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Review Article

Quantifying Model Uncertainty to Improve Stream Flow Prediction for Geba Catchment, Uppertekeze River Basin, Ethiopia

Abebe TA*

Department of Water Science, Hydraulic and Water Resources Engineering Faculty, Arbaminch Water Technology Institute, Arbaminch, Ethiopia

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1. Abstract

This study was conducted to predict stream flow at the outlet of the gauged Geba watershed and analyze the associated uncertainty that can affect its accurate prediction. Semi distributed HBV light model was applied to estimate stream flow of the Geba catchment and associated uncertainty through Monte Carlo Simulation procedure. The calibration and validation of the model was found satisfactory as performance rating criteria value of coefficient of correlation (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) is found to be 0.74 and 0.72 for calibration and 0.73 and 0.70 for validation, respectively. In the same order from the model uncertainties analysis the percentage of the simulated data within the uncertainty bound is only 35% for calibration and 29% for validation, which shows that there is uncertainty in the process. Then using Monte Carlo Simulation procedure in HBV light model parameter uncertainty was tested and found with ENS value of 0.76 for calibration and 0.79 for validation. And this shows that the overall associated uncertainty come from either conceptual or input or a combination of them but not from parameter identification. Even though the predicted amount of flow of 955.33MCM is almost equivalent to the latest study, the uncertainty might come due to either neglected abstractions or poor quality of input data. Therefore, this simulated amount should not be used for any water resource development works unless the correction of these cause of uncertainties are reduced as uncertainty in estimation of simulated flow will lead to wrong water resource management decision [1].

2. Keywords

Flow Prediction; HBV Light; ERDAS; Model Uncertainty; Geba Catchment

3. 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] (Figure 1).

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, poor lyper forming 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; The HBV model (Bergström 1976) has been applied in numerous studies, e.g., to compute hydrological forecasts, for the computation of design floods or for climate change studies. The problem of parameter uncertainty within the model, however, has not yet been fully examined [5]. A Monte Carlo procedure was used in this study to investigate the uncertainty in parameter values using the results of a large number of model runs with randomly generated parameter sets and studying for each

***Corresponding Author (s):** *Abebe Temesgen Ayalew, Department of Water Science, Hydraulic and Water Resources Engineering Faculty, Arbaminch Water Technology Institute, Arbaminch, Ethiopia, E-mail: teabeman@gmail.com*

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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/Δt	[0,inf)	60
UZL	mm	[0,inf)	50
K0	1/Δt	[0,1)	0.85
K1	1/Δt	[0,1)	0.55
K2	1/Δt	[0,1)	0.65
MAXBAS	Δt	[1,100]	1
Cet	1/°C	[0,1]	0.01
PCALT	%/100m	(-inf,inf)	24
TCALT	°C/100m	(-inf,inf)	0.9
P_{elev}	m	(-inf,inf)	10.5
T_{elev}	m	(-inf,inf)	12.5

Table 2: Performance of flow in calibration and validation period.

Simulation of Runoff	R_{eff}	ENS	PBIAS	RSR	Flow weighted efficiency	Model efficency/ LogReff
Calibration for HBV light	0.74	0.73	-	-	0.79	0.71/0.74
Validation for HBV light	0.72	0.7	-	-	0.79	0.704/0.72

parameter how good simulations of the measured runoff could be achieved at best with different parameter values [12]. 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 catchment of upper Tekeze sub basin with the aim of 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 catchment 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 km^2. The study area is bounded between latitudes 13^{0}16' and 14^{0}16' North and longitudes 38^{0}38' and 39^{0}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 meterologiocal 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 from MoWIE and ERDAS LULC2008 classification was prepared for further investigation (Figure 1).

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 evapo transpiration (ETo) 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 for the calibration

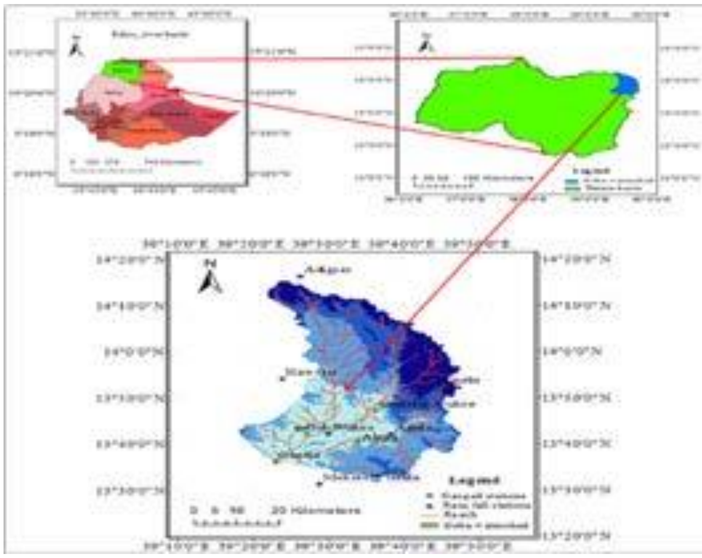

Figure 1: Location of the study area.

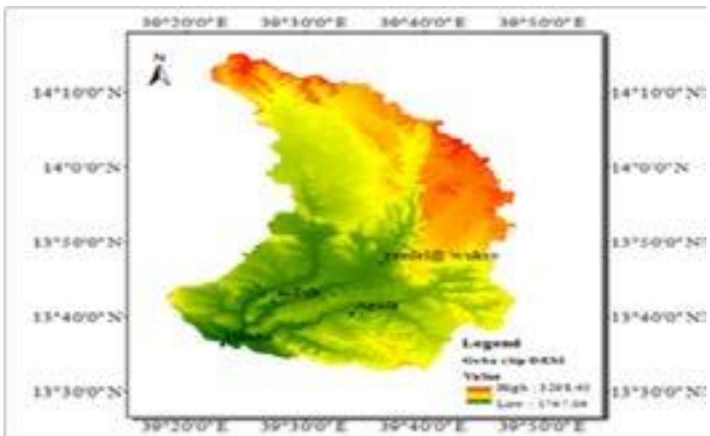

Figure 2: SRTM 30*30 DEM of Geba watershed

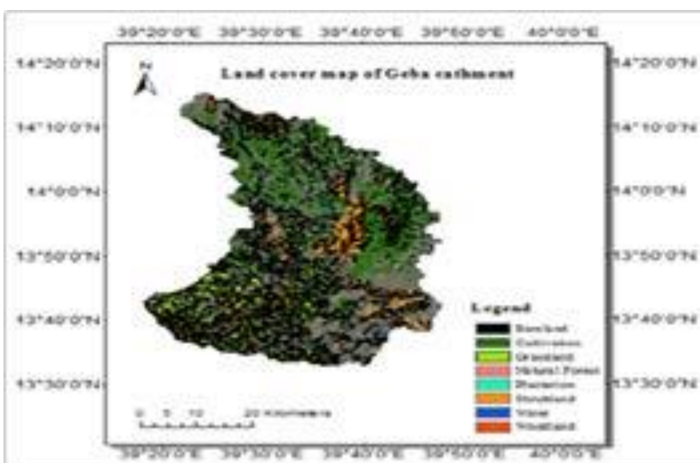

Figure 3: Land cover map of Geba watershed

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] was used for HBV light model

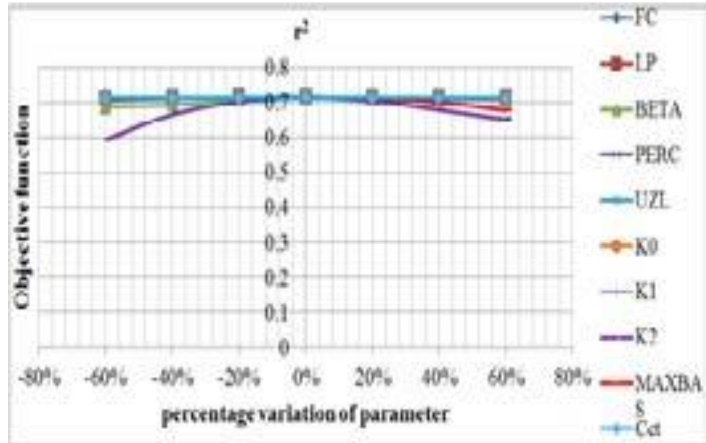

Figure 4: Sensitivity analysis by considering r2.

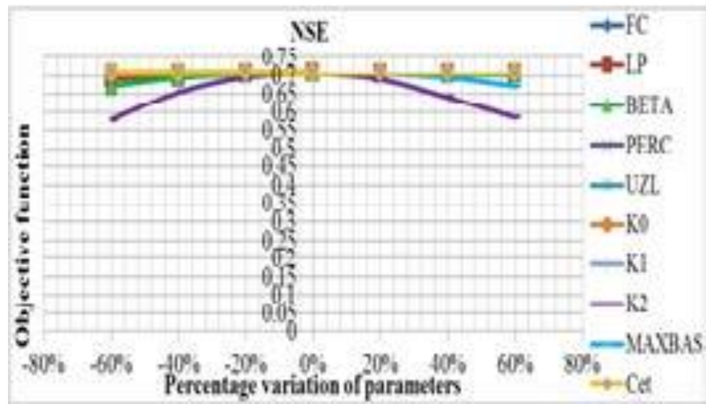

Figure 5: Sensitivity analysis by considering NSE.

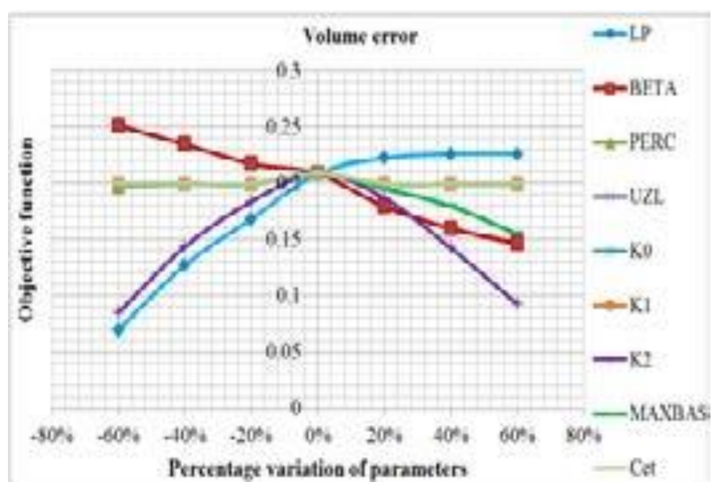

Figure 6: Sensitivity analysis by considering volume error.

2.4 Spatial Temporal Data

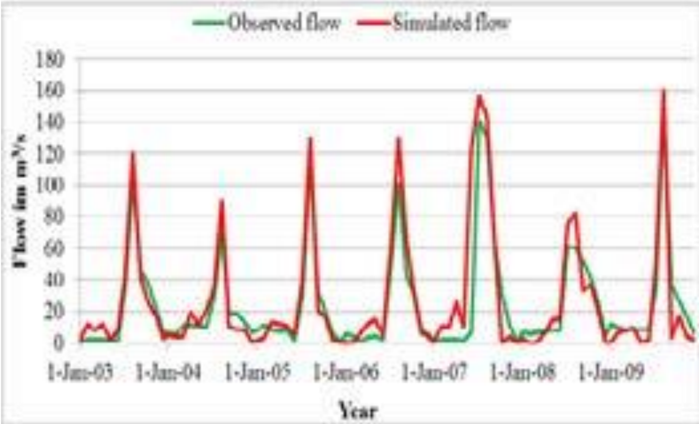

Figure 7: Observed and simulated flow hydrographs during calibration period.

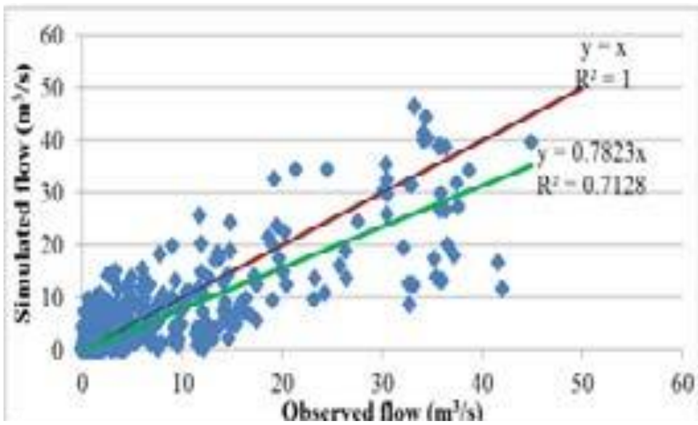

Figure 8: Scatter plot during calibration period in the Geba catchment.

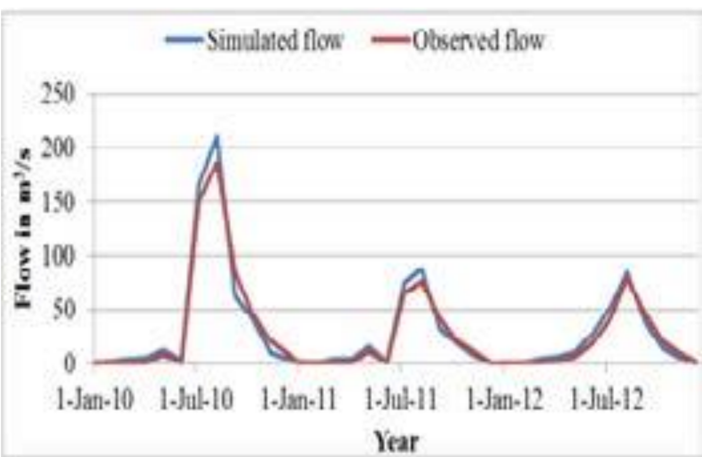

Figure 9: Observed and simulated hydrographs during validation period.

2.4.1 Topographic Map:

SRTM 30 × 30 DEM was downloaded from earth explorer. The Geba catchment was extracted from Rift valley basin DEM (Figure 1).

2.4.2 Landusel and cover map:

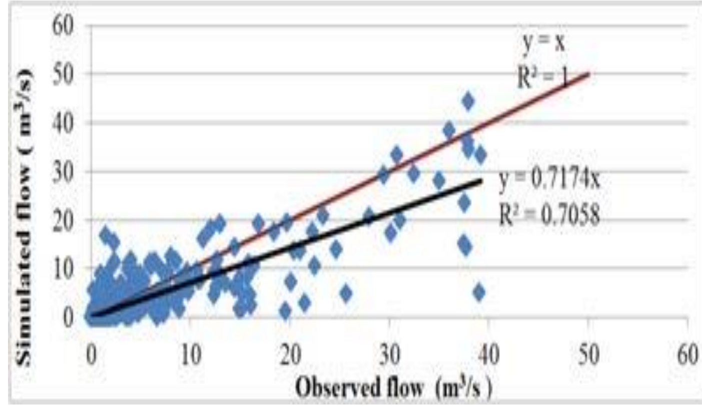

Figure 10: Scatter plot during validation period in the Geba catchment.

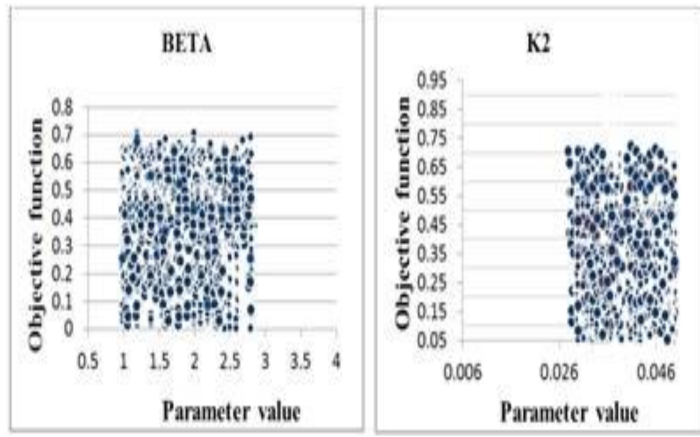

Figure 11: Dotty plot for model parameters.

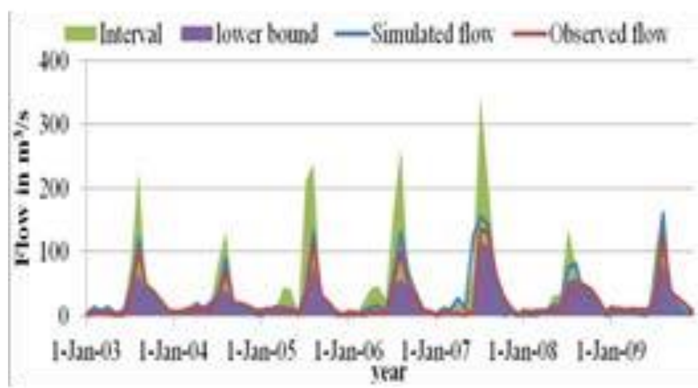

Figure 12: Uncertainty analysis in HBV light model.

From ERDAS 2008 LULC map for the study is the generated classification are as follows Shurb land, Cultivation, bareland, woodland, water body, plantation, natural forest and grass land(Figure 2).

3. Results and Discussions

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 throughout 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 throughout the objective functions (Figure 3).

3.1.2. Calibration and Validation

Eight years (from January 1, 2002 to December 31, 2009) this 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 NSE and R^2 greater than 0.60 and Reff = 0.74, NSE = 0.72 and Reff =0.73, NSE= 0.70 for the calibration and validation period (Figure 4).

3.1.3. Uncertainity Analysis HBV Light Model

For this study Monte carlo simulation procedure was used to assess the uncertainity analysis in HBV light model (Table 1).

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

These results indicate a large equifinality of parameters and many unconstrained parameters. [9] stated the concept of equinfinity concept in different catchment and he got large equinfinity and unconstrained parameters 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 (Figure 5).

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 mugger cathmentabay basin, Ethiopia (Table 2).

4. Conclusions

The following conclusions can be drawn from the foregoing discussions: The result from sensitivity analysis of HBV light model soil routine parameter β (shape co efficient), The recession curve, K2 and length of triangular weighted function (MAXBAS) were found to be the most sensitive parameters only in HBV light and due to this a major portion of the rainfall received Geba catchment quickly as direct runoff (surface dominance), This suggests different dominant runoff generation processes in the Geba catchment by the application of HBV light model (Figure 6). The majority of the ground surfaces of the study area covered with closely grown Agricultural land which its existence varying from season to season and with sparse vegetation.

Most of the soil types available in the study area have clay soil texture which is known with its less permeability. These factors generate high runoff from the rainfall events, because unprotected land and less permeable soils are fast to get saturation level (Figure 7). The generation of high runoff depth results for high sediment generation and transport.

HBV light is good due to uncertainty analysis and parameters are identifiable and the dotty plots have less equinfinity or unconstrained sample point (Figure 8-10). Form these regard further water resource development and analysis selection of HBV light model is best due to best simulation of runoff for the catchment and for the future study of runoff simulation for the catchment proper data collection and analysis should be carried to minimize the uncertainty arises from different source and from the dynamics for the model it have less performance in predicting low flow and extreme flood. Moreover, HBV light over estimate the low flow and the peak flow and poor model responses to high rainfall amount (Figure 11-12).

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