Evaluation of Stream Flow Prediction Capability of Hydrological Models in the Upper Blue Nile Basin, Ethiopia

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Abstract. This study aims to evaluate stream flow predication capability of three hydrological models including Parameter Efficient Semi-Distributed Watershed Model (PED-WM) model, Hydrologiska Byrans Vattenbalansavdelning (HBV) and Hydraulic Engineering Center-Hydrologic Modeling System (HEC-HMS) in range of sizes of watersheds, Upper Blue Nile Basin, Ethiopia. The model efficiency on daily time scale during calibration period for PED-W (NSE = 0.76, 0.81 and 0.57), HBV-IHMS (NSE = 0.68, 0.79 and 0.59) and HEC-HMS (NSE = 0.63, 0.68 and 0.48) were obtained for Anjeni, Gumara and Main Belles watersheds respectively. Similarly, for validation period PED-W (NSE = 0.6, 0.73 and 0.37), HBV-IHMS (NSE = 0.56, 0.79 and 0.55) and HECHMS (NSE = 0.52, 0.74 and 0.37) were obtained for Anjeni, Gumara and Main Belles watersheds respectively. Similarly, the model performances on monthly time steps were also varied among three hydrological models and the results better than the daily time scale. In PED-W, saturation excess is the main direct runoff process. The overall model performance indicated that PED-W model was better than the other two models. The result indicates that the models in the highlands of Ethiopia are dominantly dependent on the runoff mechanism dominantly on saturation excess runoff mechanism. Hence, there should be an approach to integrate climate region specific model in our water resource development system for predicting stream flow for ungagged catchments.

Keywords: HBV · HEC-HMS · Hydrological model · PED-W · Upper Blue Nile basin

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1 Introduction

1.1 Background

Hydrological models are simplified, conceptual representation of the hydrological cycle. As the hydrologic cycle consists of many complex components, hydrologic models are highly preferred to capture the associated issues. It also plays a great role in planning, designing, operation and monitoring of water resources. In number of models, simulating the discharge from watersheds in the Blue Nile basin has increased exponentially [1]. This type of watersheds require very suitable models are vital for understanding the change in catchment dynamics [2].

Hydrological models like physical based models that give a sound description of hydrological cycle process can be used to predict stream flow and sediment transport. However, in countries like Ethiopia, adequate data for hydrological modeling are different to access or not available. Specifically, the problem of the upper Blue Nile basin is also scarcity of data for prediction of the stream flow of the basin and for planning, design and implementation of numerous national developments projects in the area. However, models with the existing scarce data that could be capable of predicting the hydrologic models are needed. But choosing right watershed model for stream flow predication has always been a challenge [3]. Different researcher has been conducted which is related to estimate stream flow in the Upper Blue Nile basin using different hydrological distributed models. For instance, a number of models have been developed and applied to study the water balance, soil erosion, climate and environmental changes in the Blue Nile Basin. Steenhuis et al. [4] has been studied on the issue of prediction discharge in the Blue Nile Basin using PED-W model. The study found that the model performance to predicate discharge in Abbay (Blue Nile) basin was (NSE = 0.98). It is also found that PED-W model is an applicable in large watershed. But the calibration period is too short to evaluate the model performance. Collick et al. [5] has also been studied on the issue related to develop simple water balance model for the Ethiopia highlands. The study indicates that to develop a realistic simple model that is useful as a tool for planning watershed management and conservation activities so that the effects of local interventions on stream flow can be predicted at large scale. The study found that daily discharge values were predicted reasonably well with NSE values ranging from 0.56 to 0.78. The study conclude that the model could be used to predicted discharge in ungagged basins in the humid highlands. According to Tilahun et al. [6] studies on the catchments of Ethiopia highlands (Anjeni, Andit Tid, Enkulal and the Blue Nile basin) to predict discharge and sediment using PED state that the value of NSE for validation of the discharge predicting had resulted NSE = 0.77 and 0.92. The study concludes that this type of model, which requires a few calibration parameters to simulate runoff and sediment transport is important in data scarcity environment.

The study of Geberye et al. [7] showed that modeling the Upper Blue Nile basin catchments using HEC-HMS for better assessment and prediction of simulation of hydrological responses. However, this study was the run off estimation is not considering the land use basin. The runoff processes in the Upper Blue Nile basin are found to be affected much by rainfall, as the performance of model was better for those study catchments where coverages of rainfall station were good Dessie et al. [8]. The basic intention of this study was to evaluate the suitable hydrological model for stream flow prediction at various watershed scales using PED-W, HEC-HMS, HBV-IHMS models.

2 Materials and Methods

2.1 Description of the Study Area

The study was conducted in Anjeni, Gumara and Main Belles watershed, a tributary of Blue Nile River Basin which are located in the western part of the Ethiopia highland (Fig. 1). The study area lies at an altitude of 2405–2500 m, 1790–3600 m and 990–2725 m above sea level and located at latitude range 10° 40′ N to 10° 50′ N and longitude range of 37° 31′ to 37° 45′, 11° 34′ 41.41″ N to 11° 56′ 36.95″ N & 37° 29′ 30.48″ E to 38° 10′ 58.01″ E longitude for Anjeni, Gumara and Main Belles Watersheds respectively. The study was concentrated on the upper/gaged part of the Gumara watershed, which has area coverage of 1280.73 km^2 and the study also covered the Anjeni and Main Belles watersheds which have area coverage 1.13 km^2 and 3431 km^2 respectively. The annual rainfall of the study area ranges between 1550 to 1695 mm, 1600 to 1800 mm and 1500 to 1700 mm for Anjeni, Gumara and Main Belles watersheds respectively.

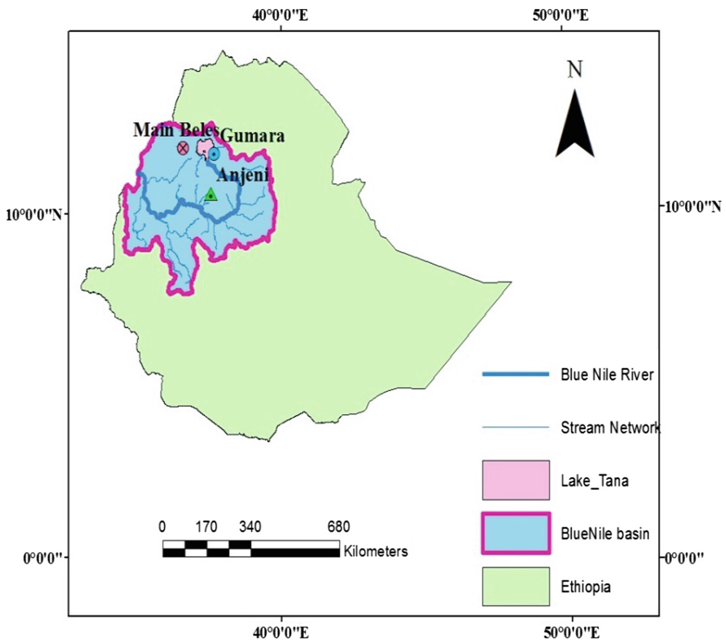

Fig. 1. Location of study area

2.2 Data Collection

In this study, all the metrological data were collected from National Meteorological Service Agency (NMSA) for nearest stations of the watersheds. Therefore, Mekaneyesus, Wanzaye, Deberatbor and Amedber, Wereta, Mekaneyesus and Lewaye metrological stations were used for Gumara watershed study (Fig. 1). The Only Station was Anjeni that used to represent the Anjeni watershed. Lastly, Pawe, Dangila, Shawra and Yismala stations are used for Main Belles watershed study.

2.3 Model Input

The model input requirements for semi distributed watershed models are daily rainfall and temperature, daily observed flow, potential evapotranspiration, digital elevation model and catchment characteristic of the area.

2.3.1 Determination of Area Rainfall

For this study, the thiessen polygon method was used for this study due to its sound theoretical basis and availability of computational tools. However, the method is dependent on a good network of representative rain gauges (Fig. 2).

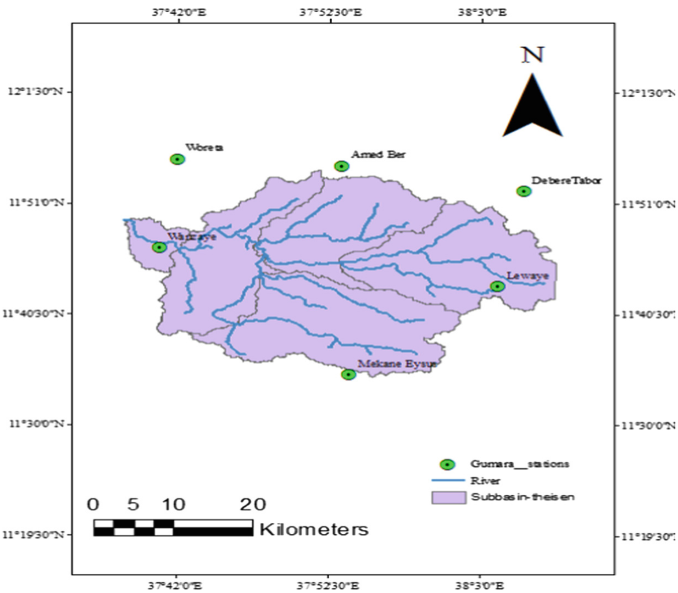

Fig. 2. Thiessen polygon for Gumara watersheds

2.3.2 Evapotranspiration

The potential evapotranspiration as a model input in this study was estimated based on simple temperature method approach showed by Enku and Melesse by [8] as indicated in equation in below. This method are used for estimation of daily evapotranspiration where they are insufficient data.

$$ET_0 = (T_{max})^n/K \tag{1}$$

Where ETo is the reference evapotranspiration (mm/day); n = 2.5, which can be calibrated for local conditions; k is the coefficient, which can be calibrated for local conditions ranging from about 600 for lower mean annual maximum temperature areas to 1300 for higher mean annual maximum temperature areas. The coefficient, could be approximated as k = 48 * Tmm-330 for combined wet and dry conditions, k = 73 * Tmm-1015 for dry seasons, and k = 38 * Tmm-63 for wet seasons, where Tmm (°C) is the long-term daily mean maximum temperature for the seasons under consideration.

2.3.3 Stream Flow Data

The daily discharge of the study area is collected from Ethiopia Ministry of Water Irrigation and Electricity (EMoWIE). Unlike the daily precipitation, the daily discharge has full data composition for the considered stations to represent the study area.

2.3.4 Catchment Characteristics

Since HBV-Light model works as semi distributed model, the catchment area can be divided in to different sub basins and the sub basins further in to different elevation and vegetation zone.

2.3.5 HEC-GeoHMS Data Processing

The point of many data are preprocessing using Arc-Hydro tools was to create input files for the GeoHMS tools. GeoHMS uses the output files from Arc Hydro and automatically create sub basins, longest and centroid flow paths, basin centroid and other watershed properties. Additionally, parameters such as slope and length are assigned to flow lines and basins. In general, GeoHMS uses spatial analyst tools to convert geographic information into parameters for each of the basins and flow lines. These parameters are used to create a HEC-HMS model that can be used within the HEC-HMS program (Figs. 3, 4 and Table 1).

2.4 Watershed Models

The methodology were used three hydrological model such as PED-W, HBV-IHMS and HEC-HMS to predicate stream flow in selected watersheds of the upper blue Nile basin. Sensitivity analysis, model calibration and validation and evaluating the model efficiency were used to select suitable hydrological models to predicate stream flow.

2.4.1 PED-W Model

PED-W (Parameter efficient semi distributed watershed) model is a conceptual semi distributed model and firstly was developed by Collick and Steenhuis. Tilahun et al. [6]

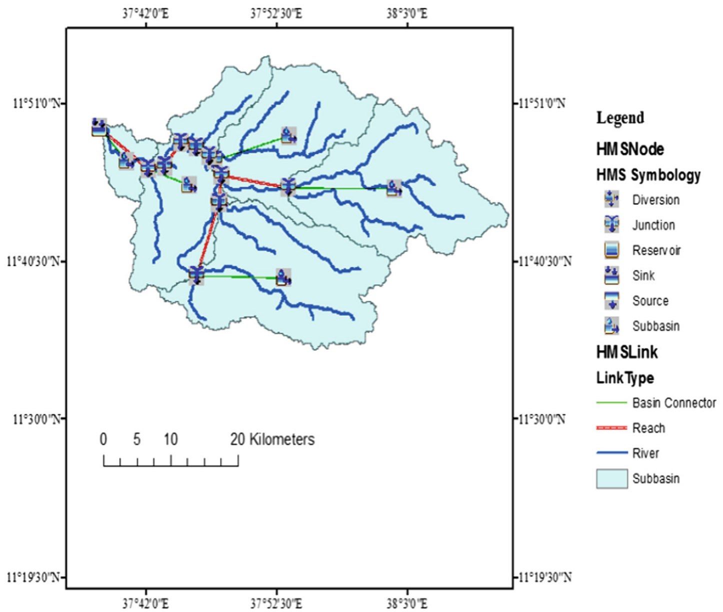

Fig. 3. Hec-Geoms processing for HEC-HMS set up for Gumara watershed

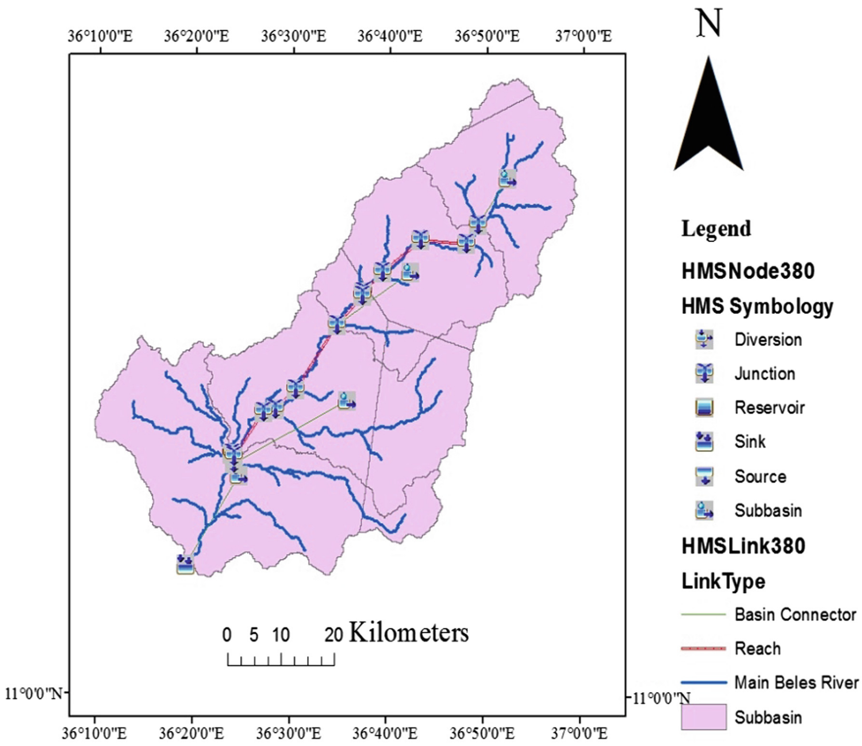

Fig. 4. Hec-Geoms processing for Hec-Hms set up for Main Belles watershed

Table 1. The input data and output of different models

Model type	Model input	Model output
PED-W	Daily RF, Temp and observed discharge	Simulated Q & sediment
HBV-IHMS	Daily RF, Temp, Q, catchment characteristics, AET	Simulated Q and sediment
HEC-HMS	DEM, RF, Temp, Q and soil, land use and land cover data	Simulated discharge

are then extended the model to predict sediment concentration in Anjeni Watershed. In PED-W model, the watershed subdivided in to three regions, two surface runoff producing zones consisting of areas near the river that becomes saturated during the wet monsoon period and the degraded hillsides with little or no soil cover. The remaining hillside areas have infiltration rates in excess of the rainfall intensity [9].

The amount of water stored in the root zone of the soil, S (mm), for hill slopes and the saturated and degraded areas were estimated separately with a water balance Eq. 2.

$$\mathrm{S} = \mathrm{S}_{\mathrm{t}-\Delta \mathrm{t}} + (\mathrm{P} - \mathrm{AET} - \mathrm{R} - \mathrm{Perec})\Delta \mathrm{t} \tag{2}$$

Where P is precipitation, (mm d^{-1}); AET is the actual evapotranspiration, (mm d^{-1}), $\mathrm{S}_{\mathrm{t}-\Delta \mathrm{t}}$, previous time step storage, (mm), R saturation excess runoff (mm d^{-1}), Perc is percolation to the subsoil (mm d^{-1}) and Δt is the time step.

2.4.2 HBV-IHMS Model

It is a conceptual hydrological model, which means it attempts to cover the most important runoff generating processes using a simple and robust structure, and a small number of parameters. The model simulates daily discharge using daily rainfall, temperature and potential evaporation as input. The general water balance equation of HBV model is illustrated under equations

$$P - E - Q = \frac{\mathrm{d}}{\mathrm{dt}}[SP + SM + UZ + LZ + L] \tag{3}$$

Where recharge is input from soil routine (mm day^{-1}), SUZ is storage in upper zone (mm), SLZ is storage in lower zone (mm) and UZL is threshold parameter (mm), PERC is maximum percolation to lower zone (mm day^{-1}), Ki = recession coefficient (day^{-1}), Qi is runoff component (mm day^{-1}).

2.4.3 HEC-HMS Model

HEC-HMS model setup consists of a basin model, meteorological model, control Specifications and input data (time series data). The basin Model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, river reach connectivity, or reservoir data. Likewise, the Meteorological Model holds rainfall data. The Control Specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval is to be used in the model, etc. Each of the HEC-HMS model provides a variety of options for simulating precipitation-runoff processes.

SCS Curve Number (CN) method is more preferable to determine the runoff volume of each watershed. Because it is simply, widely used and efficient for determining the approximate amount of runoff from rainfall, even in particular area. The model approach used to determine the runoff volume was the SCS-CN method. The standard SCS curve number method is based on the under Eqs. 4 and 5 relationship between rainfall depth, P, and runoff depth Q [11]

$$\mathrm{Q} = (\mathrm{P} - 0.2\mathrm{S})^2/(\mathrm{P} + 0.8\mathrm{S}), \text{ for P} > \text{otherwise Q} = 0 \tag{4}$$

$$\mathrm{S} = 25400/\mathrm{CN} - 254(\text{in mm}) \tag{5}$$

$$I_a = 0.2S \tag{6}$$

Where Q is the surface runoff (mm), P is precipitation; S is the soil retention (mm), Ia is the initial abstraction loss (mm), and CN is the curve number.

2.5 Sensitivity Analysis

Sensitivity analysis explores how changes in parameter values affect the overall change in the output of the model. This can be done by using simple sensitivity analysis, where only one parameter is changed or more complex arrangements that explore the relationships between multiple parameters. Thus, a sensitivity analysis for PED-W, HBV-IHMS and HEC-HMS models were performed for the entire data. Then, the most sensitive parameters were identified and used for calibration of the model.

2.6 Model Calibration and Validation

After sensitivity analysis was carried out, the calibration of PED-W, HBV-IHMS and HEC-HMS models were done manually. The calibration was carried out using the output of the sensitivity analysis of the model and by changing the more sensitive parameter at a time while keeping the rest. PED Model was calibrated through using nine input parameters. Initial values for calibrating parameters were based on different researcher done in this study area [4, 5, 12, 13]. These initial values were changed manually through randomly varying input parameters in order that the best "closeness" or "goodness-of-fit" was achieved between simulated and observed subsurface flow and overland flow in the watershed.

Model Validation is the process of testing the model ability to simulate observed data, Other than those used for the calibration, within acceptable accuracy. The model performance is evaluated by three objective functions consisting of the Nash Sutcliffe efficiency (NSE), percent bias (PBIAS), and coefficient of determination (R^2).

3 Results and Discussion

The finding of this study was presented based on model sequence as PED-W, HBV-IHMS and HEC-HMS hydrological models. Firstly, the stream flow predication was presented using PED-W, HBV-IHMS and HEC-HMS models on Anjeni, Gumara and Main Belles watersheds. Subsequently, model suitability for Anjeni, Gumara, and Main Belles watersheds in Upper Blue Nile basin was assessed by first evaluating the simulated and observed discharge at the outlet.

3.1 Sensitivity Analysis Results

Determination of the sensitive parameters is one of the most important tasks in rainfall-runoff modeling in order to reduce the parameters and the time of the calibration. Before, the calibration one parameter at a time was varied an analyses from −50% to 50% with increments of 10%, keeping all other parameters constant. The boundary condition of PED-W model in case of calibration process is the area of watershed with the range of zero up to one fraction number.

In PED-W, manual sensitivity analysis for stream flow prediction at the outlet resulted in the identification of six most sensitive parameters: the areal hill-side coverage (Ah), the saturated area (As), degraded area (Ad), Maximum base flow soil storage (BSmax), the recession coefficient (k) and half life time. From nine input PED-W model parameter five parameters were found most sensitivity such as area hillside (Ah), saturated area (As), degraded area (Ad), maximum soil storage in saturated area (Smax) and recession coefficient (K). These results of parameter sensitivity were similar as identified by Moges et al. [13] study for Awramba watershed in the Blue Nile Basin. From the five most sensitive parameters, the area of hillside is the most sensitive parameter that affect the model output. However, the rank of other parameters were varying from one watershed to another. The reason that were varying the rank due to catchment characteristics variation, topography and rainfall pattern.

HBV-IHMS had more than 13 parameters but seven model parameters that used to control the total volume and shape of the hydrograph used in this study [14]. The remaining parameters are not influencing the total volume of water and shape of the hydrograph. Out of those 7 parameters, five were found most sensitivity: field capacity (fc), soil drainage (beta), limiting for evapotranspiration (LP), storage coefficient and percolation. In HBV-Light model parameters of soil moisture routine, response function and routing routine were sensitivity for to predicate discharge for each watershed.

It was found that the most suitable method was so accounting SCS loss method, which has 10 parameters for calibrating HEC-HMS model. The most sensitive parameters in this method were Curve Number, Time of concentration, Muskingum routing and soil coefficient storage.

3.2 PED-W Calibration and Validation

For the PED-W model, all nine input parameters were calibrated. The starting values for calibrating parameters were based on the study of Collick et al. and Staneehuis et al. [4] and [5]. These starting values were changed manually through randomly varying input parameters in order that the best "closeness" or "goodness-of-fit" was achieved between simulated and observed subsurface flow and surface flow in the watershed. The optimal value of calibration parameters for different watersheds were varying (Table 2).

The calibrated model parameters for the subsurface flow represented by the half-life ($t_{1/2}$) and interflow calibration parameter t* for the different rainfall input data are almost the same for all simulations as expected and consistent with values used in simulation of Anjeni watershed and other watersheds in the Blue Nile Basins [6]. The fractional regions contributing to rapid subsurface and overland flow have different values for stream flow simulation. The total contributing area for the gauged rainfall adds up to 100% for Gumara, 78% for Main Belles and 57% for Anjeni. It is also consistent with earlier studies of PED simulation for a wide scale of watersheds study areas by [15].

The observed and simulated hydrograph in Anjeni watershed using the optimum parameter was shown in Fig. 5a. Visually inspection of the observed and simulated hydrograph shows that the performances of the model in simulating the base flow, rising and recession limb of hydrograph was good. The model simulation for peak flow was satisfactory although it under estimates very high single peak. The model results as shown below in Fig. 5b indicated that the observed and simulated hydrograph do have better agreement in mean monthly flow compared to daily flow. The hydrograph pattern in monthly time step indicated that the good relationship between observed and simulated discharge and the model efficiency was 0.94, which was higher than daily model efficiency. The calibrated PED model using gauged rainfall could represent the observed daily stream flow reasonably well for the both calibration and validation for Anjeni ($0.76 > NSE > 0.6$), Gumara ($0.81 > NSE > 0.75$) and Main Belles ($0.57 > NSE > 0.5$).

Table 2. Optimal calibrate parameters of watershed for PED-WM model

Description	Parameters	Gumara	Main Belles	Anjeni
Fraction of saturated area	$Area_1$	0.051	0.04	0.02
	S_{max} in A_1	73	100	200
Fraction of degraded area	$Area_2$	0.09	0.01	0.1
	S_{max} in A_2	15	15	15
Fraction of hill side area	$Area_3$	0.95	0.73	0.45
	S_{max} in A_3	150	150	115
$t_{1/2}$ (days)		12	40	60
τ_* (days)		6	55	10
B_{Smax}		210	100	115

Increase the time step showed increases the performance of PEW-W model was high for flow simulation in Gumara catchment during calibration period. The monthly PED-W model Calibration indicated that relation between observed and simulated discharge were good agreement. The model results as shown in the Fig. 6b indicated that the observed and simulated hydrograph do have better agreement in mean monthly flow compared to daily flow. The Nash and Sutcliffe efficiency and the correlation coefficient during the monthly calibration period were 0.93 and 0.92 respectively, which could take as high satisfactory. The model efficiency indicated that in Main Belles watershed was highly satisfactory.

The hydrograph pattern showed that in Fig. 7, the relation between daily observed and simulated stream flow hydrograph was very good. Because the performance of the model in simulating the base flow, rising, and recession limb hydrograph was good. The daily peak simulated discharge and observed peak discharge for Gumara watershed almost were the same. Due to seasonal variability and monthly average discharge were generally at some points over estimated with low flow period and peak flow.

3.3 HBV-Model Calibration and Validation

Manual calibration was done by making optimization of the parameters of different routines of HBV-Light hydrologic model based on existing catchment characteristics. A total of 15 years (2000–2014) period data was used for both model calibration and validation. Here the first year (2000) data was used for warming up period to initiate the model and the remained 14 years of data from which 2/3 data period (2000–2009) was used for model calibration and the remaining 1/3 data period (2010–2014) was also used for the validation purposes for Gumara watershed. Accordingly, running the model for a number of times was made to have the correspondent values of observed and simulated discharge. For the Anjeni watershed 14 years (1986–1998) was used for both calibration and validation. Parameter optimization was made for the Monte Carlo runs of the model by supplying the lower and upper ranges to get an optimum value for the three routine (Soil moisture, Response and Routing) except snow routine, which was left due to the absence of the snow in the watershed. The optimized parameters are described in Table 3.

Some of the peak flows were under predicated by the model in the period of between 1990 to 1994. The mean difference between the observed and simulated was 86 mm/year. Compared to the performance of models calibrated on daily time step, the simulated and observed hydrograph shows poor agreement when compared from PED-W model result hydrograph.

From the results showed in Figs. 8 and 9, it can be concluded that it is difficult to predicate discharge properly during peak flow. This can be caused by spatial average

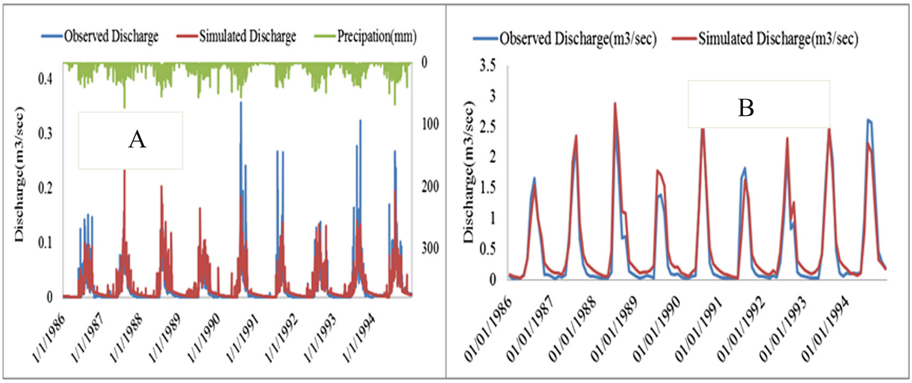

Fig. 5. Predicated and observed discharge for Anjeni watershed during calibration period (1986–1994) (a) daily and (b) monthly

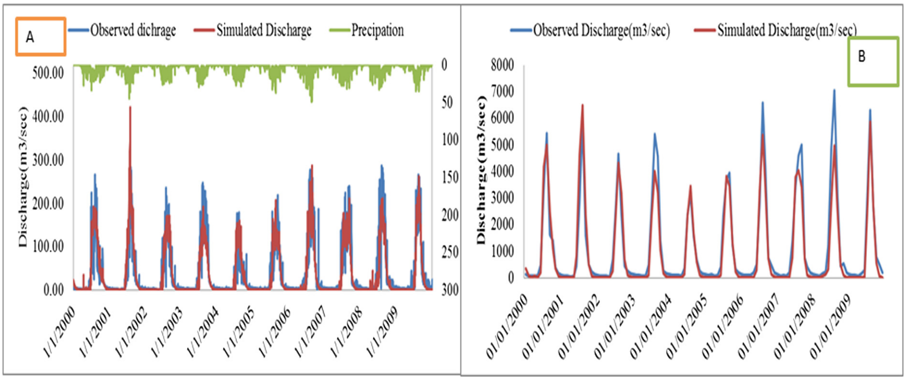

Fig. 6. Predicated and observed discharge for Gumara watershed during calibration period (2000–2009)

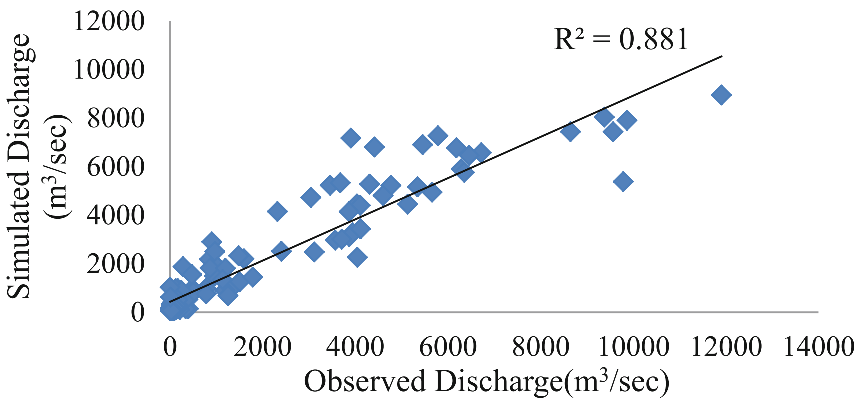

Fig. 7. Observed and simulated monthly for discharge for Main Belles watershed during calibration period (1994–2003)

precipitation that does not represent the real rainfall property. On the other hand, the constant and relative high discharge during dry periods not a realistic representation (Fig. 10).

3.4 HEC-HMS Calibration and Validation

HEC-HMS calibration was performed for a period of ten years (1986 to 1994), (2000 to 2009), (1994 to 2003) for Anjeni, Gumara and Main Belles watersheds on the daily basis. The flow was calibrated automatically using the observed flow at the outlet of Gumara, Anjeni and Main Belles watersheds. Optimization of the parameter values was carried out within the allowable ranges recommended by the US Army corps of Engineers Hydrologic Engineering Center [16]. The model results as obtained from the final manual

Table 3. The input parameters that was involved and optimized in the calibration process

Description	Parameters	Gumara	Main Belles	Anjeni
Soil Moisture Routine				
Field Capacity	FC	1500	347	1950
Beta	β	0.8	0.11	0.24
Soil moisture value	LP	2	2.99	1
Response Routine				
Maximum Percolation Rate	PERC	0.5	15.2	5.5
Threshold for the k_0 outflow	UZL	15	120	20
Recession Coefficient (Upper)	K_0	0.04	0.8	0.02
Recession Coefficient (Upper storage)	K_1	0.09	0.012	0.46
Recession Coefficient (Lower storage)	K1	0.01	0.15	0.2
Routing routine				
Length of triangular weighting Function MAXBAS		1	1	1

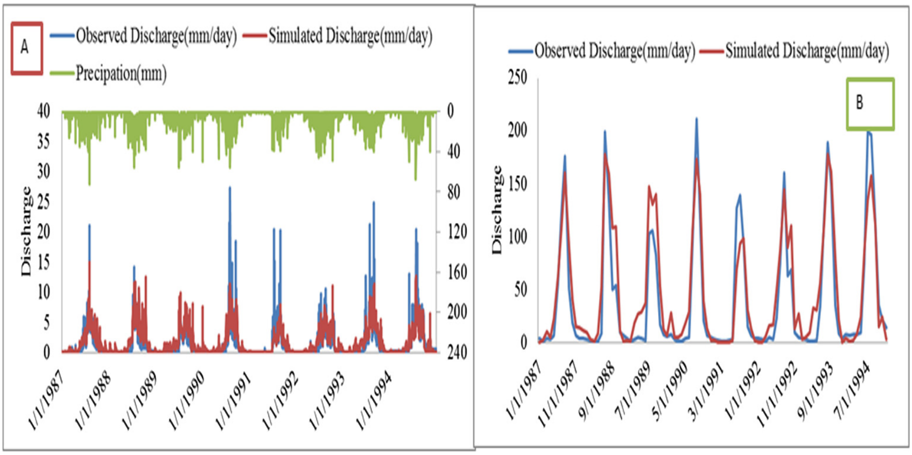

Fig. 8. Daily and monthly observed and predicate stream flow using HBV for Anjeni watershed

calibration showed that there was a good agreement between the simulated and observed flow for Anjeni, Gumara and Main Belles catchments. This was demonstrated by the correlation coefficient and the Nash-Sutcliffe (1970) efficiency values for catchments (Fig. 11).

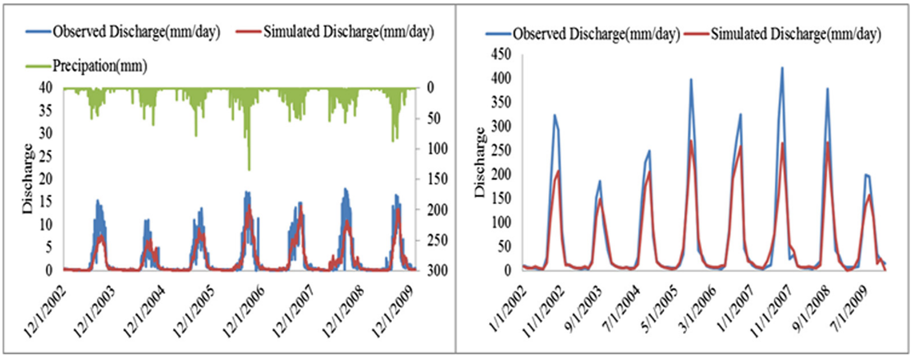

Fig. 9. Daily and monthly observed and predicate stream flow using HBV for Gumara watershed

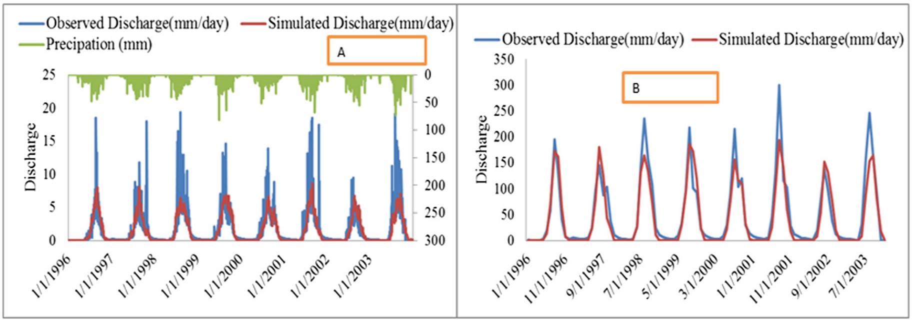

Fig. 10. Daily and monthly observed and predicate stream flow using HBV for Main Belles watershed

As shown in figure above, the daily hydrograph, simulated stream flow caught the observed flow during calibration period (1986–1994) was good simulated. However, the peak flow is under predicated in the model. The model efficiency for Anjeni watershed was 0.603. In HEC-HMS simulating hydrograph for Gumara watershed, it can be concluded that the daily observed and simulated stream flow hydrograph have a good agreement between them when we compared the other two watersheds. The model performance was checked using NSE and R^2 where these results obtained were satisfactory and acceptable to simulate the basin runoff for future projection (Fig. 12).

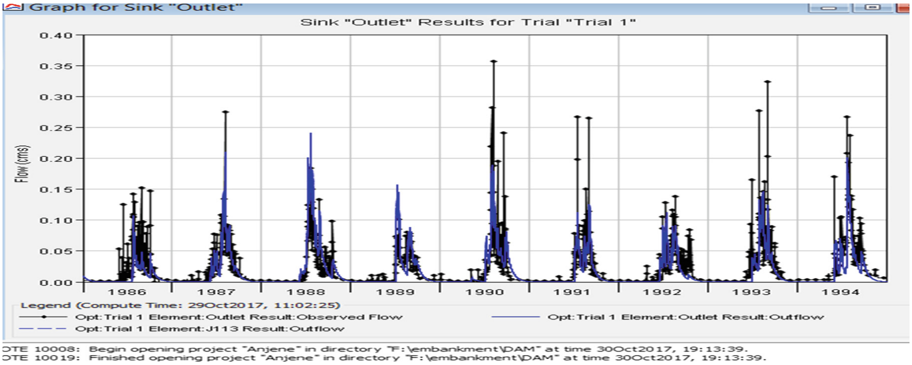

Fig. 11. Flow hydrographs for the observed and simulated flows at Anjeni gaging station

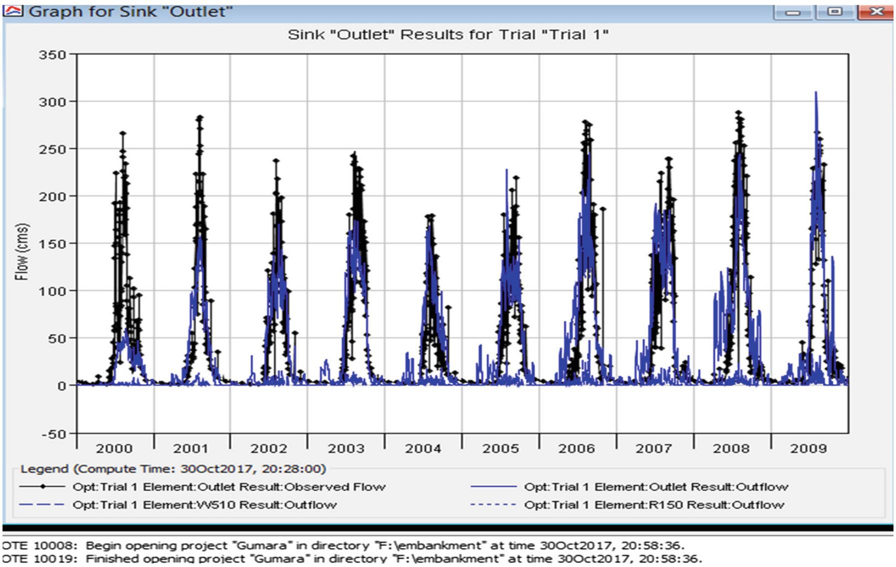

Fig. 12. Flow hydrographs for the observed and simulated flows at Gumara gaging station

The validation result indicated that how to the model efficiency evaluate to simulated discharge for different year of data. Based on the calibrated parameters values the model was validated and the model performance a little bit decreasing. So that the validation result presented as shown below in figures (Figs. 13, 14 and 15).

3.5 Model Performance and Comparison

A daily time step of the observed discharge was simulated using PED with NSE of 0.76 and 0.6 whereas for HBV-IHMS NSE was 0.68 and 0.56 and for HEC-HMS 0.63 and 0.52 during calibration and validation period respectively for Anjeni watershed. For Gumara watershed, the daily-observed discharge was simulated using PED with NSE of

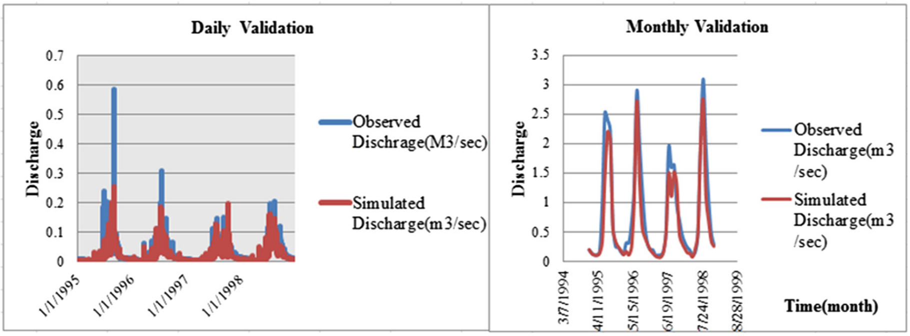

Fig. 13. Daily and monthly PED–W Validation Result for Anjeni watershed

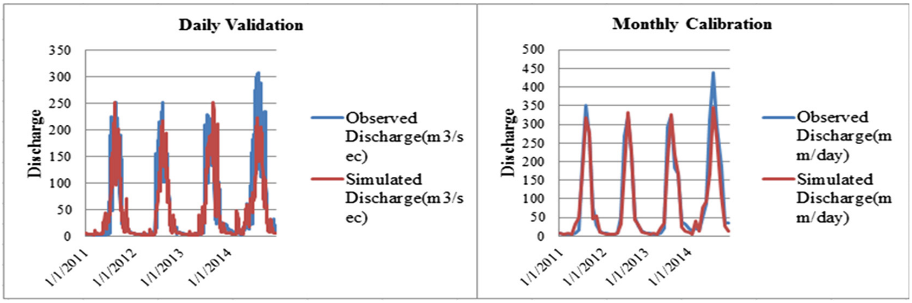

Fig. 14. Daily and monthly HBV Validation Result for Gumara watershed

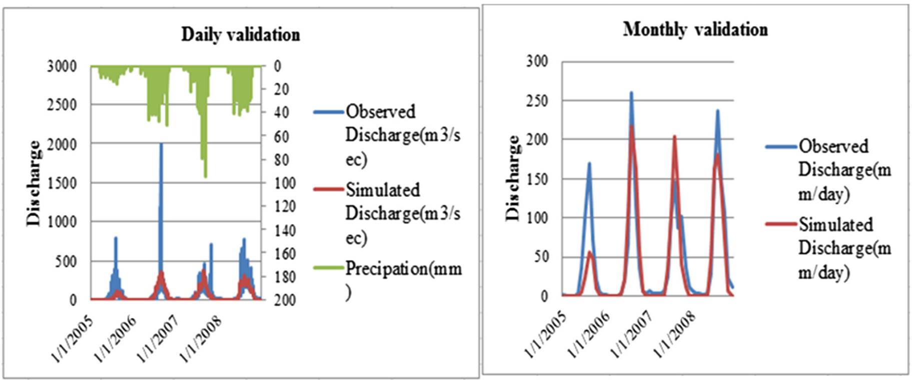

Fig. 15. Daily and monthly HBV Validation Result for Main Belles watershed

0.81 and 0.73 whereas for HEC-HMS was 0.68 and 0.73 and for HBV-IHMS was 0.79 and 0.79 during calibration and validation period in respectively. Lastly, the daily time step the observed discharge for Main Belles watershed was simulated using HBV-IHMS of 0.59 and 0.55 whereas for PED was 0.57 and 0.53 and for HEC-HMS was 0.48 and

0.37 during calibration and validation period respectively. This result of PED-W model were within the range of similarity studies: done Tilahun et al., Dagnew et al., Steenhuis et al. [4, 5, 17–20] and [13];. Similarly, for HBV-IHMS model the prediction model performance results were consistent with the study of Rientjes et el. And wale et al. [14]; and [21].

The value of Nash Sutcliffe, Root mean square error, percent bias and coefficient of determination using PED-W model during calibration period for Anjeni (NSE = 0.76, RMSE = 0.49, PBIAS = 22%, R^2 = 0.78), Gumara (NSE = 0.81, RMSE = 0.44, PBIAS = 14.14%, R^2 = 0.82) and Main belles (NSE = 0.57, RMSE = 0.66, PBIAS = −6.8%, R^2 = 0.57) in respectively watersheds and performance indicators. For HBV-IHMS model in the Anjeni (NSE = 0.68, PBIAS = −18.04%, R^2 = 0.69), Gumara (NSE = 0.79, PBIAS = 10.63%, R^2 = 0.82) and Main belles (NSE = 0.59, PBIAS = 13.62%, R^2 = 0.59) in respectively watersheds. For HEC-HMS model in the Anjeni (NSE = 0.63, PBIAS = −8.41%, R^2 = 0.78), Gumara (NSE = 0. 68, PBIAS = −4.21%, R^2 = 0.68) and Main belles (NSE = 0.48, PBIAS = 2.42%, R^2 = 0.48) in respectively watersheds.

4 Conclusion

The model efficiency on daily time step during calibration period for PED-WM (NSE = 0.76, 0.81 and 0.57), HBV-IHMS (NSE = 0.68, 0.79 and 0.59) and HEC-HMS (NSE = 0.63, 0.68 and 0.48) were obtained for Anjeni, Gumara and Main Belles watersheds respectively. Similarly, for validation period the results were PED-W (NSE = 0.6, 0.73 and 0.37), HBV-IHMS (NSE = 0.56, 0.79 and 0.55) and HECHMS (NSE = 0.52, 0.74, 0.37). PED-W (a semi distributed saturation excess runoff model) was relatively better in predicating stream flow in the three watersheds. HBV-IHMS was the next best, while HEC-HMS based on infiltration excess and was setting as last. PED-W model was also the most appropriate model to predicate stream flow for watershed scale size when we compared from the other two models. However, the PED-W model was relative less efficiency for determination of peak discharge. In generally, the results showed that all models can reproduce historical daily runoff series with an acceptable accuracy on the monthly time scale however for daily times scale model selection based on runoff mechanism was advisable.

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