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Calibration and Sensitivity Analysis of a Hydrological Model for Jamunesswari River Basin of Bangladesh

Nishan Kumar Biswas[1], Manashi Paul[2] and Muhammad RezaulHaider[3]

[1]Junior Engineer Institute of Water Modelling House-496, Road-32 New DOHS, Mohakhali Dhaka-1206
[2]Department of Agricultural &Biosystems Engineering South Dakota State University
[3]Department of Water Resources Engineering Bangladesh University of Engineering and Technology
E-mail: [1]nishan.wre.buet@gmail.com, [2]manashi.paul@sdstate.edu, [3]mrhaider@wre.buet.ac.bd

Abstract—*Runoff estimation from a given rainfall event is a difficult task due to various influencing factors. Sometimes it is impossible to determine actual field values of numerous parameters of hydrological events in developing countries like Bangladesh. Though Hydrological Modelling is a complex task, if it is well calibrated, then it makes the application of the model effective for climate change, flood forecasting, irrigation engineering and other type of watershed and water resource studies.Assessment of impact of climate change on water resources in river basin requires a proper estimation of availability of water, and that canbe achieved by hydrological modelling of the basin. In this study, a basin named Jamunesswari with three sub-basins located in the North-West region of Bangladesh is considered. Basin model is developed by using computer based Hydrological model HEC-HMS (Hydraulic Engineering Center, Hydrological Modelling System). The model is calibrated with the discharge data of basin outlet atBadarganj. The model performance and sensitivity analysis is studied by altering the four most sensitive parameters. Thus, the model may be applied to other hydro-meteorologically similar river basins. This model can also be used as a baseline study for future water resources planning and management.*

1. INTRODUCTION

Hydrologic Modelling System (HEC-HMS) is one of the computer models for simulation of rainfall-runoff correlation (Arekhi, 2012). The Hydrological Modeling system is intended to simulate the precipitation-runoff processes of dendritic watershed systems. Hydrographs produced by this program are used directly or in conjunction with the other software for studies of water availability, urban drainage, reservoir spillway design, flow forecasting, flood damage reduction, future urbanization impact, floodplain regulation and systems operation[3].Assessment of water resources is a pre-requisite in order to frame long term sustainable water management strategy. Hydrologic models, which are capable of capturing complex dynamic processes, are appropriate tools for such studies. However, hydrological modeling is a simplified representation of the real situation, which is a challenging task particularly for regions that have lacking of available data[6]. Therefore, these model should be well calibrated, and its performance should be evaluated to provide a reliable result for any study.

The HEC-HMS Model represents the watershed with five storage layers viz., Canopy - Interception, Surface-Depression, Soil Profile, Groundwater Storages (1 and 2) involving twelve parameters viz., Canopy Interception Storage, Surface Depression Storage, Maximum Infiltration Rate, Soil Storage, Tension Zone Storage and Soil Zone Percolation Rate and Groundwater 1 and 2 Storage Depths, Storage Coefficients and Percolation Rates. Rates of Inflow to, Outflow from and Capacities of the layers control the volume of water loss from or gained by each of these storage layers. Hec-HMS computation algorithm is shown in Fig. 2[1].

Now-a-days, the HEC-HMS model has been used successfully worldwide by many researchers (Beighley and Moglen, 2003), (Fleming and Neary, 2004), (McColla and Aggett, 2005), (Yusop et al.,2007)).The objectives of this study is to optimize the probable loss parameters for soil moisture for the study area.

In this background, a study on the calibration and evaluation of a watershed simulation model is done by the Hydrologic Modeling System, which is developed by the Hydrologic Engineering Center, USA (HEC-HMS) has been carried out for the Jamunessawri River basin for proper assessment and management of water resources in the basin area.

2. STUDY AREA

The Jamunesswari basin is situated in the North-West Hydrological Region of Bangladesh. The Jamunessawri river (140 km long), having originated in Chilahati, Bangladesh (26° 6' N, 88°51' E) drains a sizable portion of the three catchments named NW01U, NW01M, NW01L and finally debouches into the Karatoya River. The Jamunesswari basin extends over 1124.03 km^2, covering 0.76% of thegeographical area of the country. Average annual rainfall in the basin is 175 mm. The annual water yieldfrom the basin constitutes about 0.4% of the total surface water resources of the country. The annual utilizable water resources in the basin have been estimated to be 106704954 m^3.

(a)

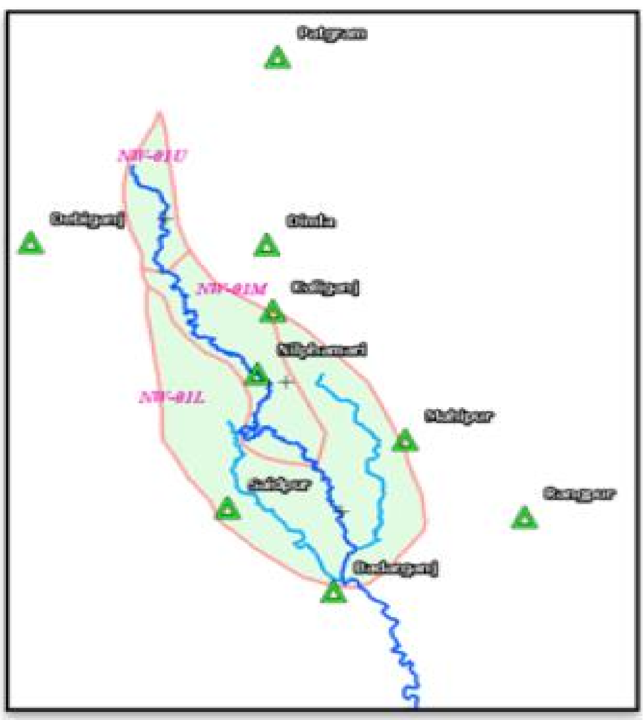

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Fig. 1. a): North-West Region b) Jamunesswari Basin with Rainfall Stations

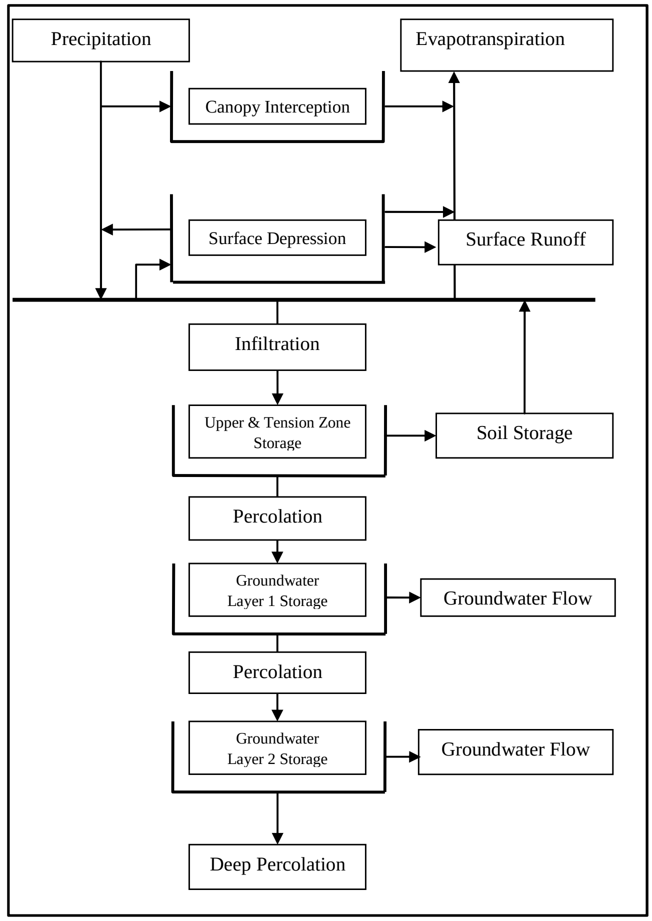


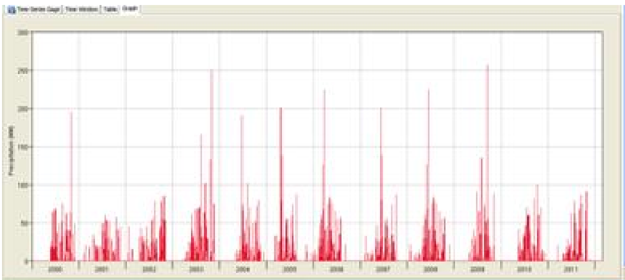
Fig. 2: Schematic Diagram of HEC-HMS Algorithm

3. METHODOLOGY

The study comprises of Data Acquisition, Processing of Meteorological Data, Delineation of Sub-basin area and boundary, Development of an HEC-HMS Model for study area, Calibration of Model with the observed data and finally Calculation of Variation of discharge volume. The sensitivity analysisis done for changing four parameters such as Surface Storage, Maximum Infiltration Rate, and Tension Zone Storage as a percentage of calibrated parameters.

Data Acquisition

The data and information, used in this study are topographic maps, meteorological data, evapotranspiration and precipitation data. The monthly averaged evapotranspiration (ET) and daily precipitation data are collected for the duration from 01 January, 2000 to 29 February, 2012.Rainfall Data are collectedat the stations named of Badarganj, Kaliganj, Debiganj, Dimla, Mohipur, Nilphamari, Patgram, Rangpur, Saidpurraingauge station of Bangladesh Meteorological Department (BMD). Discharge data for Badarganj station, which is situated at the outlet of Jamunesswari Basin are collectedfrom Bangladesh Water Development Board (BWDB). Typical precipitation pattern of this basin is shown in Fig. 3(a). The continuous discharge data of Badarganj from 31 March, 2002 to 30 March, 2006 at three hour's interval are used for the calibration of themodel.



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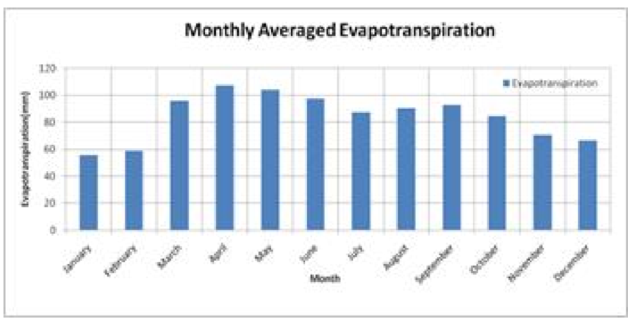

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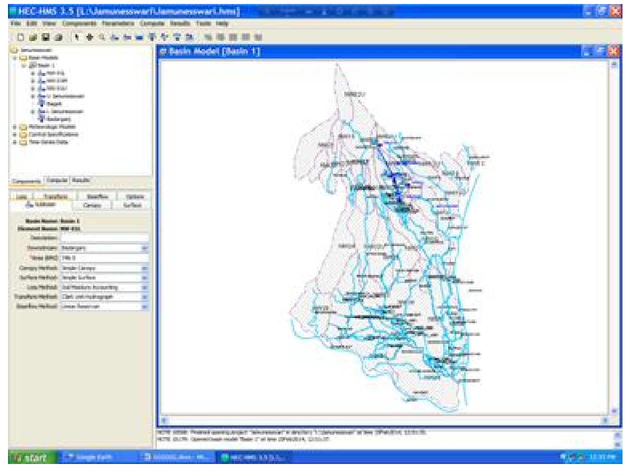
Figure 1. a) Rainfall Pattern and b) Average Evapotranspiration of Jamunesswari Basin

Processing Meteorological Data

For each sub-basin, area and boundary are collected from the North-West Hydrological Model developed by Institute of Water Modelling (IWM). The river channels Bullai, Jamunesswari and B-Chikleywas digitized by using the Google Earth. The evapotranspiration data were processed as monthly averaged data. The weightage of each rainfall gauge for each sub-basin is calculated by using Theissen Polygon feature of ArcGIS 10.

HEC-HMS Model Development

The input parameters of the HAC-HMS model are the processed meteorological data such as precipitation, monthly averaged evapotranspiration data, catchment area, and observed discharge data of Badarganj station. Control specification is kept from 01 April 2004 00:00 am to 31 March 2006 00:00 am. Calculated time interval is usedto 1.5 hours. For canopy storage calculation, Simple Canopy Method is used.



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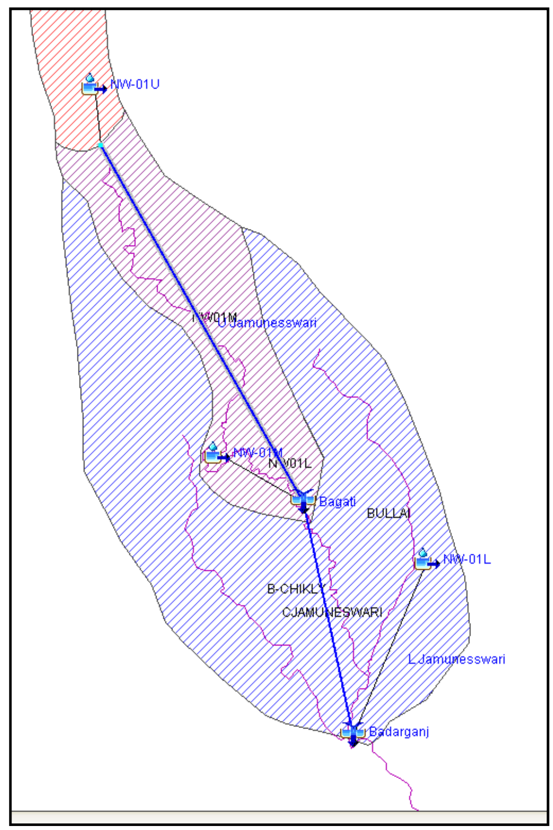

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Fig. 2.a): HEC-HMS Model Setup, b) Model Schematic View

Herefor the North-West Region of Bangladesh, the effect of canopy is negligible. Simple Surface Method is used for Surface Storage computation. For the loss calculation, Soil Moisture Accounting Method and Clark Unit Hydrograph Technique are used with the peak discharge and time of peak. In this study, Snyder's Unit Hydrograph Method was adopted to compute streamflow hydrograph. Linear Reservoir

Methodis used for Base-flow calculation. Muskingum Method of channel routing was used to generate discharge hydrograph at downstream point inall three river channel.

After the development, the model is simulated using an initial value of all the parameters. Then manual calibration is carried to calibrate the model with theobserved discharge data of Badarganj. After a significant improvement of simulated discharge hydrograph, auto-calibration feature of the model is used for the purpose of obtaining the optimum discharge hydrograph.

Before the application of any model, it is necessary to calibrate it with the observed data. Model Calibration is a process to compare the model with the actual system behavior until model accuracy is judged to be acceptable.Here, the model is calibrated using the observed discharge data of Badarganj station from April 2004 to March 2006. The following Fig. shows the comparative hydrograph of the observed and simulated runoff after the calibration of the model:

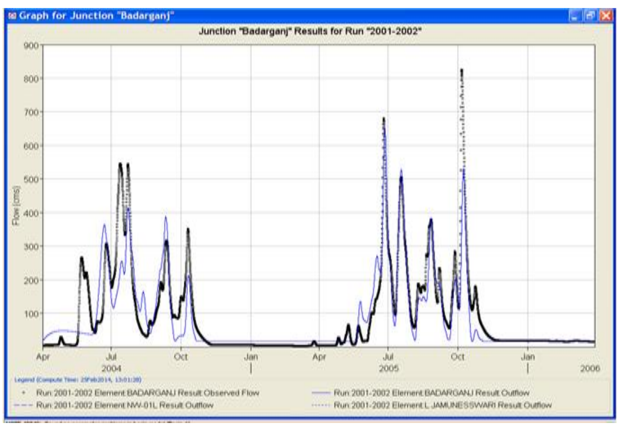


Fig. 3: Model Calibration with Observed Discharge of Badarganj station

Sensitivity Analysis

After getting the optimized parameters, their sensitivity is also observed. Among the optimized parameters, Maximum Soil Infiltration Rate and Surface Storage Capacity, Initial Surface Storage, Maximum Infiltration Rate, Tension Zone Storage Capacity shows the higher sensitivity. For these parameters, the values are changed by 10%, 20% and 30% increase and decrease from the optimized value. For that change, the total volume of runoff is obsrved.

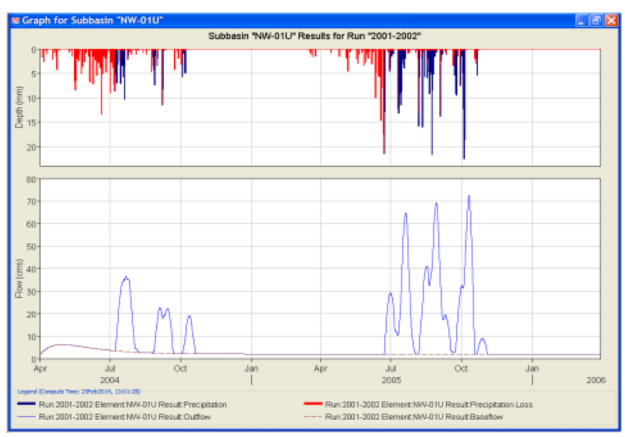
4. RESULT & DISCUSSION

After the calibration of the model, the calibrated parameters of the three different sub-basins are obtained. They are shown in the Table 1.

Table 1: Optimized HEC-HMS Parameters of Jamunesswari Basin

Hydrological Parameters		NW-01L	NW-01M	NW-01U
Simple Canopy	Initial Storage (%)& Maximum Storage (mm)	0	0	0
Simple Surface	Initial Storage (%)	0	0	0
	Maximum Storage (mm)	1000	1000	1000
Soil Moisture Accounting Loss	Soil (%)&GW 2 (%)	20	20	20
	GW 1 (%)	75	75	75
	Maximum Infiltration(mm/HR)	0.1	0.1	0.1
	Impervious (%)	0	0	0
	Soil Storage (mm)	250	250	250
	Tension Storage (mm)	50	50	50
	Soil, Ground Water 1 & Ground Water 2 Percolation (mm/hr)	0.5	0.5	0.5
	GW 1 storage (mm/hr)	300	600	600
	GW1 coefficient (mm/hr)	700	500	500
	GW2 storage(mm/hr)	350	250	250
	GW 2 coefficient (mm/hr)	3500	2000	1000
Clark Transform	Time of Concentration (hr)	150	300	300
	Storage Coefficient (hr)	30	20	10
Linear Reservoir Base Flow	Initial Type	Discharge per Area		
	GW 1 Initial($m^3/s/km^2$)	.005	.005	.005
	GW1 &GW 2Coefficient (hr)	1000	1000	1000
	GW 1 &GW2 Reservoir	1		
	GW 2 Initial($m^3/s/km^2$)	0.01	0.01	0.01
Lag routing	Reach- U Jamunesswari (minute)	180		
	Reach- L Jamunesswari (minute)	180		

Using the optimized parameters, the runoff response for individual catchment is shown in Fig. 6. Fig. 7 shows fitness of simulated discharge with the observed discharge of Badarganj station. The $r^2$is equal to 0.76.



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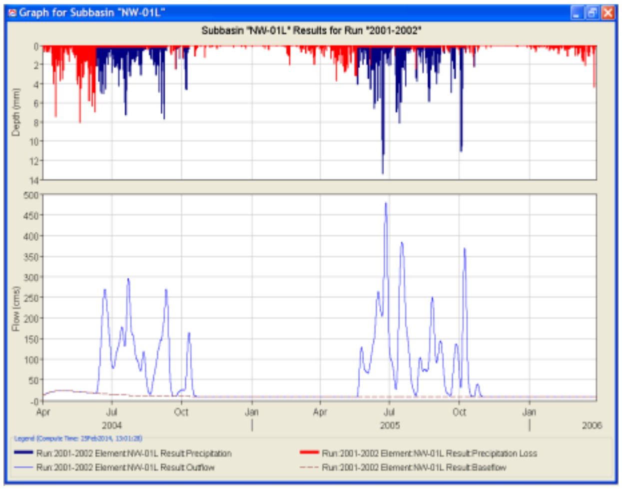

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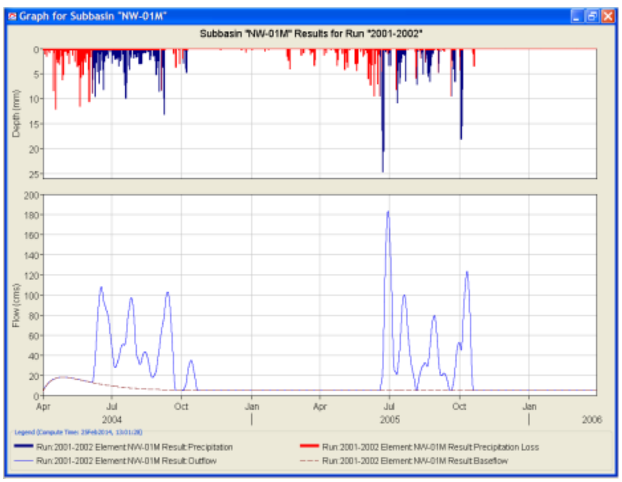


(c)

Fig. 6: Runoff along with Rainfall of Individual Catchment a) NW01U, b) NW01M and c) NW01L

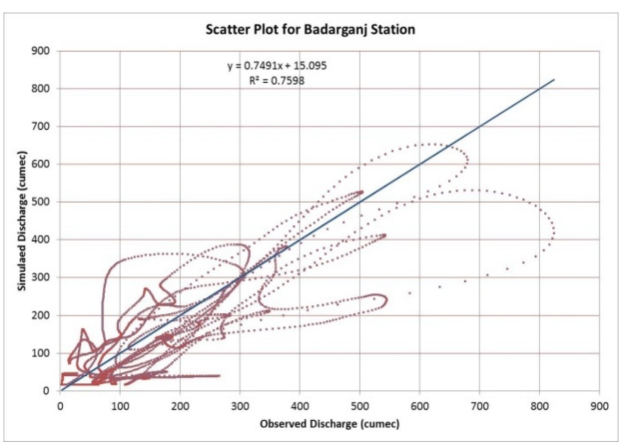


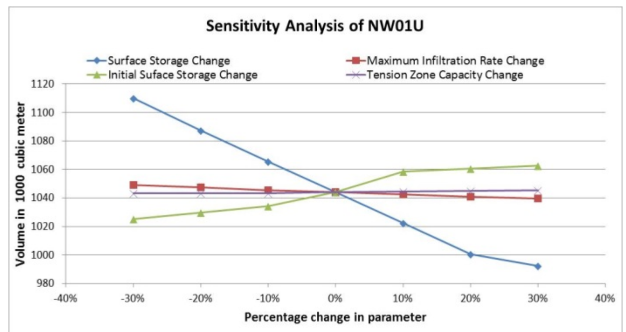
Fig. 7: Scatter Plot of Simulated vs. Observed Discharge at Badarganj Station

The total runoff statistics of the Jamunesswari Basin is stated in Table 2.

Table 2: Global Summary of Model Result

Element	Area (km^2)	Peak Discharge (m^3/s)	Time of Peak	Volume (m^3)
NW-01L	749.5	479.5	26Jun2005, 15:00	6984.9
NW-01M	263.7	183.1	29Jun2005, 09:00	2657.813
NW-01U	110.83	72.5	10Oct 2005, 21:00	1033.291

Maximum Soil Infiltration Rate and Surface Storage Capacity, Tension Zone Storage Capacity, Soil Profile Storage Capacity are increased and decreased at a rate of 5%, 10%, 20% and 30% from the optimized value and change in total volume of runoff for individual catchments as well as for the basin is observed, which are shown in Fig. 8.



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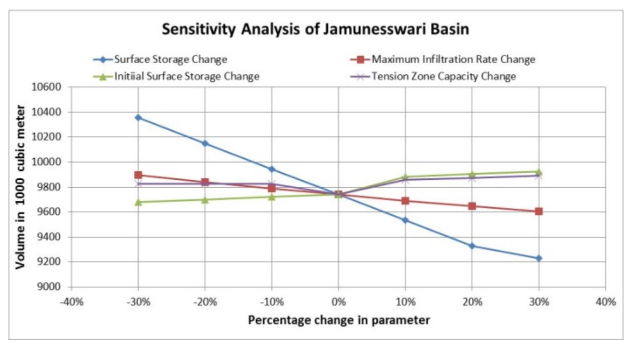

(b)

Fig. 4: Sensitivity of a) NW01L and b) JamunesswariBasin

5. CONCLUSION

From the HEC-HMSmodel study shows that, the most sensitive parameterfor Jamunesswari basin is Maximum Surface Storage as its sensitivity is the highest. Again, Tension Zone Capacity shows the most insignificant sensitivity by changes the volume of runoff bya negligible amount. The study shows that, the calibrated model performs well in simulating streamflow, and the model may be applied to other watersheds in the JamunesswariRiver basin and other hydro-meteorologically similar river basins.

Despitethe good performance of the models, development of model parameterization methodology using Geographic Information Systems (GIS) is highly recommended[7]. More hydrological data and satellite images are highly needed to take into account the climatic, hydrological and soil characteristics spatial variability in basins for better and accurate modeling of the hydrological processes in the catchment. Semi-distributed versions of these models may also improve their performance and reproduce the peak better than the lumped versions. However, more accurate data will need for the further study.

6. ACKNOWLEDGEMENTS

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