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Applicabilty of Trmm Precipitation for Hydrological Modeling Using Hec-Hms in Karnali River Basin in Nepal

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Abstract

This study aims to validate the HEC-HMS model in the Karnali river basin of Nepal, while also physically verifying the model parameters for the area. The HEC-HMS model is a semi-distributed physically based model that requires site-specific information about the weather, as well as spatial information on soil and land use. Using Arc-GIS, HEC-HMS, and HEC DSS, a hydrological rainfall runoff model was developed for the Karnali River basin at Asaraghat (DHM station 240) for the period of 1998-2005. Calibration for the time period of 1998-2001 resulted in an NSE value of 73.2% and an R2 value of 84%. Validation for the time period of 2003-2005 resulted in an NSE value of 72.4% and an R2 value of 82.02%. To evaluate the performance of the TRMM 3B42V7 rainfall product, statistical indicators such as NSE and R2 were used. Results showed that the TRMM rainfall data was reliable and had good precision in application to the Karnali River Basin. This study concludes that the TRMM rainfall data can be used as an alternative data source for basins with sparse rain gauge stations in Nepal. The results also suggest that the HEC-HMS modeling tool is good enough to relate rainfall and runoff. The model parameters for each sub-basin and reaches were analyzed with the physical characteristics of the watershed. Minor variations were found within calibrated and calculated Initial abstraction and Muskingum K, x, leading to the verification of the model parameters physically.

Keywords: *HEC-HMS, karnali river basin, hydrological model, model parameters, TRMM rainfall data*

1. Introduction

Nepal consists of large number of river networks distributed all over the country, some of which originates from China or India. Most of the rivers are snow fed and even includes arid rain-shadowed zone of Nepal and China. It is common for river basins to have difference in yearly rainfall and flow pattern. In addition, large variation in terrain, land use and soil-type within small extent is also commonly observed within the catchment. The Hydrologic Modeling System (HEC-HMS) is intended to recreate the total hydrologic procedures of dendritic watershed frameworks. The product incorporates numerous customary hydrologic examination methodology, for example, event infiltration, unit hydrographs, and hydrologic routing.

Research work performed as per the partial fulfillment requirement of Master's Degree is aimed for assessment of HEC-HMS model in Karnali watershed of Nepal River basin with detailed study in selected gauge point of Karnali basin analyzing response characteristics. Various hydro meteorological and topographical factors which effect the area of Karnali basin in Nepal and China are studied in detail. Numerous parameters are fixed for basin and their relationship with intra basin characteristics are analyzed. The estimated parameters are the then verified physically. TRMM 3B42 V7 precipitation data were used in HEC-HMS model.

2. Literature Review

Water is pretty much continually moving and changing from one state then onto the next (solid, liquid, or vapor/gas) while associating with the physical procedures present in the environment, lithosphere, and biosphere. These progressions and development of water are connected together in the hydrologic cycle. The hydrologic cycle involves many processes which includes precipitation, evaporation, snowmelt, infiltration, runoff and other processes in the hydrologic cycle. These processes continue forever and thereby a balance is maintained between them and is known as hydrological cycle. To sum up the procedures, short description is introduced and outlined in Figure 1.

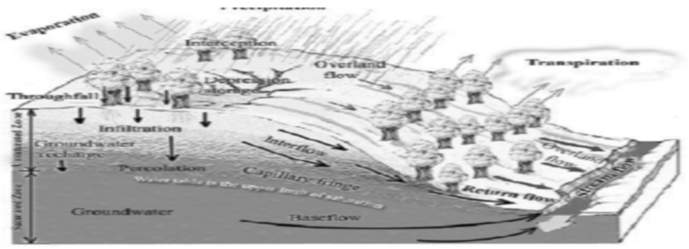

Figure 1: Physical processes involved in Runoff Generation (Source: Torbotoon, 2003)

Precipitation is considered as a fundamental procedure for generation of runoff at a catchment scale. It very well may be in the form of snow, hail, dew, rain and fog. In this reading precipitation is considered as downpour. As downpour falls on the Earth, it moves within a catchment in various ways. Some part of precipitation is blocked by vegetation, some is penetrated down to the earth and remaining streams to the channel as stream flow. The precipitation on the vegetation descends the vegetation as stem stream, dribbles off the leaves, or straightforwardly tumbles to the ground as through fall. Remaining precipitation stays at the land surface as depression storage and either evaporates, infiltrates or is released as overland stream.

The penetrated water moves principally descending way by unsaturated subsurface flow and recharges the saturated zone. This procedure is named as percolation .The infiltrated groundwater is impacted by the catchment characteristics, particularly the geological components of the catchment, before being released to the channel network system. Aquifers of the groundwater system likewise release groundwater over the catchment boundary and lastly add to stream flow.

'Hydrologic Engineering Centre - Hydrologic Modeling System' (HEC-HMS) is new –age programming for rainfall - runoff simulation. HEC-HMS, a continuator of model HEC-1 as far as both software and hydrologic engineering. It involves a graphical user 20 interface (GUI), hydrologic analysis parts, information stockpiling and management capacities.

HEC-HMS is intended to simulate the rainfall-runoff procedure of dendritic watershed framework. It is intended to be pertinent with wide scope of geographic region. HEC-HMS is helpful to complete the investigation with respect to drainage in urban area, stream determining, future impacts of urbanization (HEC-HMS, 2010). This model has been used to carry out the impact study of imperviousness. Although this model is extensively used for flood hydrology, it has also been used to carry out the study regarding the future urbanization impact.

TRMM is a joint mission between National Aeronautics and Space Administration (NASA) of USA and National Space Development Agency (NASDA) (now merged into Japan Aerospace Exploring Agency (JAEA)) of Japan. The satellite estimates rainfall and energy exchange on tropical and subtropical regions of the world based on the characteristics of cloud tops, cloud cover and temperature. TRMM satellite data are available with different levels of calibration and resolution. Among them, TRMM 3B42 version 7 has been used for the study as this product has high temporal resolution and is calibrated and produced after different levels of processing.

3 Methodology

3.1 Study Area

Karnali Basin is situated in Western Region of Nepal which originates from the south of Mansarovar and Rokas lakes situated in China and enter Nepal close to Khojarnath streaming southern way. Drainage region in China is 3155 km^2 in approximate and at Asaraghat (DHM St No 240), it is 20857 km^2. In this way the absolute drainage area is around 20857 km^2.Compared with other rivers, Karnali valley is steep and limited in narrow gorges aside from Jaksi Ghat to Sundargaon reach at where it swells to around 800 m width. The stream network and basin study territory is shown in figure 2 and 3 below.

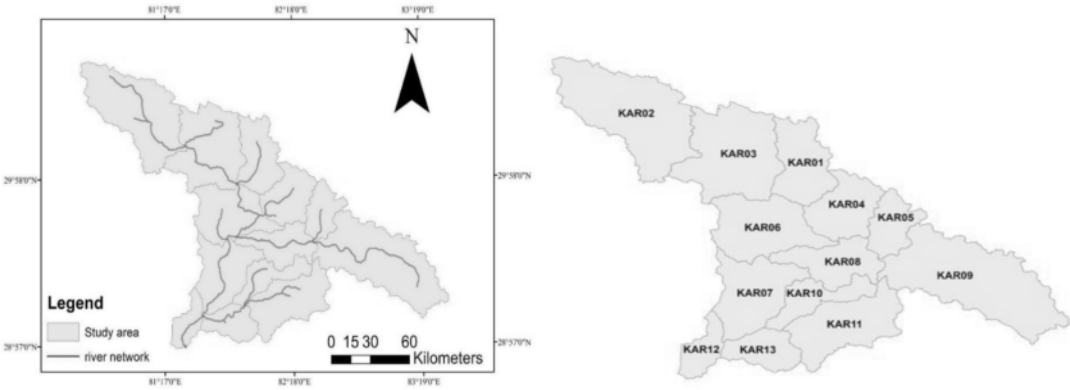

Figure 2: River network and sub basin

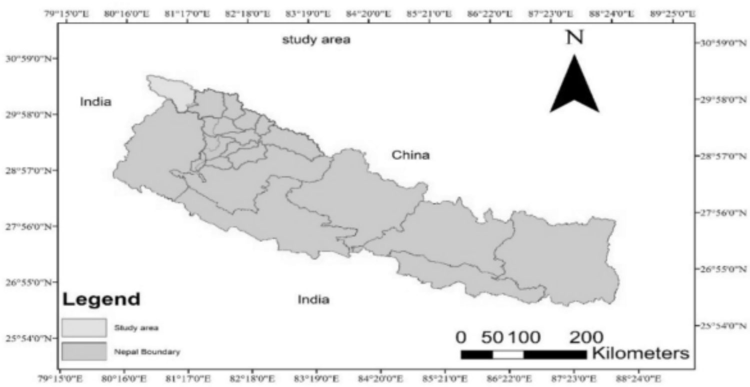

Figure 0: Study Area

3.2 Data acquisition

Digital Elevation Model (DEM) depicts the rise of any point in computerized position (digital format). It contains data on drainage, peak and discontinuities of slopes. DEM is essential spatial information source dependent on which GEOHMS extricate catchment limit, geological factors, for example, basin geometry, river networks, slope, aspect, flow direction and so on.

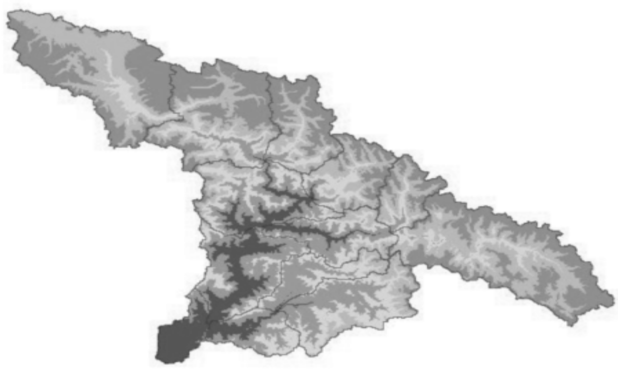

Figure 0: DEM of the study area

30m resolution DEM of whole Nepal was downloaded from SRTM, U.S.A. For Karnali basin DEM was clipped. River and watershed delineation was done with the help of HEC-GeoHMS. Tools of Terrain processing were also used for delineation of drainage areas utilizing the data of terrain. Tools for watershed processing were utilized for calculation of area, centroids and also longest flow paths of watersheds.

Soil and land use information are utilized to characterize the land surface attributes. ArcGIS gives tool to ascertain the physical boundaries required for the model simulation. Soil Data was downloaded from ISRIC website and Land use map information were extracted from the accessible land cover of Nepal, 2010 by ICIMOD in the digital format. They are used to assume the parameters for runoff generation mechanism in the watershed. Soil map was utilized to contemplate the infiltration attributes and land use maps were utilized to consider land use patterns and imperviousness, which are important parameters of Modified Universal Soil Loss Equation.

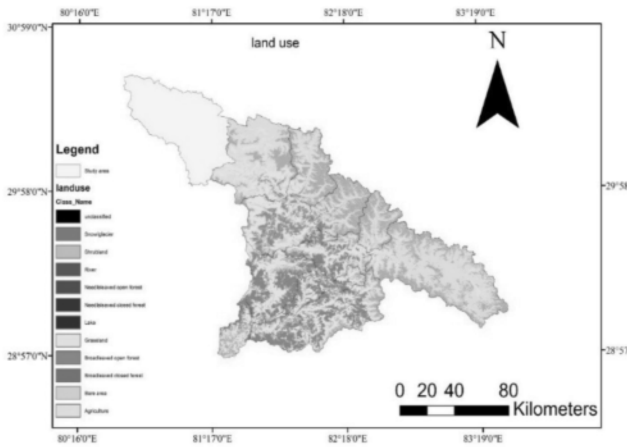

Figure 5: Land use map of study area

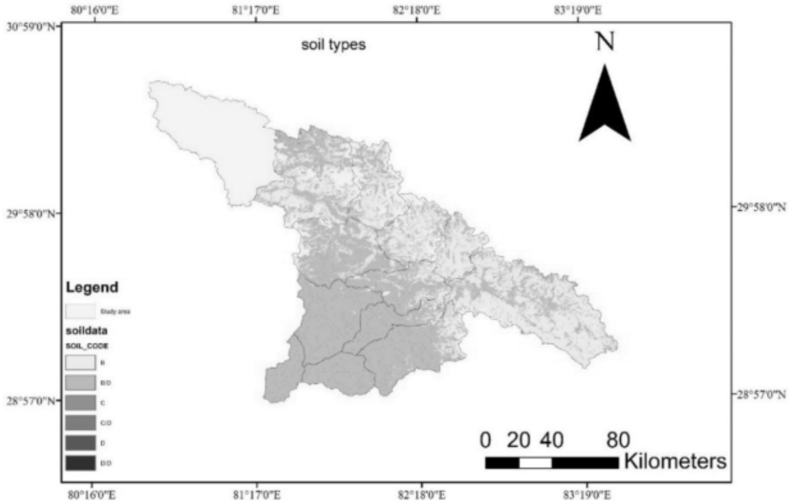

Figure 6: Soil Map of study area

The hydrological data are essential for calibration and validation of model. For this study, day to day discharge data of Station No. 240 i.e. Asaraghat station is used. The observed discharge data from 1st January1998to 31st December 2001 is used for calibration whereas from 2003-2005 is used for validation. The hydrological data are obtained from Department of Hydrology and Meteorology (DHM).

Table 1: Hydrological station

S. No.	Station No.	Location	River	Latitude	Longitude	Data Used
1	240	Asaraghat	Karnali	29̇57' 10	81̇26' 30"	1998-2005

The precipitation data are used as model input in HECHMS to simulate catchment response. For this study, TRMM 3B42V7 day to day rainfall data were used. Daily rainfall data from the 1st January 1998 to 31st December 2008 was downloaded from pmm.nasa.gov/data-access/download/trmm. The data were acquired in NetCDF format. NetCDF is an interface for logical information get to that actualizes a machine autonomous, self-portraying, extendible file format.

DHM daily precipitation and Global Data (swat) were also used in our study for comparing the acquired data i.e TRMM 3B42V7.

3.3 Comparison of TRMM 3B42V7 Data with DHM and Global Data

Further strategies were undertaken for comparing the datasets on annual monthly and daily basis. TRMM 3B42 Data were compared with DHM data and Global data for a period of 11 yrs. i.e. 1998-2008. Comparison is shown in following table and presented in figure as well.

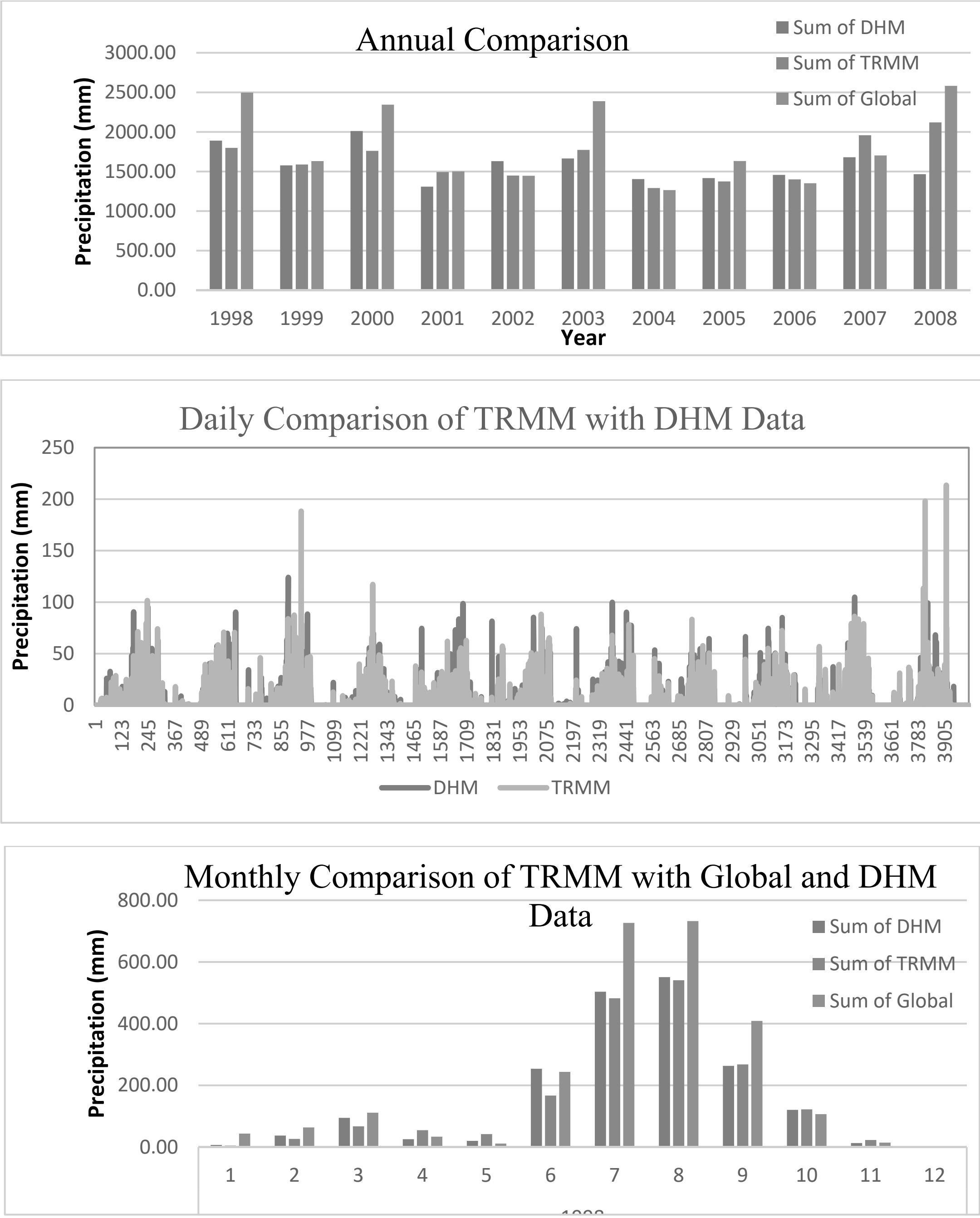

Figure 7: Comparison of TRMM Data with DHM data and Global Data

Comparison shows that the grid base TRMM precipitation grid data after transferred to the point data on precipitation stations of DHM resembled with the observed data of DHM. After this satisfactory result from the comparison, centroid of each sub basin (i.e. 13 sub-basins) were found using ARC-GIS and the gridded data were transferred to each sub- basin centroid directly and given as input in HEC-HMS.

3.4 Basin Model

Basin model generated by HEC-Geo HMS is imported into HEC-HMS. Basin model consist of hydrologic network that contains HEC-HMS model elements and their connectivity. This process creates a HMS Link layer, which shows the connectivity, and the HMS Node layer, which shows sub basin and junction node locations. Node locations for sub basins are placed at the center of the sub basin.

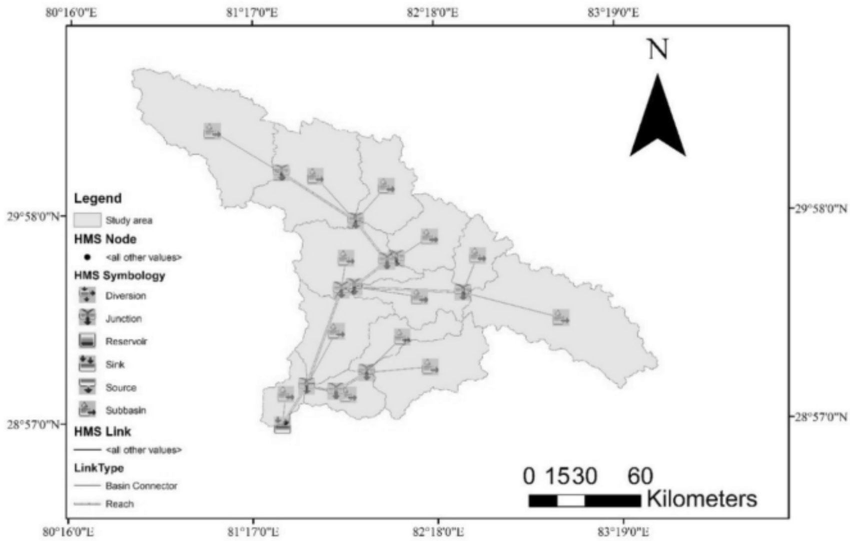

Figure 8: Basin Model in HEC-HMS

3.5 Calibration and Validation of HEC-HMS model

Calibration uses observed hydro-meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search often is referred to as optimization. Year 1998-2001 is selected as calibration period.

Validation of model determines the applicability of the model with calibrated parameters to simulate the runoff for a time period other than the calibration period. It is just the comparison of simulated and observed runoff for selected time period. Year 2003-2005 is selected as validation period. Unless the model is satisfactorily validated, the calibration process is repeated to find new parameter values.

3.6 Quantitative approach of Model evaluation

The quantitative approach comprises of Nash Efficiency and volume deviation, which can do the quantitative justification of the calibration and validation. The Nash - Sutcliffe efficiency (NSE, 1970) criteria is given as

$$Efficiency = 1 - \left[\frac{\sum_1^n (Q_{obs} - Q_{sim})^2}{\sum_1^n \left(Q_{obs} - Q_{avg})^2\right)}\right]$$

Where, Q_{obs}, Q_{sim} and Q_{avg} are the observed, simulated and observed mean daily flow over the n day period respectively.

Similarly, the volume deviation is given as

$$D_v(\%) = \frac{(V_{obs} - V_{sim})}{V_{obs}} \times 100$$

Where, V_{obs} and V_{sim} are the observed and calculated volume of annual runoff respectively.

In addition to Nash- Sutcliffe efficiency and volume deviation, coefficient of determination (R^2 -value) is also determined. It is the square of coefficient of correlation and is a more convenient and useful way for interpreting the dependence between the variables. It gives the percent of variation explained by one variable on other.

If the predicted and observed values are equal, then NSE, Dv and R2-value produces the optimal value of 1, 0 and 1.

4. Results and Discussions

4.1 Flow Calibration

The calibration of the simulated discharge with the daily-observed value was done for the period of Jan 1998 to Dec 2001 at Asaraghat gauge point of Karnali basin. The analysis of simulated result and observed flow data comparison was considered on daily basis. The summary of flow calibration results for Asaraghat gauge point of Karnali basin is presented in table. The observed and simulated daily flow hydrographs and correlation between observed and simulated discharge for calibration period is shown in figures below

Table 2: Flow Calibration Results at Asaraghat Outlets

Outlet	**Cumulative volume (10^6m^3)**		**Average Flow (m^3/s)**		**Model efficiency**			**Run Period**
Asaraghat	Observed	Simulated	Observed	Simulated	NSE	R^2	PBIAS	1998-2001
	64340.91	52639.04	509.8	444.17	73.20%	0.84	18.18%	

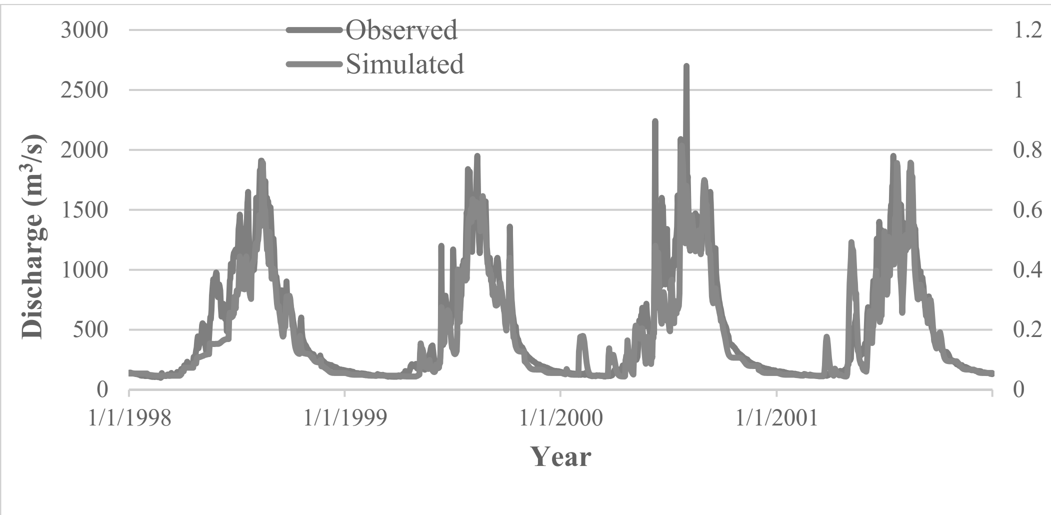

Figure 9: Flow Calibration (1998-2001)

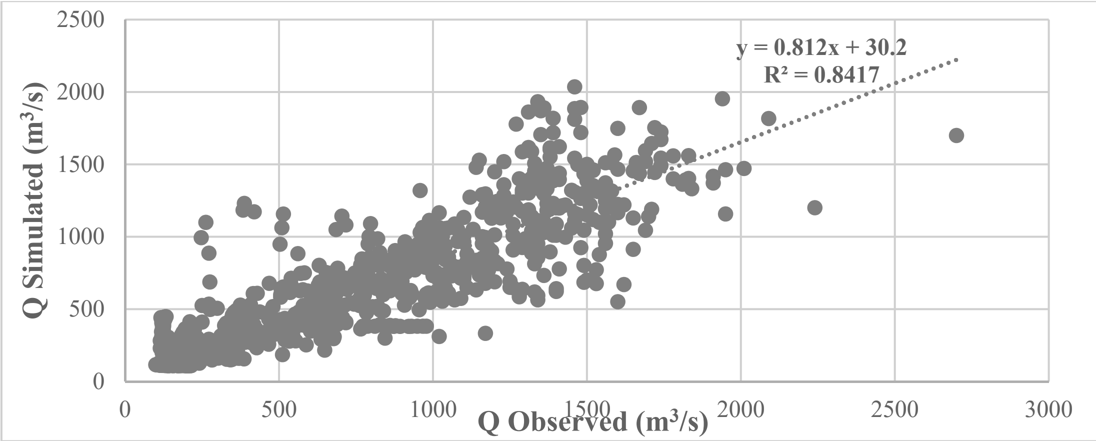

Figure 10: Scatter plot for calibration

4.2 Flow Validation

The validation of the simulated discharge with the daily-observed value was done for the period of Jan 2003 to Dec 2005 at Asaraghat gauge point of Karnali basin. The analysis of simulated result and observed flow data comparison was considered on daily basis. The summary of flow validation results for Asaraghat gauge point of Karnali basin is presented in Table. The observed and simulated daily flow hydrographs and correlation between observed and simulated discharge for validation period is shown in figure below.

Table 3: Flow Validation Results at Asaraghat Outlets

Outlet	**Cumulative volume ($10^6 m^3$)**		**Average Flow (m^3/s)**		**Model efficiency**			**Run Period**
	Observed	Simulated	Observed	Simulated	NSE	R^2	PBIAS	
Asaraghat	42007.67	36819.34	443.75	394.42	72.40%	0.82	12.35%	2003-2005

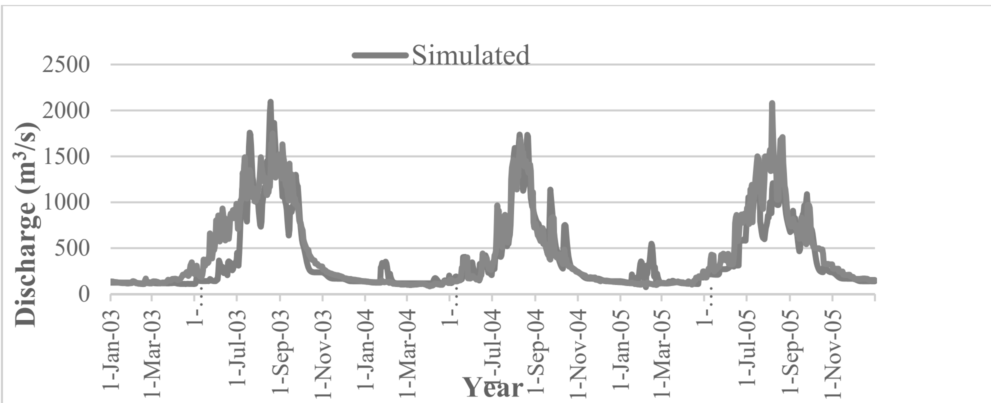

Figure 11: Flow Validation (2003-2005)

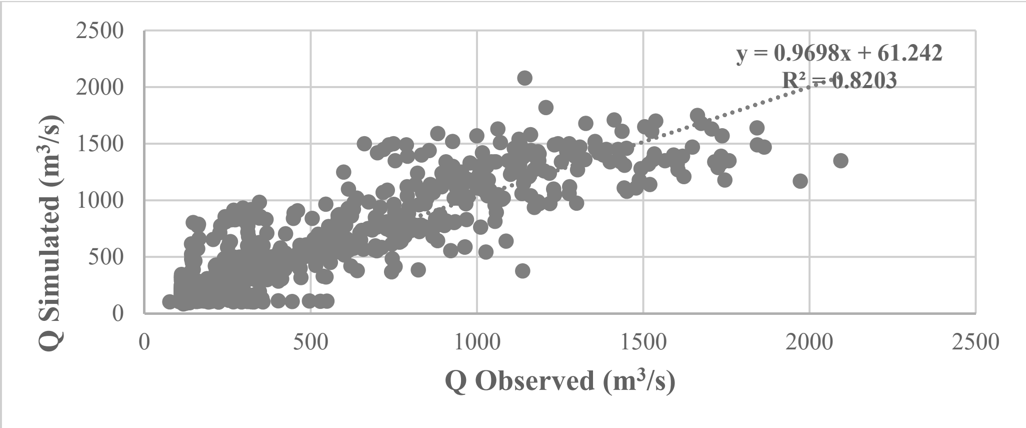

Figure 12: Scatter plot for validation

For Calibration process NSE, and R^2 values were obtained to be 73.2% and 0.84 where the simulated volume was underestimated by 18.18% and for validation process NSE, and R^2 values were obtained to be 72.4% and 0.82 and the simulated volume was underestimated by 12.35 %. (Najim, Babel, & Loof, 2006) suggest the limit of variation of simulated and observed values to be within 20%. Thus the volume underestimated in our study is within the recommended limit.

4.3 Calibration Parameters

4.3.1 Initial Abstraction

Initial abstraction Ia (mm): It represents the presence of the vegetation, which prevents permanently or temporary the precipitation from reaching the soil surface. To estimate its initial value was defined using the equation below,

$$Ia = 0.2 * (\frac{25400 - 254 * CN}{CN})$$

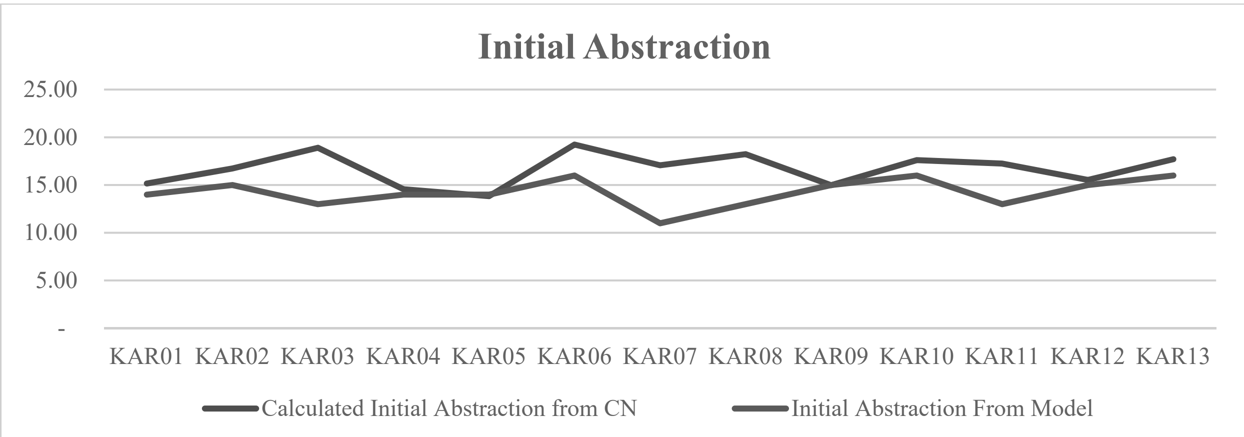

Figure 13: Calculated and Calibrated Initial Abstraction (Ia)

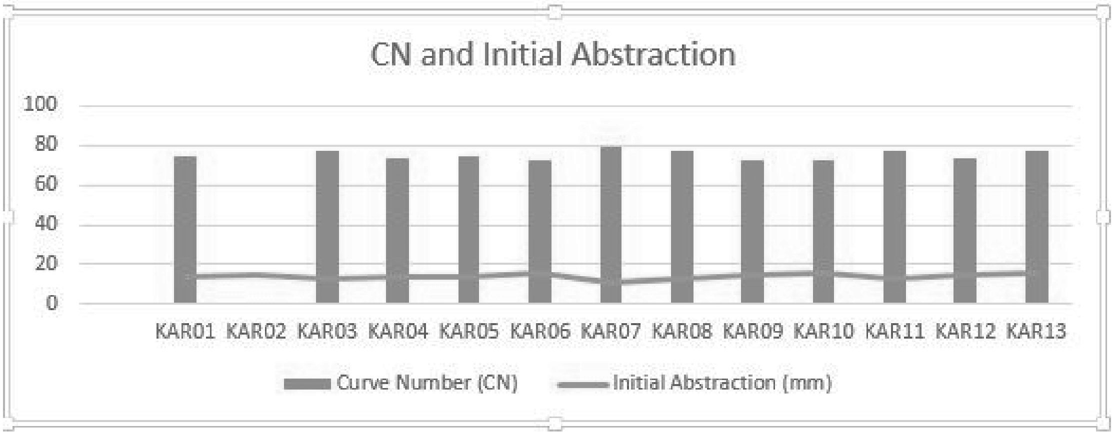

Figure 14: Curve Number and Initial Abstraction

CN has a range from 30-100, lower number indicate low runoff potential while larger numbers are for increasing runoff potential. The lower the curve number, the permeable the soil is. The runoff cannot begin until the initial abstraction has been met.

4.3.2 Muskingum K and x

To apply Muskingum routing method to a reach, it is necessary to determine values for the parameters K and x which are used to describe the storage characteristics of the reach.

Calibrated Muskingum K,x are the optimized parameters in HEC-HMS, when the model was best fitted. Also these parameters were calculated manually and given as input in the model, which showed no significant change in the model output results. Thus the parameters are verified physically.

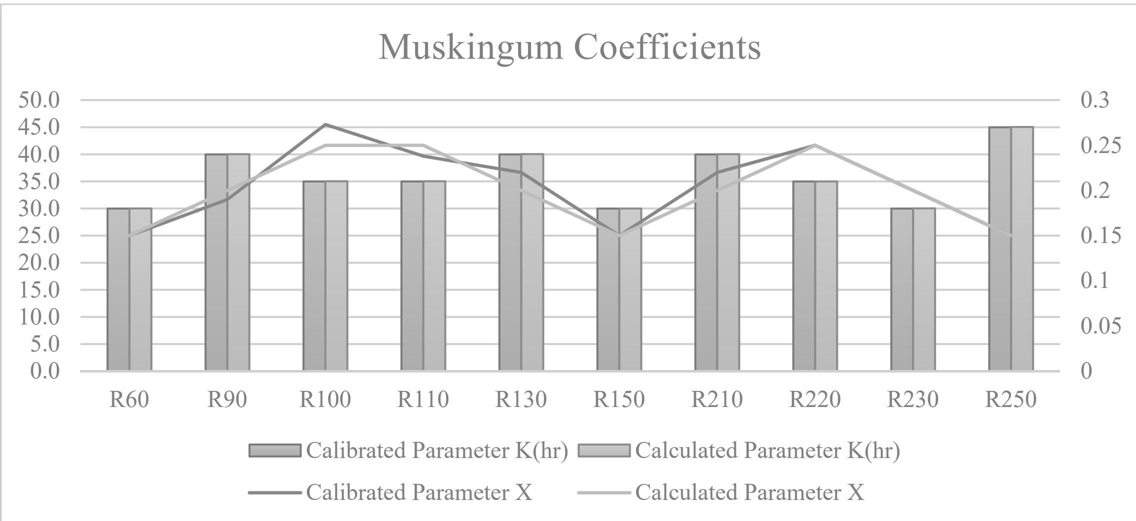

Figure 15: Calibrated and Calculated Muskingum K, x

4.3.3 Sensitivity analysis of CN, Muskingum K and Muskingum x

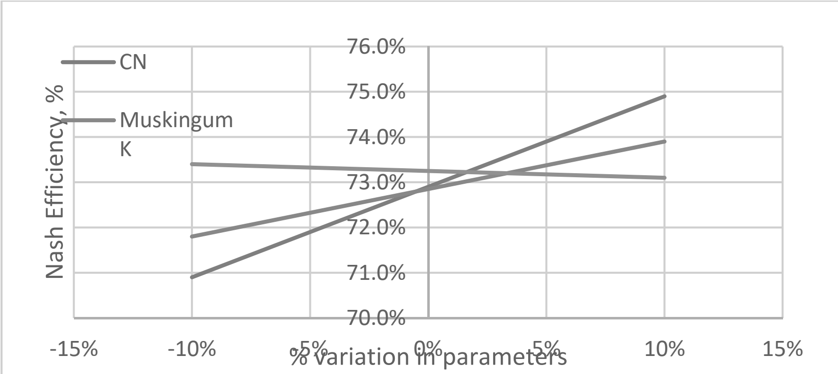

Figure 16: Graph for sensitivity analysis based on Nash Efficiency

For the sensitivity analysis CN, Muskingum K, x were taken into considerations. The optimized parameters were varied by (-10% to +10%) and the results obtained were plotted respectively based on Nash Efficiency, PBIAS and simulated volume. From the sensitivity analysis CN (Curve Number) parameter was found to be most sensitive.

5. Conclusions and Recommendations

5.1 Conclusions

The Hydrologic Modelling System model is run at Karnali Basin and calibrated with DHM gauge data at Asaraghat. A HEC-HMS model was developed where the TRMM 3B42V7 data from 1998-2005 was given as Input. Analyzing the results obtained and discussions in previous chapter, following conclusions are drawn out.

a. To evaluate the performance of the TRMM 3B42V7 rainfall product, statistical indicators, NSE, R^2 were considered. NSE 0.73 and R^2 0.84 for calibration and NSE 0.72 and R^2 0.82 for validation conclude that TRMM 3B42 rainfall data was reliable and had good precision in application to the Karnali River Basin. Results suggest that the TRMM 3B42V7 rainfall data can be used as an alternative data source for basin with sparse rain gauge stations in Nepal.

b. The direct comparative analysis between the observed rainfall and TRMM satellite data indicates the suitability of TRMM data for Karnali river basin in Nepal.

c. TRMM overestimated the rainfall for NAGMA (308) and ASARAGHAT (206) stations whereas underestimated the rainfall for MAINAGAUN (418), DARMA (313) and CHAINPUR WEST (202) stations of DHM.

d. As physical parameters are also similar to calibrated parameters, the HEC-HMS parameters can be determined from landuse, soil and topographic data. So, this model can be used for the prediction in ungauged basins.

5.2 Recommendations

a. In this study only TRMM gridded data are used for the modelling and results are obtained. The results obtained and calibrated parameters from this study is recommended to be compared with results obtained by using other data sources.

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