

Figure 14. Observed and simulated flow hydrographs during validation period.

![Figure 15](Sample dotty plot for selective sensitive parameters.)

Figure 15. Sample dotty plot for selective sensitive parameters.

N.B: The x axis indicates parameter range and the y axis for objective function

### i. Parameter uncertainty
As we see from the distribution of the sample point most of the point is aligned away from the objective function which indicates that the HBV light model is less reliable in identifiability of parameter in a comparative approach to that of SWAT model.

ii. Uncertainty Analysis
The uncertainty of the calibrated model in SUFI-2, 95PPUs, The uncertainty was represented by the p-factor and the r-factor. In terms of monthly stream flow, the p-factor and the r-factor was 69 % and 0.64 for calibration. This indicated about 69 % (Out of a perfect 100 %) of the measured monthly stream flow could be bracketed by the 95PPU with a very narrow 95PPU band of 0.64 (close to a perfect 0) in the calibration period [12].

4. Conclusions
The following conclusions can be drawn from the foregoing discussions: The result from sensitivity analysis of the SWAT model showed that the land use and antecedent soil water conditions (CN2) was the most sensitive of all followed by the ground water determinant parameters for flow in the watershed (GWQMN) and The soil properties of the watershed (SOL_AWC).

| Simulation of Runoff       | R_eff | ENS  | PBIAS | RSR | Flow weighted efficiency | Model efficiency/LogReff |
|---------------------------|-------|------|-------|-----|--------------------------|-------------------------|
| Calibration for HBV light | 0.71  | 0.70 | -     | 0.7 | 0.79                     | 0.71 / 0.74             |
| Validation for HBV light  | 0.71  | 0.71 | -     | 0.7 | 0.79                     | 0.70 / 0.72             |
| Calibration for SWAT model| 0.81  | 0.73 | -1    | 0.53| -                        | -                       |

Form these regard further water resource development and analysis should be carried to minimize the uncertainty arises from different source. And from the dynamics of hydrographs both models have less performance in predicting low flow and extreme flood. More over, HBV light over estimate the low flow and the peak flow beside SWAT model under predict the low flow and over predict the peak flow which can be attributed to inadequate representation of the spatial variability of rainfall and poor model responses to high rainfall amount.

References
[1] Abbaspour. (2009). SWAT-CUP2: SWAT Calibration and Uncertainty Programs. In A User Manual. Department of System Analysis, Integrated Assessment and Modeling (SIAM), Eawag, Swiss Federal Institute of Aquatic Science and Technology (p. 95). Duebendorf, Switzerland.

[2] Abraha. (2009). Assessment of spatial and temporal variability of river discharge, sediment yield and sediment-fixed nutrient export in Gega River catchment, northern Ethiopia. PhD thesis, Katholieke Universiteit Leuven, Belgium.
[3] Birhane et al. (2013). Estimation of monthly flow for ungauged catchment (Case Study Baro - Akobo basin) Ethiopia. MSc thesis. Addis Ababa University, Ethiopia.

[4] Finicia et al. (2008). Understanding catchment behavior through stepwise model concept improvement, Water Resour. Res., 44, W01402, doi: 10.1029/2006WR005563.

[5] Gebre yohannes et al. (2010). Large-scale geological mapping of the Geba basin, northern Ethiopia [Tigray Livelihood Papers; 9].

[6] Gonfa. (1996). Climate classification of Ethiopia. Addis Ababa, Ethiopia.

[7] Hundecha. (2005). Regionalization Parameters of Conceptual Rainfall - Runoff Model, University of Stuttgart Germany.

[8] IHMS. (2006). "Integrated Hydrological Modeling System Manual." Version 5.1.

[9] Iuliia et al. (2014). Simulating Water Resource Availability under Data Scarcity—A Case Study for the Ferghana Valley (Central Asia). 6, 3270-3299.

[10] Kumela. (2011). Performance comparison of rainfall runoff model on Muger catchment, abay basin, M.Sc. Thesis, addis ababa, ethiopia.

[11] Moreda. (1999). Conceptual Rainfall-Runoff Models for Different Time Steps with Special Consideration for Semi-arid and Arid Catchments Laboratory of Hydrology and Inter-University Program in Water Resources Engineering.

[12] Wagener et al. (2003). Towards reduced uncertainty in conceptual rainfall-runoff modeling: dynamic identifiability analysis, Hydrol. Processes. pp. 17 (2), 455-476.