DEVELOPING A SEMI-DISTRIBUTED HYDROLOGICAL MODEL AND RAINFALL FREQUENCY ANALYSIS OF BANGSHI RIVER BASIN

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ABSTRACT

Bangshi River is one of the most important rivers in the central part of Bangladesh in respect to irrigation, fisheries, transportation, recreational uses. HEC-HMS has been used in order to setup a semi-distributed hydrological model to simulate precipitation-runoff process for both event based and continuous precipitation. A 90m Digital Elevation Model (DEM) has been used to delineate the watershed and river network using HEC-GeoHMS. The whole basin was subdivided into 6 basins having a total area of 1445.8 sq.km. The model was run and calibrated for the year 2011 and validated for the year 2012 at Nayarhat station. Sensitivity analysis of the model was carried out for the input parameters. The study revealed that the peak discharge is sensitive to maximum infiltration and percentage of impervious area. The Nash-Sutcliffe model efficiency criterion(NSE), percent bias(PBIAS) and the RMSE-observations standard deviation ratio(RSR) were used for performance evaluation. The model demonstrated good performance, with above mentioned performance indices values ranging from 84.8-94.3%, -10.81-3.441%, 23.9-39%. In addition, Gumbel's Frequency analysis has been carried out for precipitation. Changes in runoff has been studied by increasing and decreasing the precipitation by 10%,and 30% of the base year, which is assumed to be 2001(having annual rainfall close to that with return period T=2.33 years).

Keywords: *Semi-Distributed Hydrological Model, HEC-HMS, Gumbel's Frequency Analysis, Sensitivity Analysis, Bangshi River Basin*

1. INTRODUCTION

Bangladesh is a low-lying, riverine country located in South Asia with a largely marshy coastline of 580 km (360 mi) (CIA World Factbook) on the northern littoral of the Bay of Bengal. Formed by a delta plain at the confluence of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries, Bangladesh's alluvial soil is highly fertile, but vulnerable to flood and drought. Hills rise above the plain only in the Chittagong Hill Tracts in the far southeast and the Sylhet division in the northeast. Bangladesh lies across the Tropic of Cancer and has a tropical monsoon climate characterized by heavy seasonal rainfall, high temperatures, and high humidity. Bangladesh receives some of the heaviest rainfall in the world. The heavy rainfall over this area is an important part of the atmospheric heat source that controls Asian summer monsoon circulations. Heavy rainfall often causes flooding in Bangladesh and the country is one of the most flood-prone countries in the world due to its geographic position.

Bangshi River (also spelt Bansi) is an important river in central Bangladesh in respect to irrigation, fisheries, transportation, recreational uses. The water of Bangshi River is undergoing continuous changes in terms of quality. The degradation of water quality of Bangshi has aggravated at an alarming rate because of increasing industrialization, urbanization, and development activities. HEC-HMS nowadays has become a widely used hydrological tool because of its application in various fields like Flood forecasting analysis, Flood Inundation Mapping, Water quality analys. Hydrological models are the most important tools nowadays in understanding the response of river runoff to various channel characteristics and to the various processes in hydrological cycle like precipitation, evaporation, etc.

Bangshi River originates at Jamalpur from the course of the old Brahmaputra and flows past the Madhupur tract. It flows through Tangail and meets the Tongi in Gazipur. It passes near Jatiyo Smriti Soudho in Savar and falls into the Dhaleshwari. In its northern reaches the river joins with the old Brahmaputra and ultimately turns into an offshoot of the Old Brahmaputra. The Upper Turag-Lower Bangshi is the main source of water in the region and flows through the site. All associated beels and other floodplain areas are connected to the main river through a series of khals and other channels.

This is a deeply flooded area in the low-red soil plateau of Madhupur tract. The floodplain is inundated when water flows over the banks of the Turag-Bangshi river making all the low areas become a connected sheet of water in the monsoon. During the rainy season, the water area is about 43 km² while in the dry season the water area becomes less than 7 km². About 2, 68,900 people live in this area with 84% of households being involved in fishing, and 15 % of households are full time fishers. After the change of the Brahmaputra in 1787 to its present Jamuna channel, the head of the Bangshi had been gradually cut off. It flows more or less 90 deg E meridians. There are the Banar Rivers in the east, Fuljani and Jhenai River in the west and old Brahmaputra and Dhaleswari in the north and south of the river respectively. The river has a length of about 148 miles of which only 25 miles is in the district of Dhaka.

Previously, several work has been done using HEC-HMS. Chatterjee et al (2014) evaluated HEC-HMS model (Hydrologic Modeling System),for its applicability for the Damodar river basin in eastern India. Sensitivity analysis of the model was carried out for the input parameters. The study revealed that both the peak discharge and runoff volumes to be sensitive to rate of infiltration and percentage of impervious area. The Nash-Sutcliffe model efficiency criterion, percentage error in volume, the percentage error in peak and net difference of observed and simulated time to peak were used for performance evaluation. The model demonstrated good performance, with aforementioned performance indices values ranging from 75-81%, -10.5-19.4%, -18.0-29.6% and 0-1 day for simulation of stream flow. Thus the model may be successfully applied to watersheds in the Damodar river basin.

G.M Jahid Hasan et al studied the the amount of rainfall received over an area is an important factor in assessing availability of water to meet various demands for agriculture, industry, irrigation, generation of hydroelectricity and other human activities. The distribution of rainfall in time and space is, therefore, an important factor for the economic development of a country. Due to rapid urbanization in various parts of the north-eastern region of Bangladesh, there is a growing need to study the rainfall pattern, and also frequency of the heavy rainfall events. This study was checked monthly average rainfall from daily records of last 50 years for this region. In order to check the major events, time history of monthly rainfall data were transformed into frequency domain using the Fast Fourier Transform (FFT). Estimated peak frequency (11.98 month) depicts that major rainfall events of a year are occurring earlier than the previous year. The variability of rainfall in time scale was also checked from filtered signals, which is very useful for long-term water resources planning, agricultural development and disaster management for Bangladesh.

Hence, hydrological Hydrologic modelling system is indispensable to reproduce precipitation-runoff process in a watershed system. The entire procedure requires pre-processing of necessary data to develop basin hydrology. Considering all the aspects , objectives of the study were setup to

1. Develop a semi-distributed hydrologic model of Bangshi basin in HEC-HMS and
2. Rainfall frequency analysis of the Bangshi River Basin using Gumbel's Method.

Study area is hence depicted in Figure 1.

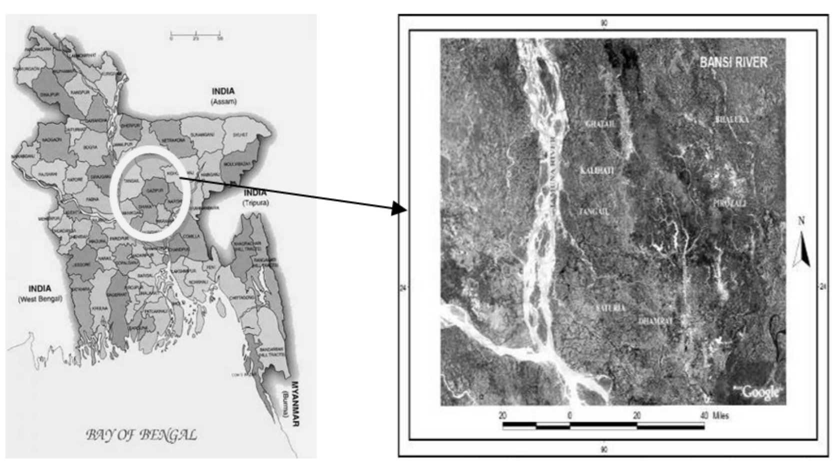

Figure 1: Bangshi River (Google earth, Department of Geography and Environment, JU)

2. METHODOLOGY

A methodology is the systematic, theoretical analysis of the methods applied to a field of study. It comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge. Typically, it encompasses concepts such as paradigm, theoretical model, phases, and quantitative or qualitative techniques.
A methodology describes which method or set of methods can be applied to a specific case in order to calculate a specific result.

Data Collection

The data that were collected were Digital Elevation Model (DEM) of Southeast Asia from the website og CGIAR Consortium For Spatial Information (CGIAR-CSI), Discharge Data were collected from the Bangladesh Water Develpoment Board for 14 years (2000-2013) at Nayarhat Station (SW14.5) and precipitation dta awere collected for two rainfall stations CL2 and CL21 from Bangladesh Water Development Board for 14 years (2000-2013).

Processing of Necessary Data

The data collected were then processed following a few steps which will be discussed in the next section.

2.2.1 Delineation of Stream Network

It is the initial step of hydrological modeling. It is required to obtain some basic information on the watershed such as area, slope, flow length, stream network density, etc. Arc Hydro Tools 10.1 has been used in order to do the delineation (Merwade, August 2012c). Output files from the terrain processing have been used to create input files for HEC-HMS using HEC-GeoHMS.

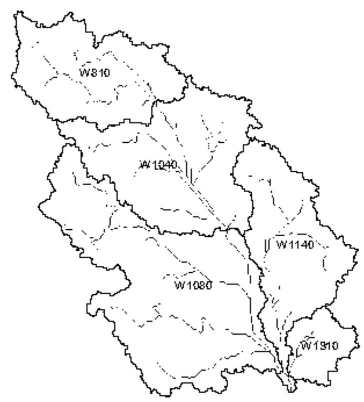

Figure 2: Delineated Stream Network of The Bangshi River Basin

2.2.2 Development of HEC-HMS Model Using HEC-GeoHMS

HEC-GeoHMS has been used as a tool to define the project for Bangshi river basin, extract basin characteristics, merge the sub basins and create a schematic map for the output and to specify basin parameters (Merwade, August 2012b).

2.2.3 Determination of Gage Weight Factors

Only two rainfall stations fell on the watershed of Bangshi river basin. Therefore arbitrary values for gage weights have been considered here.

Bangshi basin file and GAGE-WEIGHT.met files are prepared for HEC-HMS project. Map is converted to HMS units. HMS schematic tool creates a GIS representation of the hydrologic system using a schematic network with basin elements (nodes/links or junctions/edges) and their connectivity. Two shapefiles: one for river and one for sub-basin are created in the project folder. HMS legends and Corodinates are added. Corodiante tools add geographic coordinates to features in HMSLink and HMS Node feature classes. This is useful for exporting the schematic to other models or programs without losing the geographical information.
BANGSHI.hms project is created through Create HMS project. This function copies all the project specific files that have created (.map and .met) to a specified directory and creates a BANGSHI.hms file that will contain information on other files for input to HMS (Merwade August 2012b).

2.2.4 Model Setup

BANGSHI.hms project is started in HEC-HMS4.0. Basin model is imported from the directory where the basin file was created. Background maps with flow directions are added from the View Option. The basin model schematic diagram geographically locates the hydrologic elements, which are created within GIS (Hydrologic Engineering Centre). The number of sub-basin, reach, junction and outlet are 5, 11 and 12 respectively.

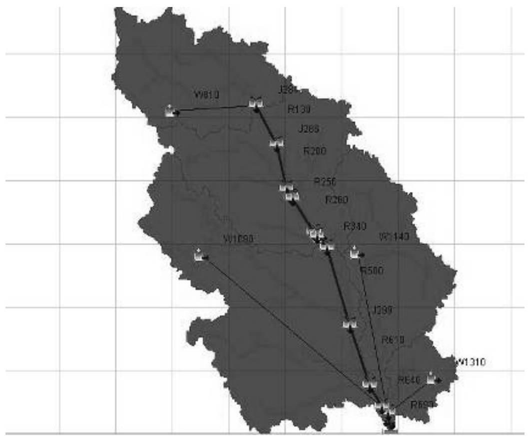

Figure 3: HEC-HMS Model Of The Bangshi River Basin

3. ANALYSIS AND RESULTS

3.1 Model Calibration and Validation

Model Calibration is the process of adjusting parameters until model results match observed data. Each method in HEC-HMS has specific parameters. Some of the parameters may be estimated by observation and measurements of stream and basin characteristics, but some of them cannot be estimated. Nayarhat station is selected as the calibration point. Calibration period has been selected for the year 2011 starting from 1st Jan 2011 to 31 Dec2011. The calibration results are as depicted below in Figure 3.

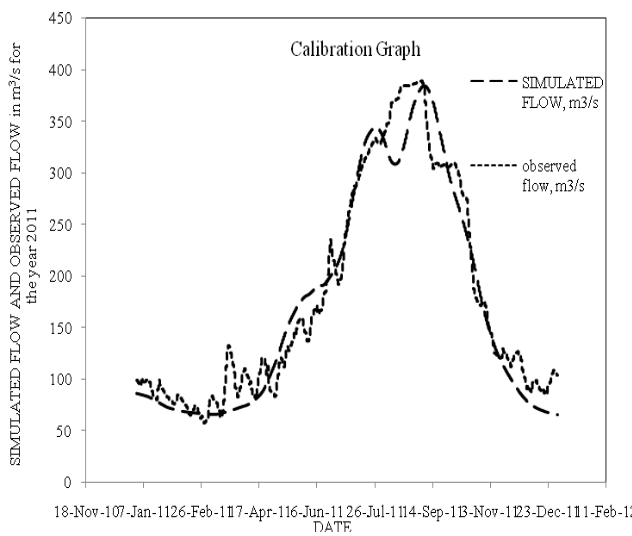

Figure 4: Calibration Graph of the Model

It is necessary to test whether the calibrated model parameters give satisfactory reesults for other time periods or not. Validation is a detailed proecess of confirming that the model is operating effectively and to determine tht a model is an accurate represntation of the real process. The calibrated Bangshi River Basin Model is run for the year 2012 (April to Dec) to check how closely the simulated results and observed flow matches as shown in Figure 5.

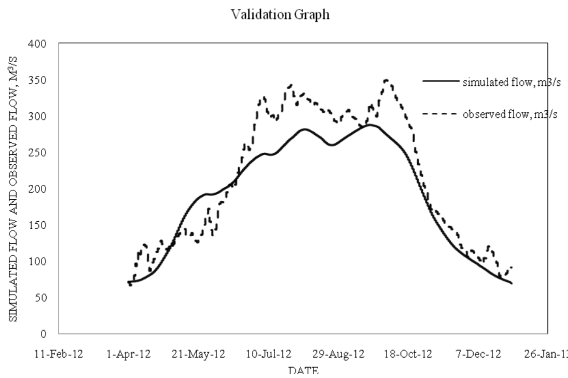

Figure 5: Validation Graph of the Bangashi River Basin

3.2 Goodness of Fit Indices

Goodness of fit indices has been used as a tool for fixation of parameters. For different trials using different parameters percent error in peak has been determined.for the calibrated model that the goodness of fit indices is found to be Z=1.28% which is lowest among all the trials. For the validated model Peak observed flow occurred at 2nd October 2012 and is 349m^3/s while the model gave an outflow of 287.8 m^3/s on the 21st of September. Goodness of fit indices Z=17.54%.

3.3 Model Evaluation

Some of the model evaluation techniques used are Nash -Suctliffe Efficiency (NSE), Percent Bias (PBIAS) and RMSE-Observations Standard Deviation RMSE-Observations Standard Deviation Ratio (RSR). The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (noise) compared to the measured data variance (information) (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits in the 1:1 line. Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0. Low-magnitude values indicating precise model simulation. Positive and negative value indicates model underestiamtion bias and model overestimation bias respectively (Gupta et al.1999). RMSE is one of the most commonly used error index statistics (Chu and Shimohommadi, 2004). RMSE is standardized by RSR using observation standard deviation combines both an error index and the additional information recommended by Legates et al. (1999). RSR is calculated as the ratio of the RMSE and standard deviation of measured data.the values of the NSE, PBIAS and RSR are therefore shown in Table 1.

Table 1: Model Performance Evaluation

	NSE	**PBIAS, %**	**RSR**
Validated model	0.848	10.81	0.390
Calibrated model	0.943	3.441	0.239

The values of NSE, PBIAS and RSR are hence compared with the recommended values by Moraisi et al as shown in Figure 6. Hence NSE and RSR show very good performance rating while PBIAS shows very good performance rating for the Calibrated model and good performance rating for the Validated model.

General performance ratings for recommended statistics

Performance Rating	RSR	NSE	PBIAS (%)		
			Streamflow	Sediment	N, P
Very good	0.00 ≤ RSR ≤ 0.50	0.75 < NSE ≤ 1.00	PBIAS < ±10	PBIAS < ±15	PBIAS< ±25
Good	0.50 < RSR ≤ 0.60	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15	±15 ≤ PBIAS < ±30	±25 ≤ PBIAS < ±40
Satisfactory	0.60 < RSR ≤ 0.70	0.50 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25	±30 ≤ PBIAS < ±55	±40 ≤ PBIAS < ±70
Unsatisfactory	RSR > 0.70	NSE ≤ 0.50	PBIAS ≥ ±25	PBIAS ≥ ±55	PBIAS ≥ ±70

Figure 6: Recommendded Values For NSE, RSR and PBIAS (Moraisi et al. 2007)

3.4 Parameter Sensitivity Analysis

After calibration and validation the runoff response to changes in certain parameters have also been studied as discussed in the later sections.

3.4.1 Effect of Changes of Percent Impervious on Runoff

As shown below in Figure 7 the value of peak discharge increases with increasing percent impervious. This parameter is very important as it is related to the land use change. Hence an increase in percent impervious indicates increase in civilization or industrialization and therefore we can conclude that with the increase in civilization the surface run-off will increase.

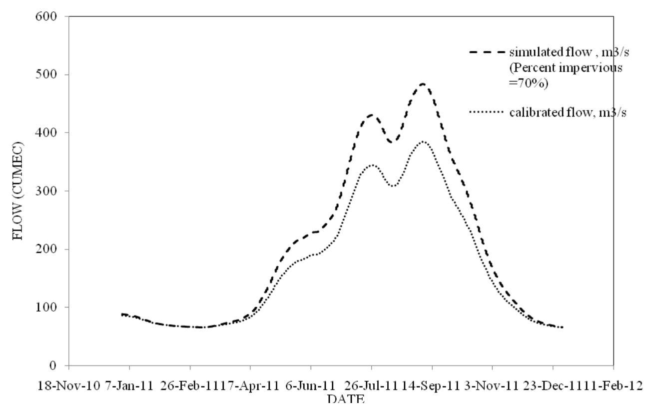

Figure 7: Effect of Changes off Percent Impervious On Runoff

The percentage rise in peak discharge from a change of 40% to 70% in percent impervious is 25.87%. Hence it can be concluded that peak discharge is sensitive to the parameter percent impervious. This phenomenon is depicted in Table 2.

Table 2: Effect of changes in percent impervious on peak discharge

Percent Impervious (%)	Peak Discharge (cumec)
40 (calibrated model)	384.2
70	483.6

3.4.2 Effect of Changes of Maximum Inflitration on Rnoff

The value of peak discharge increases with increase in maximum infiltration as manifested in Figure 8.

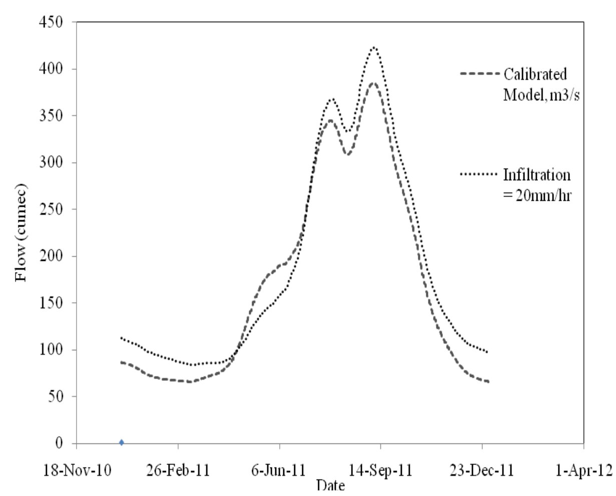

Figure 8: Effect of Changes of Maximum Infiltration on Surface Runoff

The percentage change in peak flow has also been calculated. As infiltration changes from 0mm/hr to 20 mm/hr, peak discharge increases by 9.78% as shown in Table 3.

Table 3: Effect of Infiltration on Peak Discharge

Infiltration (mm/hr)	Peak Discharge (cumec)
0 (calibrated model)	384.2
20	421.8

3.5 Gumbel's Frequency Analysis

It is one of the most widely probability distribution functions for extreme values in hydrological and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc. Since the value of the variate for a given return period,x_T determined by Gumbel's method can have errors due to the limited sapmle data used, an extimate of the confidence limits of the estimate is advantageous. Hence confidence interval is calculated whch indicates the limits about the calculated value between which the true value can be said to lie with a specific probability based on sampling errors only (Subhramanyu, 2013-2014).

So, initially the calibrated model was run for the base year 2001 which depicted the following results as shown in Figure 9.

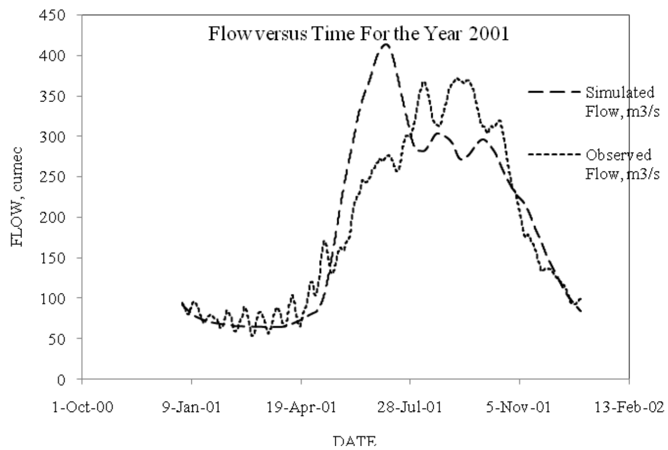

Figure 9: Flow Generated At Nayarhat Station For TheYear 2001

3.5.1 Rainfall Frequecny Analysis

For the rainfall station CL2 the X_{50} and X_{100} was calculated and found to be 2784.498 cumec and 3034.375 cumec respectivley.similarly for the rainfall station CL21 X_{50} X_{100} were found to be 3175.673 cumec and 3481.884 cumec respectively.

The cofidence interval was hence calculated and shown in Table 4.

Table 4: Confidence interval for Rainfall Stations CL2 and CL21

	50% confidence limits for 50 years rainfall, mm	80% confidence limits for 50 years rainfall, mm	95% confidence limits for 50 years rainfall,mm	50% confidence limits for 100 years rainfall,mm	80% confidence limits for 100 years rainfall,mm	95% confidence limits for 100 years rainfall,mm
Rainfall station CL_2	X_1=3058.505 X_2=2510.49	X_1=3305.680 X_2=2263.316	X_1=3581.312 X_2=1987.684	X_1=3308.382 X_2=2760.368	X_1=3555.557 X_2=2513.193	X_1=3831.189 X_2=2237.561
Rainfall station CL_21	X_1=3569.438 X_2=2781.908	X_1=3924.644 X_2=2426.702	X_1=4320.746 X_2=2030.600	X_1=3875.649 X_2=3088.119	X_1=4230.855 X_2=2732.913	X_1=4626.957 X_2=2336.811

3.5.2 Effect of Changes of Rainfall on Runoff at Nayarhat Station

The precipitation was increased and decreased by 10% and 30 % of the year 2001, which was selected as the base year. Then the model was run with the respective changes and compared with the observed flow as shown in Figure 9.

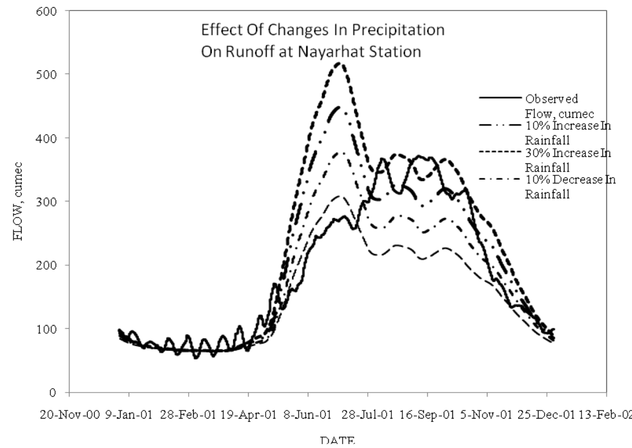

Figure 9: Effect of Changes of Rainfall on Runoff at Nayahat Station

4. CONCLUSIONS

Hydrologic models have become an indespensable tool for studying basin hydrology. In this study, hydrologic model of the Bangshi River Basin has been succesfully developed. Delineated watershed of the basin using ARC GIS 10.1 and HEC-GeoHMS has been an aid for the successful represntation of basin hydrology.

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