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Performance Assessment of the IHACRES Model in the Upper Catchment of Dawa Sub-basin, Borna Rangeland, Ethiopia

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Abstract: This paper is focused on the applicability of IHACRES model in areas were hydraulic data are the limitation factor. For the existence and development of society, water resources are essential renewable natural resources. Long term stresses such as land use/land cover change and climate change have an effect on hydrologic systems. Widespread land use changes have often been associated with changes in the local hydrology as hydrologic responses of a catchment are influenced by land cover. Proper utilization of these resources requires assessment and management of the quantity and quality of the water resources both spatially and temporally. In order to establish the rainfall-runoff relationships, hydrological models from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations have been used over the entire world in different circumstance. The purpose of this paper is to evaluate the performance of IHACRES in the upper catchment of the Dawa sub basin in southern Ethiopia.

Keywords: IHACRES, Borana, Hydrological Model

1. Introduction

For the existence and development of society, water resources are essential renewable natural resources. Long term stresses such as land use/land cover change and climate change have an effect on hydrologic systems. Widespread land use changes have often been associated with changes in the local hydrology as hydrologic responses of a catchment are influenced by land cover. Significant changes in evapo-transpiration, leaf area index, soil moisture content, infiltration rates, (sub-) surface flow regimes, surface roughness, surface runoff, and soil erosion may arise as a result of changes in land cover through interactions with vegetation, topography, soils, geology and climate processes Nejadhashemi et al. [7].

For water resources to be successfully managed, the qualitative analysis of the effect of land use practice and changes in climate conditions of an area on stream flow and water quality is essential. Rainfall after rainfall-runoff processes yields surface water in the form of lake and river discharge (runoff). Long runoff series enables to make a decision, design and control of water resource system in a given area. On the other hand, for flood control and reservoir regulation in the future, flows shall be forecasted with rainfall runoff models. A number of rainfall runoff models exist for generation of flow, forecasting and other purposes.

In order to establish the rainfall-runoff relationships, hydrological models from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations have been used over the entire world in different circumstances. As the computing capability of those models increasing the results in their simulating of the catchment become standard. Various areas of water resource development, assessing the available resources, studying the impact of human interference in an area such as land use change, deforestation and other hydraulic structure like dams and reservoirs require the utilization of models Moreda [6] the main objectives of this study was to analyze the performance of a conceptual rainfall-runoff model (IHACRES) in the upper catchment of the Dawa sub basin in southern Ethiopia, to increase the long runoff (stream flow) data availability in the rangeland for future water resource management as the scarcity of data is an issue in the area and to determine the effect of different data sources on prediction capability of the IHACRES conceptual model.

2. Materials and Methods

2.1. Study Area

The Dawa River headwaters are located in the Sidama Mountains along which the Western catchment boundary diminishes gradually in elevation to around 1500m in a Southerly direction. The major tributaries are Awata, Mormora and Kilkile. These tributaries converge at around elevation 800m upstream of the main river gauging station at Melka Guba. In its lower reaches, the Dawa River receives water from a sizeable area draining Ken territory, and along the final reach the river marks the National border with Somalia.

The region has a semi-arid savannah landscape, marked by gently sloping lowlands and flood plains vegetated predominantly with grass and bush land. The geology is composed of a crystalline basement with overlying sedimentary and volcanic deposits. People are predominantly involved in small-scale subsistence agriculture production and mainly on livestock husbandry.

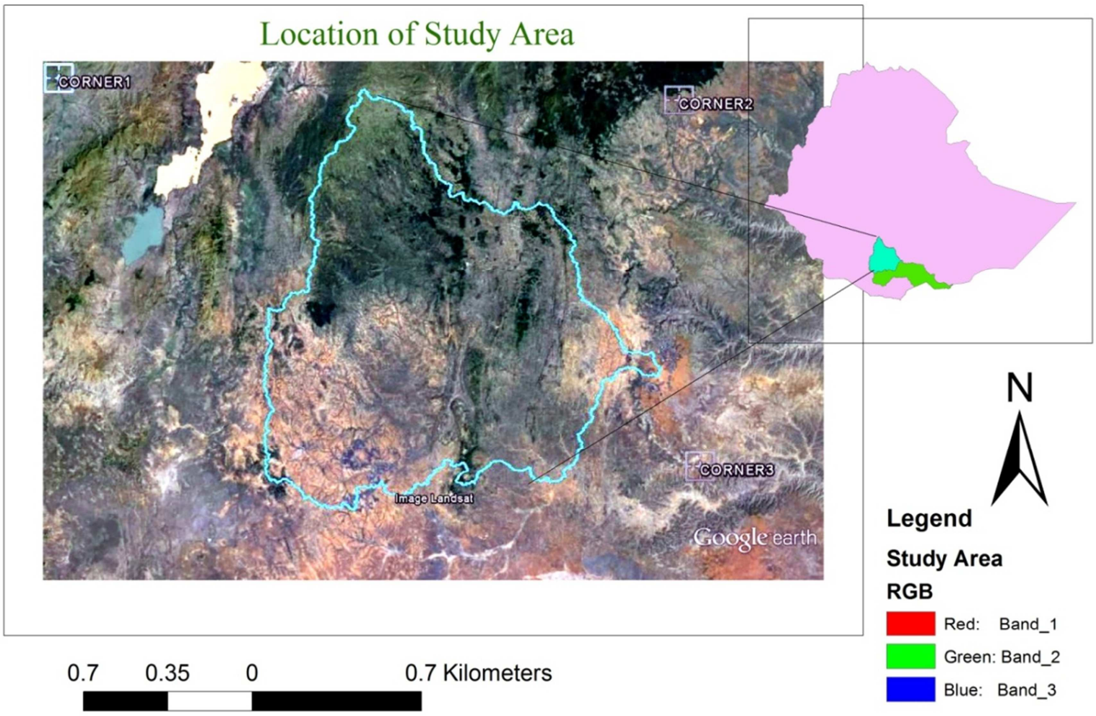

Figure 1. *Location of study area.*

2.2. Methods

2.2.1. Data Requirement IHACRES Rainfall-Runoff Model

The IHACRES model minimum data required is daily bases rainfall, temperature and stream discharge. According to Wheater *et al*. [9], rainfall-runoff models fall into several categories: metric, conceptual and physics-based models. To characterize the response of a catchment, Metric models using observed data (rainfall and stream flow) and are typically the simplest ones. Depending on the structure of the model, Conceptual models impose a more complex representation of the internal processes involved in determining catchment response, and can have a range of complexity. Physics-based models involve numerical solution of the relevant equations of motion.

2.2.2. Model Selection

Selection of models depends on the availability of data and issue to be addressed. IHACRES model which is the hybrid of conceptual- metric model reduce the parameter uncertainty in hydrological models due to it is metric model, at the same time internal process is detail represented as since it is conceptual model.

2.2.3. Model Calibration

In order to evaluate the performance of rainfall runoff models the choice of appropriate parameters on calibration data set is essential since it affects the output dramatically. Among objective functions that are added in the IHACRES the Nash- Sutcliffe efficiency indicator is used to assess the model performance.

$$R^2 = 1 - \frac{\sum_i (Q_{o,i} - Q_{m,i})^2}{\sum_i (Q_{o,i} - Q_{av})^2} \quad (1)$$

Where Q_{av} is average of observed flow the observed flow Q_o, and modeled flow Q_m which are represented in the model as square root (R2_sqrt), logarithm (R2_log) and inverse

(R2_inv) of the flow objective functions which are less biased to peak flow, and more to low flows. In the catchments of arid and semi arid the objective function R2_sqrt is help full in interpretation of calibration as the occurrence of base flow component is rare in those catchments. Generally the value for R^2 greater than five is indicate the performance of the model is acceptable (Santhi et al, [8]

2.2.4. The Application of IHACRES to Upper Catchment of Dawa Sub-basin

i. Data preparation

One of the limiting factors to use hydrological model in arid and semi arid areas like in a case of Borana lowland is the availability of continues measured or observed data. In this study from four stations in the catchment daily time step data of precipitation and maximum temperature as well as observed stream flow at Melka Guba gauging station were used from Ethiopian meteorology agency and Ministry of water and energy. The other source of data is Climate Forecast System Reanalysis (CFSR) from global meteorological data set.

The measured data of precipitation and temperature was collected from Yabello, Hageremariyam, Bore and Negelle stations as shown in (Fig. 8) below while the fifth station MelkaGuba is the gauging station for stream flow.

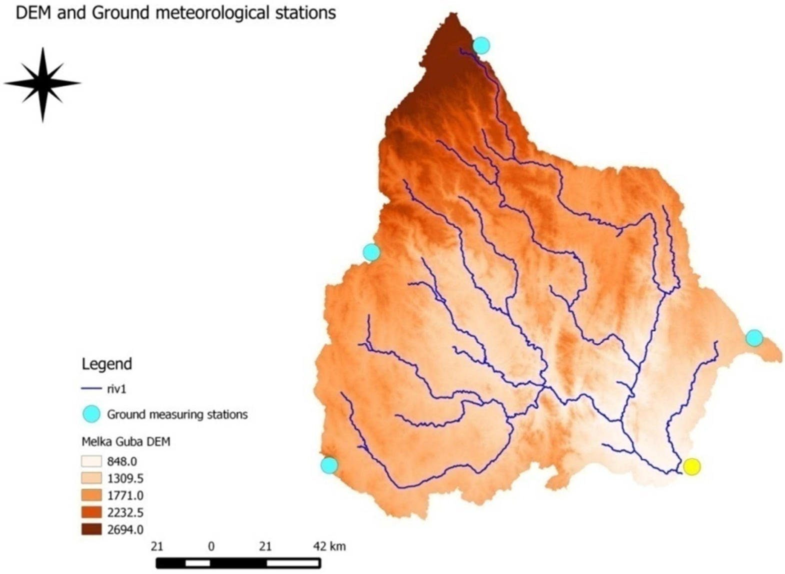

Figure 2. *Map of ground meteorological measuring station.*

The CFSR (Climate Forecast System Reanalysis) data from global meteorological data set was acquired from Internet. (http://globalweather.tamu.edu/home) [11] and the map in (Fig. 3) below shows the most center grid stations prepared using ArcGIS 9.3 software (Szent Istvan University).

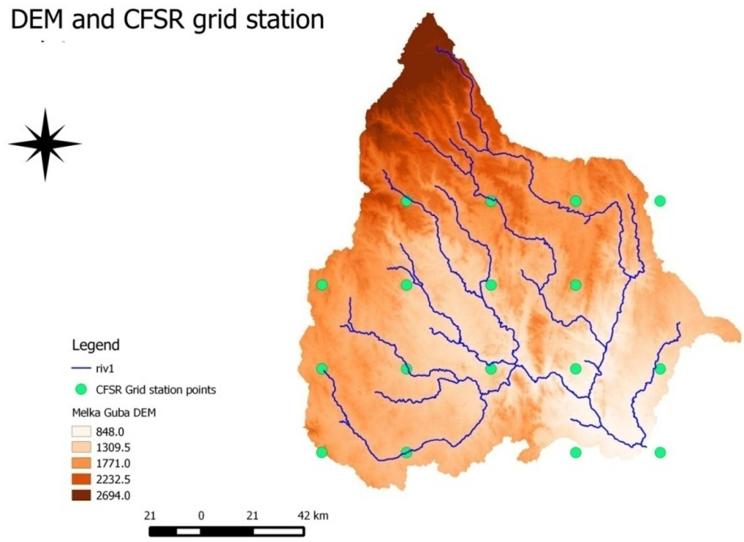

Figure 3. *Grid station location map in the catchment.*

The Melka Guba gauging station had catchment contributing area of 19611 km^2. In order to have smaller catchment area Melka Guba gauging station for stream flow, ArcGIS 9.3 was used as the total sub basin area is partitioned in other smaller sub watersheds or tributaries. Since the data for the four stations must be average the years that had less missing data were selected and interpolated using excel linear interpolation method. The data extended between January 1, 1995 and December 31, 2004 as year for simulation was selected.

ii. Model calibration

Daily time step data from January 1, 1997 to December 31, 2001 was used as calibrating time. Depending on the cross correlation function from the IHACRES model and the nature of catchment (highly ephemeral) delay time was adjusted since it improves the model performance. Five classic module parameters are corrected their values in such as way that to get better values in R^2, R2_sqrt etc after calibration.

3. Result and Discussion

In hydrological studies watersheds or catchment areas that are contributing flow to the outlet must be determine. Hence watershed areas, drainage networks and flow accumulation can be obtained using GIS (Geographic Information system) environment from DEM processing. For the upper catchment of Dawa sub-basin 44 watersheds with different area sizes were produced depending on the outlet (pour) point at Melka Guba station. From those sub-watersheds, small watershed on the Malka Guba station with an area of 1453.5km^2 was selected in order to run the IHACRES.

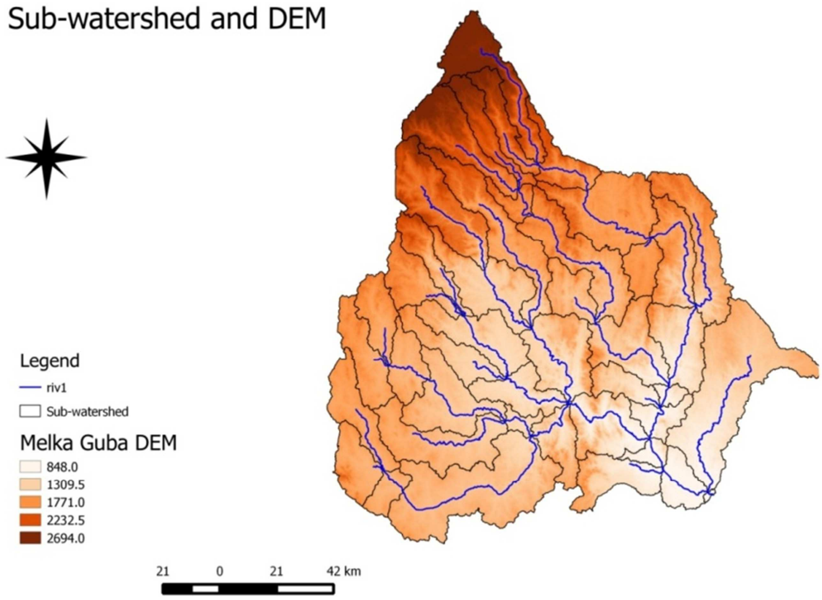

Figure 1. *Drainage network and sub watersheds contributing flow for MalkaGuba station.*

After running the IHACRES model the results expressed in relation to Nash- Sutcliffe efficiency indicator (R^2) which are represented in the model as square root (R2_sqrt), logarithm (R2_log) and inverse (R2_inv) of the flow objective functions. Those objective functions are the result if uncertainty analysis between the measured and observed data.

The objective function values R^2 = 0.550, R2_sqrt = 0.586, R2_log = 0.608 and R2_inv = 0.604 for calibrated years and for the rest of data R^2 = 0.594, R2_sqrt = 0658, R2_log = 0.687 and R2_inv = 0.696 was obtained from measured gauging station data. From the data CFSR global weather data R^2 = 0.432, R2_sqrt = 0.591, R2_log = 0.661and R2_inv = 0.675 for calibrated year and R^2 = 0.432, R2_sqrt = 0.592, R2_log = 0.662and R2_inv = 0.678 was obtained from the analysis. The model fit statistics and the fitted parameter values for the non linear module and linear parameters are shown in Table 1.

Table 1. *Calibration parameters and results.*

Parameter	Measured data	CFSR global weather data
mass balance term (c)	0.0003545	0.000073
dry rate at reference temperature (tw)	587	587
temperature dependence of drying rate (f)	2.7	4
reference temperature (tref)	20	20
moisture threshold for producing flow (l)	100	0
power on soil moisture (p)	1	1
Recession rate (α)	-0.945	-0.964
volume proportion (v)	1	1
R^2	0.594	0.432

Analysis of the statistics for individual years (four out of ten) with the flow data perform poorly with a negative R^2 values for the drier years with the peak flow. This resulted from lack of base flow component of the catchment.

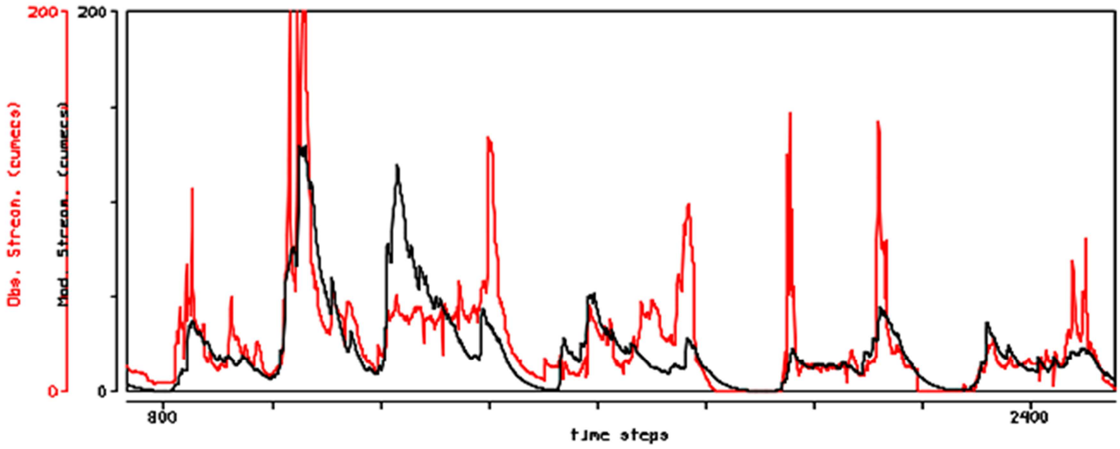

Figure 5. *Calibrated hydrograph for year 1997-2001 for measured data.*

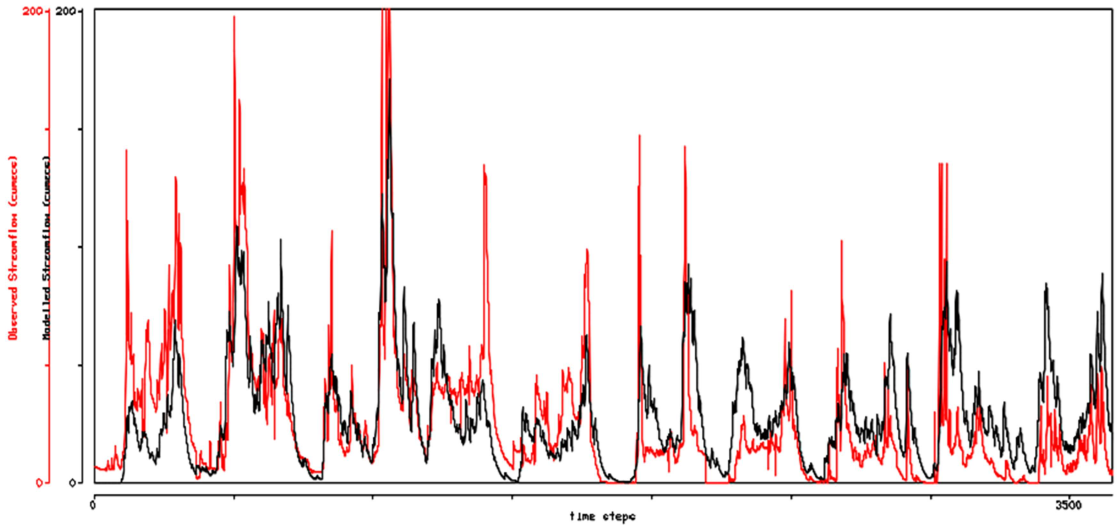

Figure 2. *Simulated hydrograph for measured data (1995-2004).*

The trained of base flow during calibration and simulation period reproduced in acceptable manner for both data sources (measured and CFSR global weather data sets) while the peak flow is under estimated by the model. The main reasons may express as the nature of rainfall, the catchment area for the gauging station and the IHACRES model deficiency in prediction peak flow.

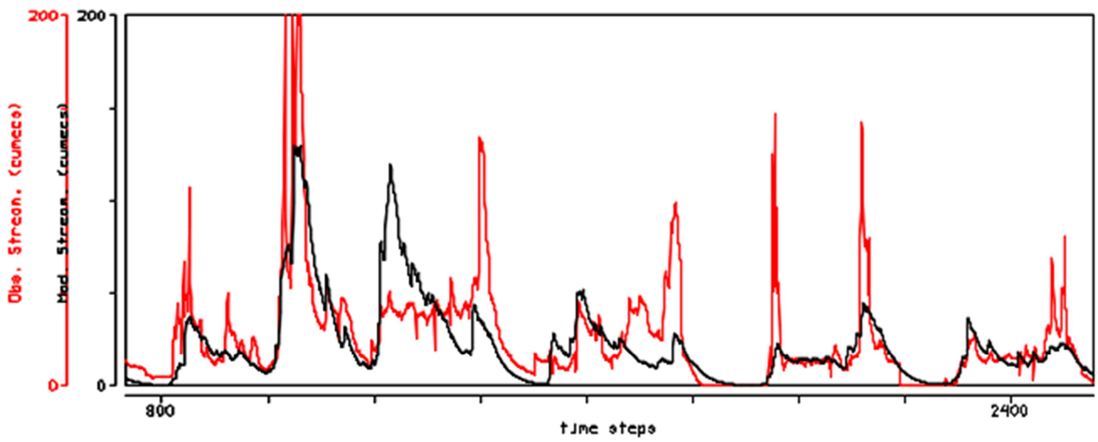

Figure 3. *Calibrated hydrograph for CFSR data (1997-2001).*

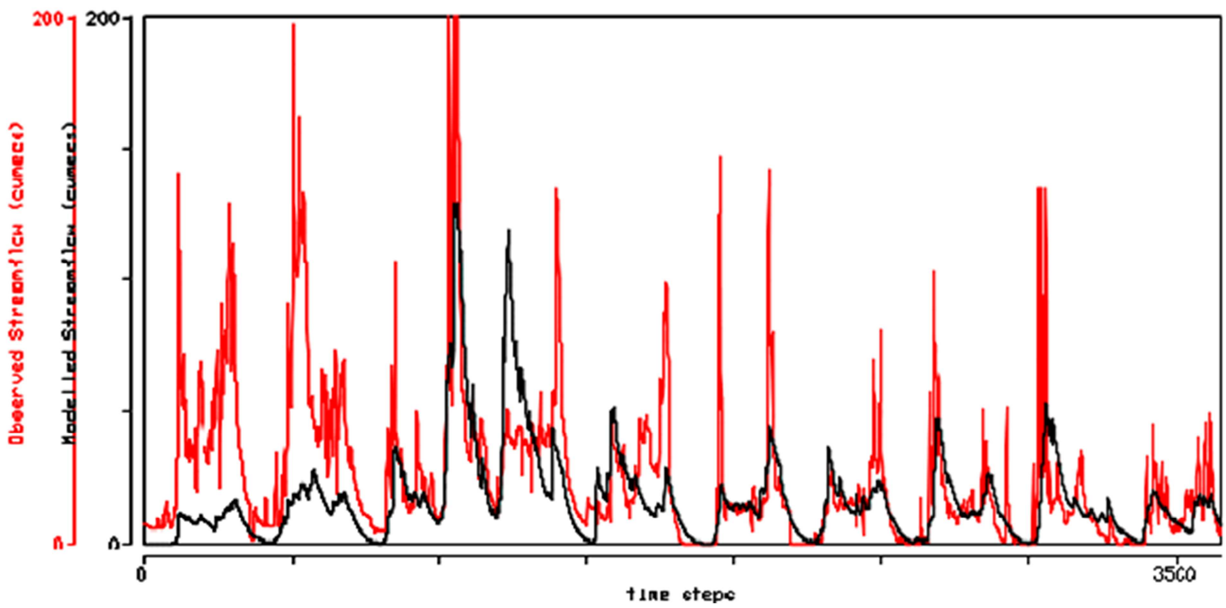

Figure 8. *Simulated hydrograph for CFSR data (1995-2004).*

The difference between the modeled and observed flow is highly noticeable for quick flow peaks. Large values for objective functions R2_log and R2_inv ≈ 7 is the evidence that the model have quite representing the slow flow component in the catchment using both measured and CFSR data sources. For underestimation of quick flow may not be only the performance of the model but also that the attribute catchment is large and had only one gauge station for observed stream flow data.

4. Conclusion and Recommendation

As the result of the study the following conclusions are listed below

- IHACRES have a potential to generate useful information on prediction of stream flow using measured (observed) data for arid and semi arid catchments in Ethiopia
- The performance using CFSR global weather data set is less than that of observed values but in areas where the data source is an issue, it can produce preliminary data for watershed and water resource managers since the value for testing performance NES (R^2) is near to five.
- It is important that to have large enough data set to use IHACRES model to predict stream flow for better performance.
- Lack of gauging station numbers in the sub basin also can be a factor in reducing model performance
- Comparing with physically based hydrological models (e.g. SWAT) the amount of data required and time to analysis, IHACRES is much faster and less data utilization to produce necessary information.
- Generally, conceptual models like IHACRES are essential in water resource management of areas where limitation in availability data is observed since the model is perform enough to produce vital source of information.

Recommendation

- It is important that the number of stations for measured data should be increased in as much as possible in the range land since the area is larger and for further study to provide information and knowledge in hydrology.
- Other models must be studied their performance in their applicability in such a way that to preserve historical data in the basin for coming generation.

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