ESTIMATION OF DISCHARGE FOR UNGAUGED CATCHMENTS USING RAINFALL-RUNOFF MODEL IN DIDESSA SUB-BASIN: THE CASE OF BLUE NILE RIVER BASIN, ETHIOPIA.

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ABSTRUCT
Runoff estimation in ungauged catchments is probably one of the most basic and oldest tasks of hydrologists. This long-standing issue has received increased attention recently due to the prediction in ungauged basin initiative by the International Associations of Hydrological Science. In developing countries like Ethiopia most of the Rivers are ungauged. Therefore, applying regionalization techniques for ungauged or poorly gauged river basin is crucial. This paper deals with predicting discharge at ungauged catchments using conceptual lumped rainfall-runoff model HBV-96 in Didessa sub-basin. Four regionalization methods were applied to transfer model parameter values from the gauged to the ungauged catchments. In regional model, gauged catchments model parameters and physical catchment characteristics of ungauged catchments were used to develop the equations. Sensitivity analyses of eight model parameters were performed manually by trial and error. The evaluation shows that runoff coefficient (Beta), recession coefficient of upper reservoir zone (Khq), limit for evapotranspiration (LP), field capacity (Fc), percolation (Perc) and capillary rise coefficient (Cflux) are more sensitive than others. The model performance was evaluated using Nash Sutcliff efficiency and relative volume error. The result shows that from seven gauging river four of them have good agreement and distribution since Nash Sutcliff efficiency greater than 0.60 and relative volume error lies between +10% and -10%. The model parameters in ungauged catchments were determined by using regional model, sub-basin mean, area ratio and spatial proximity methods and simulated the discharge by using HBV-96 model. River flow from ungauged catchments simulated by regional model method was the best. Therefore, regional model method is recommended in predicting discharge for ungauged catchments.

KEY WORD: HBV-96; Regionalization; Stream flow simulation; Didessa sub-basin

INTRODUCTION
Hydrological data are necessary for assessment of water resources. Information on water level in rivers and lakes, discharge, sediment and water quality is necessary for a range of projects, in which information on the time series, maxima or minima of the variable may be needed. Although significant insight as been gained in recent years, the establishment of the prediction in

ungauged basin initiative by the International Associations of Hydrological Science (IAHS) shows that much as still to be done in this area [Wagener and Wheater, 2006].
Ethiopia has 560 gauging stations of which 454 are operational for both Lake and rivers [Gebeyehu, 2013]. The situation in Ethiopia is problematic, as there are no evenly distributed hydrometric stations, as large areas lack gauging stations; and only a few years of data are available. Despite the fact that the Didessa sub-basin study area provides the largest amount of the Blue Nile River flows and is comparatively well equipped with lengthy hydrological and meteorological data series, most studies related to the Blue Nile River have focused on the northern part of the Blue Nile Basin [Bizuneh, 2011]. This makes the Didessa sub-basin is less studied areas, and a key to better understanding the overall hydrological regime of the Blue Nile.

Estimation of flow of ungauged catchments is usually based on transferring or extrapolating information from gauged to ungauged site, a process called 'Regionalization'. The area ratio, spatial proximity, sub-basin mean and regional model regionalization methods are used to predict discharges from ungauged catchments. This regionalization method allows using the relationships between the parameters of the model and physical catchment characteristics of Didessa sub-basin by using HBV-96 model.

HBV-96 is a semi-distributed conceptual hydrological model for continuous stream flow simulation, which was originally developed by SMHI in the early 70's to assist hydropower operations [SMHI, 2006]. It is flexible and robust in solving water resource problems and applications and also needs only few input variables such as rainfall, evapotranspiration, and temperature and elevation zone data to simulate stream flow for ungauged catchments.

Estimation of runoff for ungauged catchments are essential for design, planning and management of river basin projects that deals with conservation and utilization of water for irrigation and various purposes.

MATERIALS AND METHODOLOGY

DESCRIPTION OF STUDY AREA

Didessa sub-basin has a drainage area of nearly 25,796 km^2 and it has 363 km longest flow path. The drainage area lies under the three administrative zones of Oromia regional state of Ethiopia such as: Jimma Zones in the most upper and middle part, Illibabur Zone in the middle part and East/West Wellega in the lower part down to its confluence to the Blue Nile River [Bizuneh, 2011]. It is geographically located between 35^0 45' and 36^0 56' East longitude and between 7^0 52' and 9^{0}47' North latitude.
The mean annual rainfall and temperature in this watershed ranges from 1484mm to 2363mm and 15.22^{0}C to 23.56^{0}C respectively. The major soil groups of Didessa sub-basin are Alisols, Acrisols, fluvisols, Leptosols, Vertisols and Regosols. The slope of the catchment ranges between 5.4% to 19.8% and also the altitude ranges between 848m- 3208m amsl.

DATA COLLECTION

Even though more than 14 gauging stations were found in the basin, only seven gauging stations data were accessible from MoWIE, Hydrology department for this study.

Meteorological data was collected from the National Meteorological Agency (NMA). A request for daily rainfall, maximum and minimum temperature of 18 years period from1987-2004 data of nine rainfall stations was collected.

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 (ETo) when the standard meteorological variables including air temperature, relative humidity and sunshine hours data are available [Tufa, 2011]. 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.

Selection of representative physical catchment characteristics

Runoff generation is governed by catchment physical characteristics (PCCs). In this study a SRTM DEM 90 m × 90 m resolution has been used to delineate gauged and ungauged catchments of the study area using Soil and Water assessment Tool (SWAT) and GIS software. Twenty seven physical catchment characteristics are selected in each four gauged and 11 ungauged catchments.

MODEL SENSITIVITY ANALYSIS

Sensitivity analysis was applied manually by changing the value of one model parameter at a time. 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.

MODEL CALIBRATION

It was performed manually by trial and error from 1987 to 1996 by changing one model parameter at a time until the model simulated stream flow match with observed stream flow.

MODEL PERFORMANCE

RELATIVE VOLUME ERROR: The relative volume error between +5% and -5% indicates that the model performed well while relative volume error between +5% and +10% or between -5% and -10% indicated that the model performs reasonably. It was performed by the following formula;

$$RVE = \left[\frac{\sum_{i=1}^{n} sim - \sum_{i=1}^{n} obs}{\sum_{i=1}^{n} obs}\right] * 100 \qquad (1)$$

Where; *sim* = simulated discharge
obs = observed discharge

NASH-SUTCLIFFE EFFICIENCY: The Nash-Sutcliffe efficiency (NSE) is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. NSE measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. It can be defined according to the following equation.

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{oi} - Q_{si}\right)^2}{\sum_{i=1}^{n}\left(Q_{oi} - Q_{om}\right)^2} \qquad (2)$$

Where; Q_{oi}= Observed discharge
Q_{si}= Simulated Discharge
Q_{om}= mean observed discharge

REGIONALIZATION

There are many definitions of regionalization available but a general definition as stated in Bloschl and Sivapalan [1995] is used most often. "Regionalization is the process of transferring information from comparable catchments to the catchment of interest". The four regionalization methods that are used to predict discharge from ungauged catchments are;

SIMILARITY OF SPATIAL PROXIMITY: The transfer of catchment information was based on some sort of PCCs similarity between ungauged and gauged catchments. The PCCs were determined using Arc GIS integrated with Arc SWAT. Therefore, calibrated model parameter values from gauged catchments were transferred to the ungauged catchments based on PCCs similarities.

AREA RATIO METHOD: Parameter set of gauged catchments are transferred to ungauged catchments of comparable area based on the assumption that catchment area was the dominant factor for controlling the volume of water that can be generated from the rainfall.

SUB-BASIN MEAN METHOD: It represents the arithmetic mean [Kim and Kalaurachchi, 2008] of calibrated model parameters of gauged catchments to simulate the stream flow for ungauged catchments.

REGIONAL MODEL: Catchments for which flow time series are to be estimated may not have comparable gauged catchments. Thus, prohibiting extrapolation using similarity of spatial proximity. Therefore, the methods of regionalization using similarity of catchment characteristics (regional model) were applied to estimate the flow of ungauged catchments [Parajka and Bloschl, 2005].

RESULT AND DISCUSSIONS

SENSITIVE ANALYSIS OF MODEL PARAMETERS

The sensitivity analysis of model parameters was performed based on NSE and RVE using graphical plots for visualization in Arjo, Angar, Dembi and Uke sub-catchments. The most sensitive model parameters are runoff coefficient (Beta) and recession coefficient for upper zone reservoir (Khq) while a measure for the nonlinearity of the reservoir (Alfa) and recession coefficient (K4) are relatively less sensitive (see Figure 1).

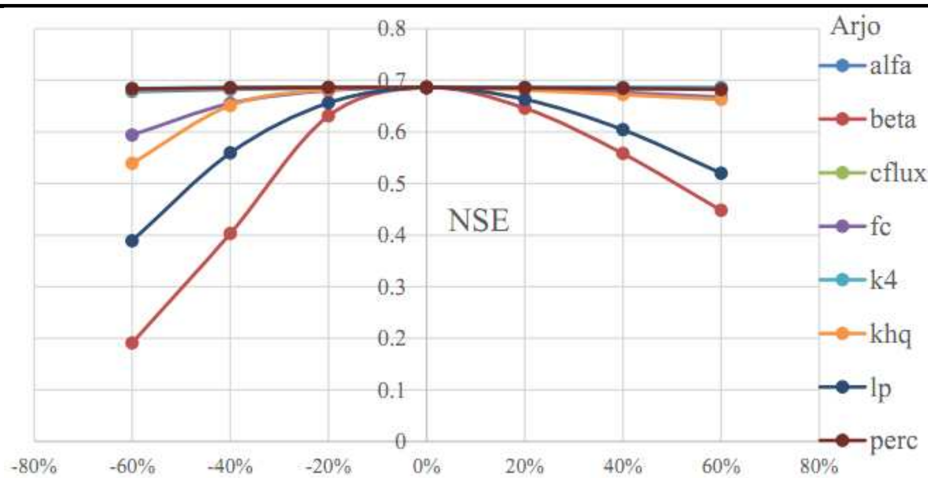

Figure 1: Sensitivity analysis results at Arjo

HBV MODEL CALIBRATION RESULTS

Model calibration result shows the model performance of Arjo, Angar, Dembi and Uke are satisfactory with NSE greater than 0.60 and RVE lies between +10% and -10%. For catchments that have relatively small area such as Tato (46 km^2), Indris (67 km^2) and Yebu (38 km^2) calibration results was not satisfactory. In such case it is possible to assume that rainfall runoff time series of those catchments, especially with smaller catchment area cannot be considered trustworthy and that model parameters of those catchments cannot used for regionalization.

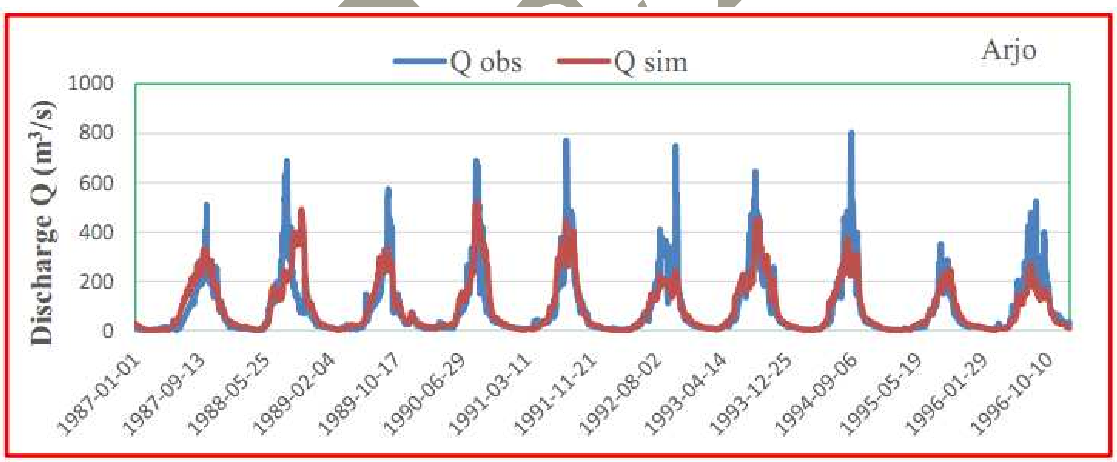

Figure 2: Comparison of observed and simulated discharge during calibration period (1987- 1996).

MODEL VALIDATION

In this study the results show the model validation done for each catchment satisfy the objective function values of calibration period.

The NSE performance of model validation of Angar, Arjo and Dembi is increasing their performance and no significance change for the Uke catchment as compared to calibration result. The overall model validation shows good performance since NSE is greater than 0.60 and RVE lies between -10% and 10%. Figure 3 shows the validation of Arjo catchments NSE of 0.76 and RVE is -1.20 %.

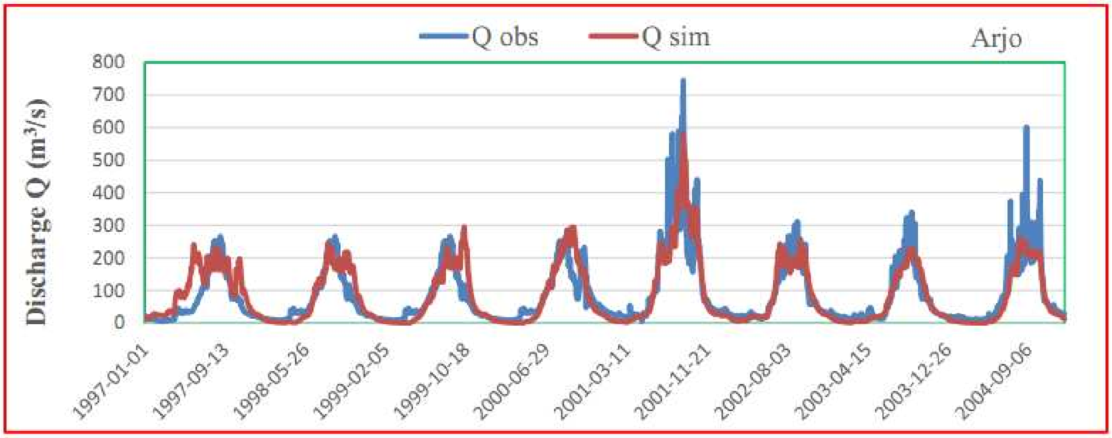

Figure 3: Graphical comparison of observed and simulated discharge from (1987-1996)

RESULT OF REGIONALIZATION

CATCHMENT SELECTION CRITERIA FOR REGIONALIZATION

Obviously, using larger number of catchments increases the reliability and the efficiency of the regional model. Based on the results of calibration Arjo, Angar, Dembi and Uke catchments are selected for regionalization since the objective function of RVE between +10% or -10% and the NSE value greater than 0.60. Therefore, these catchments MPs were used for regionalization.

RELATION OF CATCHMENT CHARACTERISTICS AND MODEL PARAMETERS

The optimized MPs and PCCs of gauged catchments were used to determine the correlations. As the result shows, the correlation coefficient r lies outside critical values of -0.90 to 0.90; the corresponding correlation is statistically significant. The simple linear regression showed that the significant correlation between MPs and PCCs found 14 out of 216 relations.

MULTIPLE LINEAR REGRESSIONS

Relations between PCCs and MPs were assessed through multiple linear regression analysis. Depending up on the R^2 ($\geq$0.90) and significance or p-value ($\leq$ 0.10 for 90% confidence interval) the PCCs were selected to establish the regression equations. For each MP eight equations were developed to determine MPs of ungauged catchments in regional model method.

DETERMINATION OF MPS FOR UNGAUGED CATCHMENTS

A total of eleven ungauged catchments representing 75.5% of the Didessa sub-basin have been selected; four of them are parts of downstream of gauging stations, three of them are catchments that failed calibration including as ungauged area and the remaining four are completely ungauged catchments. Therefore, to determine MPs of those ungauged catchments the following four regionalization methods are used:

REGIONAL MODEL METHOD:

Table 1. Model parameters estimated for ungauged catchments using regional model.

catchments	Alfa	Beta	Cflux	FC	K4	Khq	LP	Perc
Angar d/s	1.309	1.226	1.767	1255.5	0.037	0.008	0.282	0.738
Arjo d/s	1.875	0.767	1.224	875.0	0.037	0.073	0.438	0.206
Dembi d/s	1.707	2.431	1.065	1243.5	0.043	0.049	0.333	0.196
Uke d/s	1.876	1.021	0.045	240.8	0.037	0.073	0.341	0.836
Indris	1.818	0.710	0.837	163.3	0.043	0.010	0.337	0.744
Tato	1.747	0.522	0.828	158.6	0.050	0.032	0.340	0.705
Yebu	1.255	0.877	0.756	302.0	0.039	0.085	0.326	0.465
Dabana	1.178	0.775	0.454	202.2	0.037	0.125	0.332	0.663
Wama	1.845	0.820	0.943	117.9	0.045	0.079	0.550	0.258
Littlean	0.519	0.872	1.230	167.2	0.038	0.037	0.273	1.240
L.Didessa	1.120	0.999	1.837	190.7	0.037	0.112	0.278	1.438

SPATIAL PROXIMITY METHOD:

MPs of gauged catchments are transferred to the most similar sites by calculating the correlation of each gauged and ungauged catchments. Figure 4 shows the transfer of MPs from gauged to ungauged catchments.

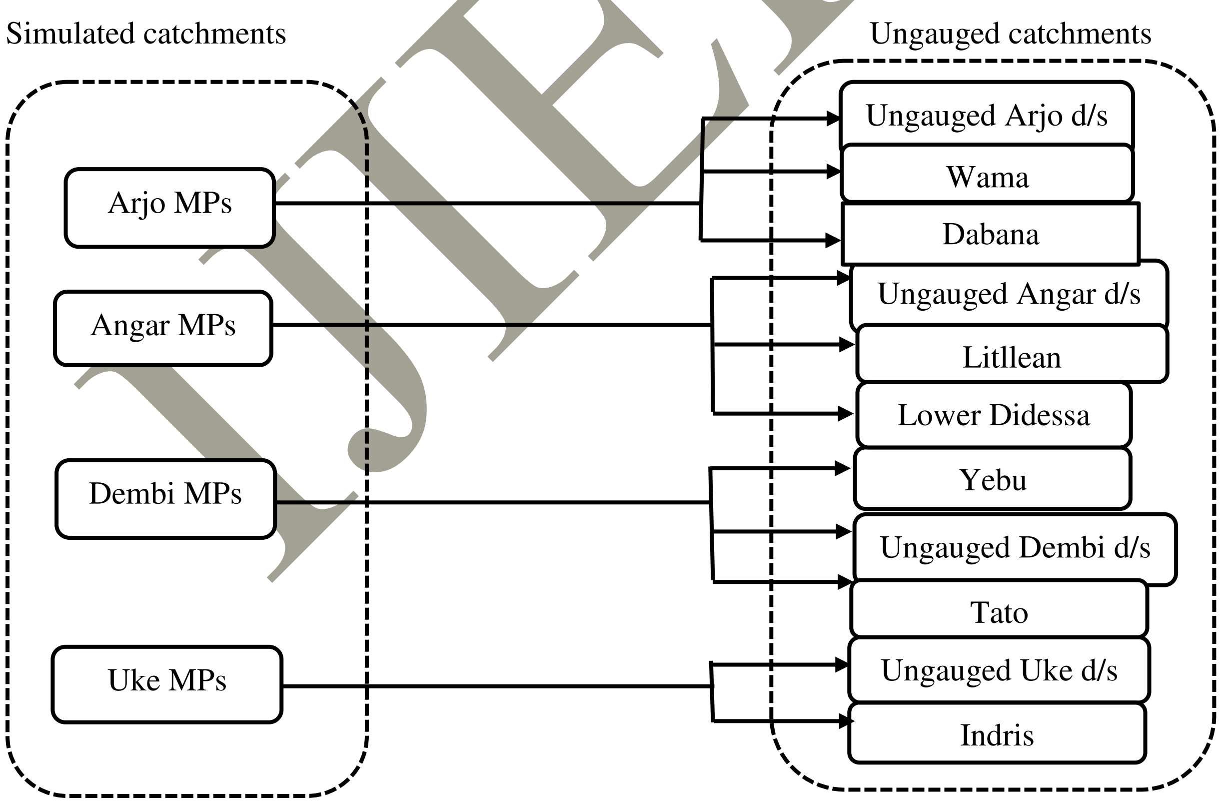

Figure 4: Model parameters transfer by spatial proximity method.

AREA RATIO METHOD (AR): As the result shows gauged Arjo MPs are not transferred to any of ungauged catchments in this study since the area ratio between Arjo and those ungauged catchments are greater than 50%. Figure 5 shows model parameter transferred from simulated catchments to ungauged catchments based on area ratio method.

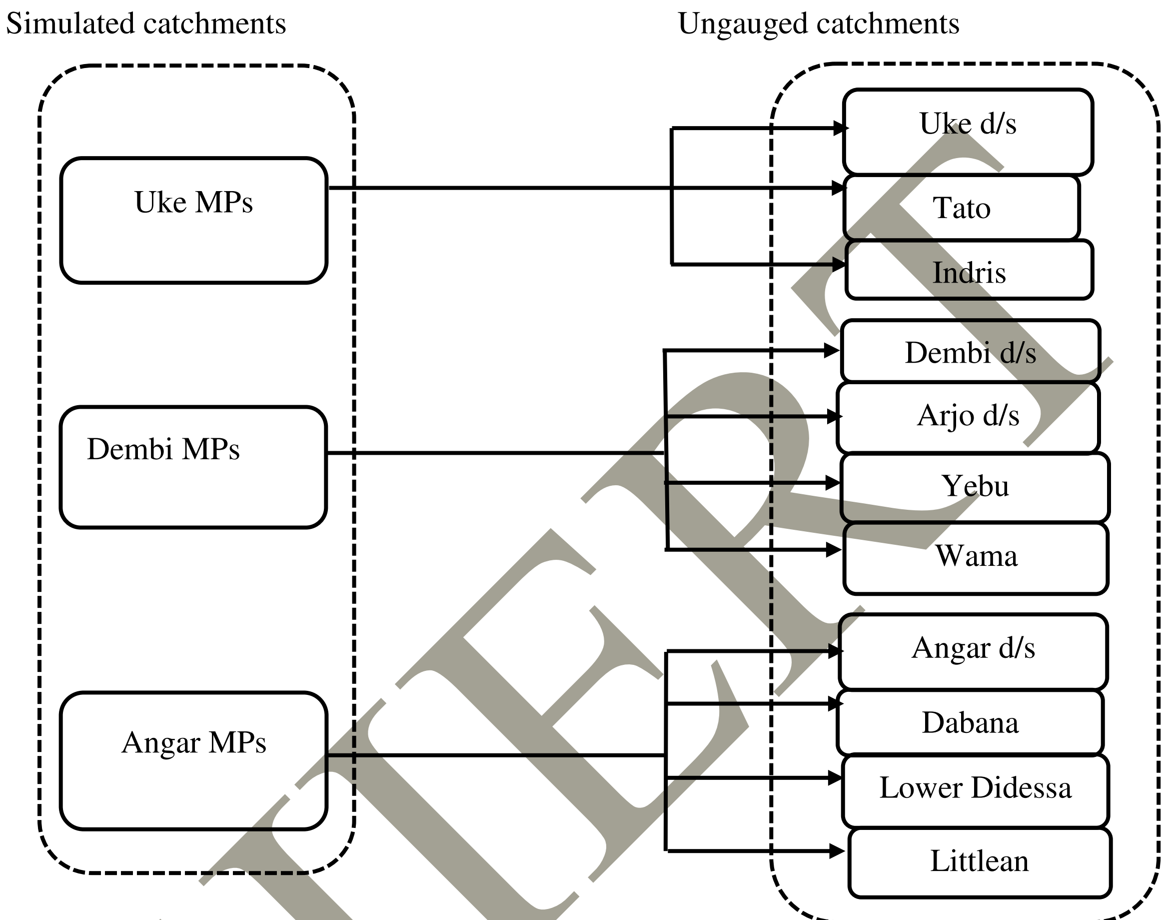

Figure 5: Model parameter transfer by area ratio method.

SUB-BASIN MEAN METHOD: The average value of gauged catchments (Dembi, Arjo, Angar and Uke) model parameters was taken for each ungauged catchments to simulate the stream flow for ungauged catchments.

SIMULATION OF DISCHARGE FOR UNGAUGED CATCHMENTS

As the result shows the simulated discharge in AR and SP are equal in ungauged Yebu catchment since some ungauged catchments were obtained their MPs from one gauged catchments (Demb). Figure 6 shows daily simulated runoff results for ungauged Dabana sub-catchments.

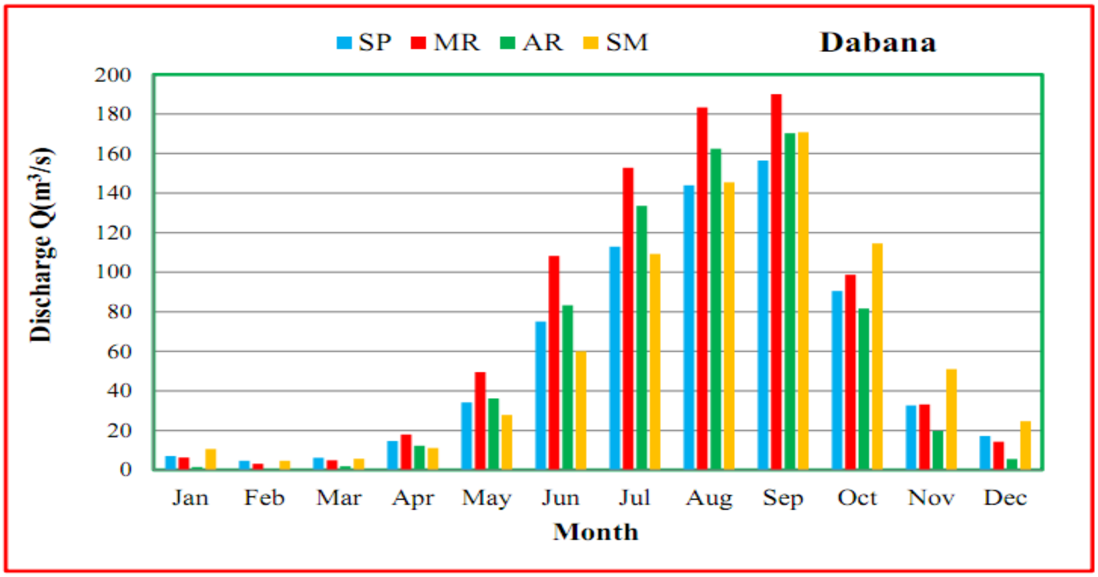

Figure 6: Comparison of daily runoff simulated for ungauged Dabana watershed (1987-1996).

COMPARISON OF FOUR REGIONALIZATION METHODS

For this study, Indris gauged catchment that are not satisfy the objective functions in calibration period are taken for comparison of regionalization methods. In spatial proximity and area ratio method, the MPs were obtained from Dembi and Uke gauged catchments respectively. Figure 7 shows comparison of four regionalization methods in Indris catchment.

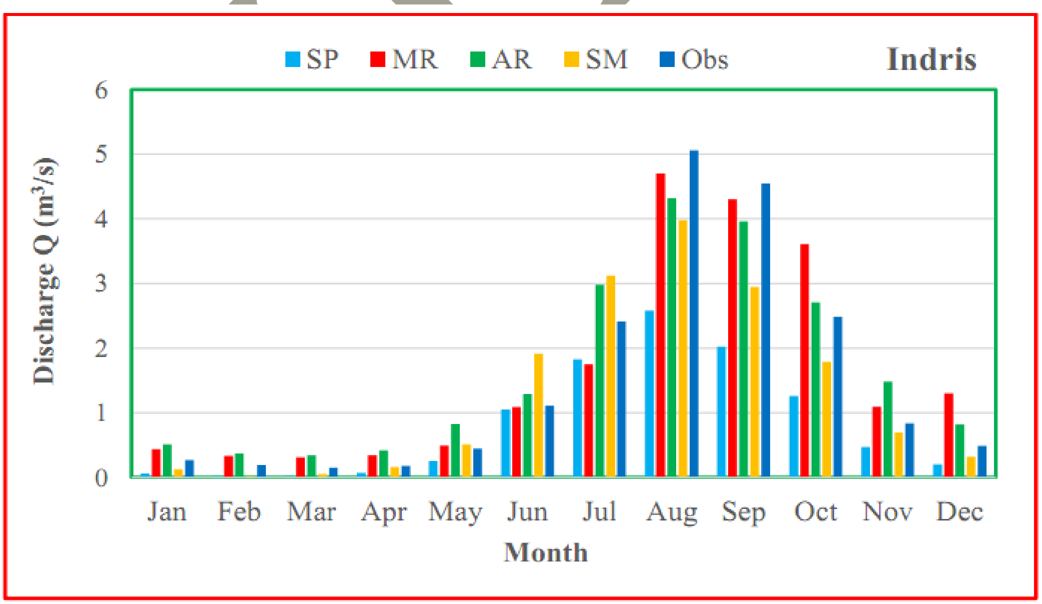

Figure 7: Comparison of daily runoff simulated by four regionalization methods (1987-1996).

SP is spatial proximity method, MR is multiple regression method, AR is area ratio method, SM is sub-basin mean method and Obs is observed discharge in indris river.

According to the regionalization result shown in (Figure 7), the runoff estimated based on MPs determined by regional model method is the best method rather than others since the MPs of ungauged catchment was derived independently from its own PCCs. Therefore, regional model method is successful in predicting discharge for ungauged catchments in Didessa sub-basin.

CONCLUSION

In this research, an attempt was made to determine model parameters required for estimating daily flow for gauged and ungauged watersheds in Didessa sub-basin. Also to develop regional model this would enable us to relate some of the model parameters to basin characteristics using regression analysis. A relationship between gauged and ungauged catchment were also made using four regionalization methods. Thus, based on the applied methodology and results obtained, the following conclusions are drawn:

In the Didessa sub-basin there are 14 gauging stations while seven of them have continuous river flow data from 1987 to 2004. From these seven gauged basins, only four of them have been simulated with a reasonable performance NSE greater than 0.60 and RVE smaller than +10% or -10% and it covers only 24.5% area of the basin.

Sensitivity analysis of HBV-96 model parameters was carried out manually by trial and error. According to the sensitivity analysis, Beta, khq, LP, and Fc were more sensitive model parameters while K4 and Alfa are relatively less sensitive.

The model was calibrated manually by changing one model parameter at a time using observed stream flow, temperature, evapotranspiration and rainfall as input from 1987 to1996 and validation 1997 to 2004 for gauged catchments. The results show catchments that have relatively small areas such as Yebu, Indris and Tato do not satisfied the objective functions. Therefore, these sub-catchments model parameters were not used for regionalization.

Model parameters estimated from ungauged catchments were simulated by HBV-96 model using four regionalization methods. As the result show the regional model method contributes the highest stream flow volume followed by sub-basin mean method while the result of spatial proximity is relatively the least.

Four regionalization methods were compared using observed discharge. According to the result, regional model method is the best method in predicting discharge for ungauged catchments.

RECOMMENDATION

It is observed that the parameters Alfa and K4 in this study do not show significant effect on the model performance. Thus, it can be kept as default value when applying the HBV-96 model to another regionalization studies.

For this study, due to availability of limited reliable gauged stream flow data only seven gauged catchments that found within the Didessa sub-basin were calibrated using HBV-96. However, four of them that have relatively large areas have best performance while three of them that have relatively small areas have poor performance. Therefore, it is recommended to use HBV-96 model for catchments that have relatively high catchment area.

For this study, due to availability of limited gauged stream flow data four gauged catchments that found within the Didessa sub-basin were calibrated using HBV-96 model. However, to establish a best performing regional model for ungauged catchments a model parameter has to be calibrated for more gauged catchments. Therefore, for next study it is recommended to use more gauged catchments.

In various cases, Ethiopia has a wide range of rainfall distributions in space and time. However, available rainfall stations were not well distributed to represent these rainfall events. As such, the use of remote sensing data to estimate areal rainfall should be further explored.

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