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A Conceptual Model Based Approach to Assess the Hydrologic Processes in Dakshin Dinajpur district of West Bengal, India

[1] Rupak Kumar Paul
Assistant Professor, Department of Geography, Dewan Abdul Gani College, P.O – Harirampur, District – Dakshin Dinajpur, West Bengal, India

Abstract- **The lumped version of HBV model was calibrated for areas comprising five adjacent catchments to which the district Dakshin Dinajpur is nested. With the calibrated parameter the model was applied to the district to simulate the components of hydrological system (e.g. runoff, actual evaporation, groundwater recharge etc.,) and subsequently multiple linear regression analysis was done to assess the impact of natural and human factors, if any, on each component with a view to having a comprehensive understanding of behavior of hydrologic system pertaining to the district. To substantiate the output of regression analysis Mann-Kendall test was applied to observe whether the trend in explanatory variables, if any, correspond to that in response variables. It is observed that in last sixteen years on an average there is no change in monsoon rainfall while non-monsoon rainfall is decreasing gradually that causes reduction in annual runoff by about 31.93% with respect to its estimated value in the base year 2000. Direct runoff is decreasing at the rate of 6.84 mm per year. There is no change in groundwater recharge that comes from monsoon rainfall through the base flow is declining over the time at the rate of 6.73 mm per year and this can be attributed to increasing withdrawal of groundwater for irrigation use in a lean season so far as the result of regression analysis indicates. Thus, two factors – rainfall and groundwater based irrigation – have been proved statistically to be capable of explaining the changing behavior of hydrologic processes in the district.**

Index Terms**: Alteration of hydrologic processes, HBV model application, Mann-Kendall test, Simulation of components of hydrological cycle.**

I. INTRODUCTION

Understanding hydrologic process i.e. evaporation, infiltration, snowmelt, interflow, etc. is fundamental to water resources and environmental engineers and scientists [1]. The human interferences in hydrologic system through alteration of land use and land cover, excess surface and ground water extraction for agriculture and industrial use, coupled with climate change [2-6] have raised, in present era, the need for updated information on their effect on hydrological processes particularly runoff alteration, change in groundwater recharge etc.; so that proper water resources planning can be formulated. Here the role of hydrologic model is utmost important for assessment and prediction of complex behavior and significant variability of hydrologic processes in changing natural as well as man-made environments.

A model (by definition) is a formulation that mimics a real-world phenomenon and by which predictions can be made [7]. It describes a system based on some input variables, model parameters, and initial conditions [1]. Hydrologic models are primarily used for hydrologic prediction and for understanding hydrologic processes [8]. They can be categorized into three different groups [9]: first, physically-based models that are based on solving governing equations such as conservation of mass and momentum equations; second, conceptual models that estimate processes with simple equations rather than solving governing partial differential equations and to replace the partial differential equations with simple statements, a variety of different model parameters are introduced into the model that may have little physical meaning; and third, empirical models that are based on analyzing observed input (e.g. rainfall) and output (e.g. discharge) and linking them through statistical or other similar techniques [1]. In the present study HBV-Light – a conceptual model based on HBV model concept – has been used to generate data base on various components of hydrological cycle, e.g. runoff (both surface runoff and base flow), actual evaporation, ground water recharge etc. for the study area, Dakshin Dinajpur district of West Bengal province in India (Fig. 1). The model application has been followed by regression analysis to assess the impact of natural as well as human factors on alteration of those hydrologic parameters in order to have a comprehensive understanding of complex hydrologic system. Such model has been selected because of its simplicity and requirement of minimum numbers of input data. For physical-based models like SWAT huge numbers of data on various parameters of soil, land use, weather etc. are required while empirical models, on other hand, very often use very fewer variables than conceptual

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models do but they do not always represent the ground scenario required for further analysis. As for example, the NRCS-CN [10] is a widely used empirical method which uses only rainfall, soil type and land use to simulate runoff. But this method simulates only surface runoff. Thus for present study it is not suitable since here surface runoff and base flow both the variables are essential for further analysis.

The hydrologic models are usually used over drainage basin for various reasons. One of such reasons is the fact that a drainage basin is a well demarcated natural entity having a definite input and output paths that make observation on hydrologic processes much easier. But most water resources development plans are formulated for administrative units and hence a gap in required data base is developed. It is the investigator who must come forward to fix this problem by calculating the respective shares of administrative unit for hydrologic processes simulated for basin areas in which the former is nested. Such an attempt has been taken here and it has been stated in methodology part of this paper. The very objectives of present study are to simulate each component of hydrologic system (e.g. runoff) using HBV model and to analyze the impact of natural (e.g. rainfall) as well as man-induced factors (e.g. ground water extraction for irrigation) on those elements by using statistical tools. Basic aim is to have a comprehensive understanding of behavior of hydrologic system in the study area so that the generated data base can be used for formulation of water resources development plan in view of wise use of this defined natural resource.

II. THE STUDY AREA

Located in the southern most frank of the Teesta-Mahananda fan where the topography gradually transforms into flood plain the district of Dakshin Dinajpur belonging to province of West Bengal in eastern India covers the area of 2219 km2 extending from 25010'15" N to 25 035' 34" N and from 88010' 49" E to 880 58' 46" E (Fig. 1)[11]. Geological deposits [12] dating back to early Pleistocene period characterize the geological formation upon which there have been developed Barind uplands dissected by present day flood plain, along many present day active drainage lines with erosional and depositional in-channel features.

General slope is southward with altitudinal variation of only 20 meters ranging from less than 25 to more than 40 m above mean sea level. Climate is of purely monsoonal type with mean daily maximum temperature of 34.60C; mean daily minimum temperature of 21.90C and annual average rainfall being 1600 mm [13]. Older alluvium upon Barind Tract and recent alluvium upon present day flood plain denote the soil characteristics of the district. Fine Loamy Typic Ustocrepts with Fine Loamy Typic Ustorthents occupies most part of the district while in some patches there is Fine Loamy Aeric Haplaquepts with Fine Loamy Fluventic Ustocrepts [14]. Four major rivers – Tangan, Punarbhaba, Atrai and its tributary Jamuna – pass through the district appearing from Bangladesh in north and exiting towards south in Malda district of West Bengal and Bangladesh. Atrai enters into Chalan Bil in Bangladesh while Tangan joins Mahananda in Malda and Punarbhaba joins the same in Bangladesh. Ultimately all are debouching into river Ganga.

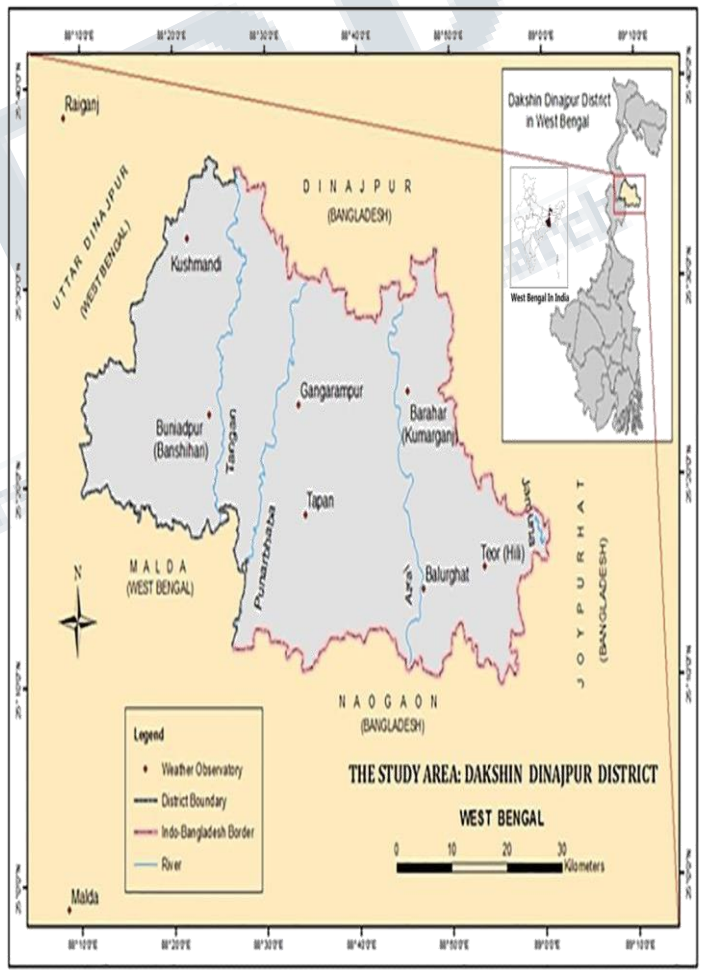

Fig. 1 The study area

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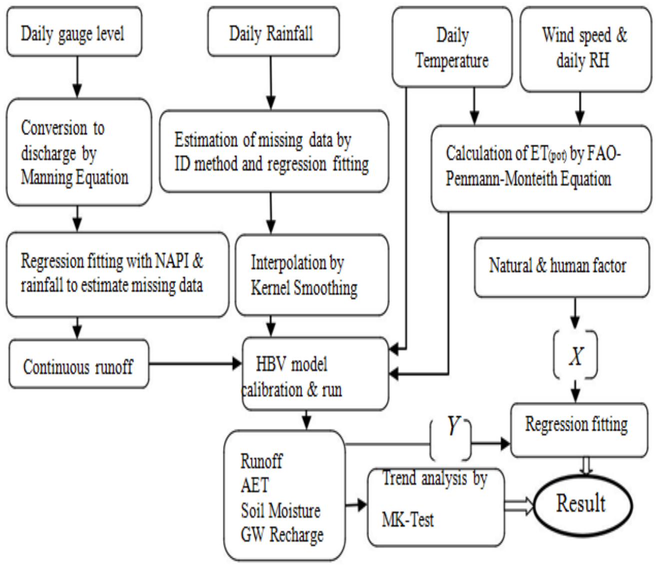
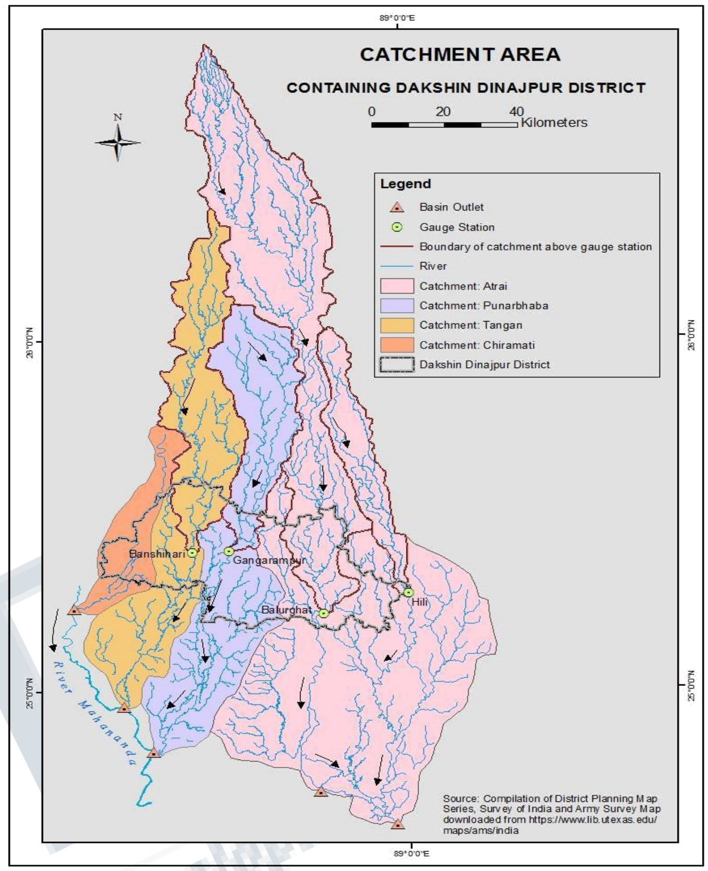


Fig. 2 Flow diagram to show methodology adopted for the present study

Total population of the district is 1,670,931 with 14% of urban share (Census, 2011), [15]. Forest occupies very negligible portion being only 0.93 hectares while 15% of the district area [16] is allocated to use for the purpose other than agriculture and the rests of the land area is thus used for cultivation.

III. METHOD AND DATA BASE

The HBV model (Hydrologiska Byråns Vattenbalansavdelning) has been used for simulation of direct runoff [L], base flow [L], actual evaporation [L], ground water recharge [L] and soil moisture [L] on daily basis for the period of sixteen year from 2000 to 2015. Input data required for calibration of model include daily precipitation [L], mean daily temperature [L], daily runoff [L] and mean monthly evaporation [L]. The use of runoff data is optional when to run the model using calibrated parameters. Calibration has been done for five adjacent catchments in which the district is nested (Fig. 3) and with the calibrated parameters the model is run for the district. HBV model can be used as semi-distributed or fully distributed model where study area is divided into various relief and vegetation zone. Since the present study area and the concerned catchments are of monotonously flat and vegetation cover is negligible the lumped version of the model has been used where entire



area is considered as a single unit or zone. The output value of simulated hydrologic variables are available in terms of depth [L] and since the study area is nested in the basin area for which calibration has been done with same calibrated parameters the model can be run for the district or any administrative zone nested in the basin area for which calibration is done. After generation of data base multiple linear regression model has been formulated where hydrologic variables (e.g. runoff) each has been used as response variable and rainfall, ground water irrigated area, crop area statistics etc. (sum total of 14 variables including both natural and human factor) have been used as explanatory variables in order to observe whether there is any

impact of natural (e.g. rainfall) and human factor (ground water irrigated area) on hydrologic variables (e.g. runoff). Step wise method has been used to exclude those explanatory variables which are proved to be insignificant for the model. The mathematical form of the regression model is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 ....\beta_k X_k + \varepsilon ....[Eqn.1]$$

Here, Y is the response variable, X is the explanatory variable, β is the constant and ε is the error term. Since the period of study covers only sixteen years (2000 to 2015) Mann-Kendall test has been applied to substantiate the output of regression model. Here, attempt has been made to observe whether trend in response variable corresponds or not to that in explanatory variable. Final result has been interpreted accordingly. Rainfall data is available from seven rainfall recording stations locating in and around the study area while temperature, relative humidity, and wind speed data are available from three observatories as Raiganj, Balurghat and Malda. These data base have been collected from India Meteorological Department, Govt. of India, Kolkata and Directorate of Agriculture, Govt. of West Bengal, Malda. Discharge has been calculated using Manning formula [17] from gauge level data which has been collected from Irrigation and Waterway Department, Govt. of West Bengal. The agricultural data that is required for regression analysis has been collected from District Statistical Hand Book of various years (2000 to 2015).

IV. INPUT DATA PREPARATION

A. Meteorological Data

A few temporally sporadic data point for rainfall from Gangarampur and Teor (Hili) observatories and on temperature from some of the observatories have been identified. The missing rainfall data from Gangarampur observatory has been estimated using inverse distance method which is usually used by US National Weather Service. Such technique has been adopted as it is suitable one for this station due to having its ideal location for which the technique can be applied as per the guideline for application of the technique [18]. Missing rainfall data for other observatory and missing temperature data have been estimated by formulating multiple linear regression analysis. The potential evaporation [L] has been calculated on monthly basis using FAO- Penmann-Monteith equation [19] using temperature, relative humidity and wind speed data All these meteorological data have been interpolated by Kernel Smoothing Operation which is of the form:

$$EP(x_i, y_i) = \frac{\sum RP(x_i y_i) \times K_i}{\sum K_i} \text{..............................} [Eqn.2]$$

$$K_i = e^{-\frac{d^2}{2h^2}} \text{..} [Eqn.3]$$

The entire area is divided into one km by one km grid. EP is the estimated parameter (e.g. rainfall) for a particular grid point having a definite location of longitudinal xi and latitudinal yi value, while RP is the recorded parameter (e.g. rainfall) for weather observatory having a definite location of longitudinal xi and latitudinal yi value. Ki is defined in equation no. 3 where d is the distance between grid point and weather observatories while h is the band width (a constant) whose value is determined by cross validation method. In the present study the value of h has been identified as 1.5 for rainfall and 10 for temperature and potential evaporation each. The value has been accepted wherever the sum of square difference between observed and recorded value of meteorological parameter has been found as minimum. Finally the data have been arranged as time series on daily basis for the duration of 2000 to 2015 for their use as input to HBV model.

B. Discharge Data

Manning formula that has been used to convert the daily gauge level data into daily discharge is of the form:

$$Q = \frac{1}{n} A \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \text{..........} [Eqn.4]$$

Here Q is the discharge [L3T-1], while A is the cross sectional area [L2] of river, R is the hydraulic radius [L] and S is the water surface slope [-]. In gauge level data a large data gap for non-monsoon period of almost every year has been identified. To estimate the missing data regression model has been formulated where discharge is taken as response variable and square root of daily rainfall and normalized antecedent precipitation index (NAPI, calculated following Garg Method, 1987) [20] have been used as explanatory variables. Finally the average of five adjacent catchments for the area above gauging station has been calculated and thereafter the value has been converted into runoff depth [L] on daily basis for its use as input to HBV model.

V. CONCEPT AND STRUCTURE OF HBVMODEL

A. Model Description

The HBV model was originally developed by Bergström [21] at Swedish Meteorological and Hydrological Institute (SMHI) and since then it has been modified by developer himself [22-24] from time to time and by many other authors [1, 25-28]. Presently the model exists in different versions (Swedish, Norwegian, Finnish, Swiss, etc.) but their basic structure remains same. The HBV – Light v4.0.0.10 that has been used in present study is a community based free Window version software developed by Jan Seibert [29] based on original HBV model concept. The mechanism of simulation of hydrologic variables (e.g. direct runoff, base flow) has been conceptualized using a number of model parameters and introducing two ground water boxes. As Seibert [29]

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describes, it consists of four modules (or sub-model): Snow Routine, Soil Moisture Routine, Response Function and Routing Routine (Fig. 4). In snow routine precipitation is simulated to be either snow or rain depending on whether the temperature is above or below a threshold temperature, TT (0C) (please note all model parameters are in bold). All precipitation simulated to be snow, i.e. falling when the temperature is below TT, is multiplied by a snowfall correction factor, SFCF [-], which represents systematic errors in the snowfall measurements and the 'missing' evaporation from the snow pack in the model. Snow melt is calculated with the degree day
method (Eqn. 5). Melt water and rainfall is retained within the snow pack until it exceeds a certain fraction, CWH [-], of the water equivalent of the snow. Liquid water within the snow pack freezes according to a freezing coefficient, CFR [-] (Eqn. 6). In soil moisture routine rainfall and snow melt (P) are divided into water filling the soil box and groundwater recharge depending on the relation between water content of the soil box (SM (mm)) and its largest value (FC (mm)) (Eqn.7). Actual evaporation from the soil box equals the potential evaporation if SM/FC is above LP [-], while a linear reduction is used when SM/FC is below LP (Eqn. 8).

$$melt = \boldsymbol{CFMAX} \cdot (T(t) - \boldsymbol{TT}) ....[Eqn.5]$$

$$refreezing = \boldsymbol{CFR} \cdot \boldsymbol{CFMAX} .(\boldsymbol{TT} - T(t)).....[Eqn.6]$$

The output of soil moisture routine enters into response function. The HBV – Light v4.0.0.10 provides options of using eight different types of structures of response function. The structure which has been used for the present study is 'Response Routine with Delay'. In this structure as shown in Fig. 5 the recharge is divided into two parts. One part directly enters into upper ground water box where from surface runoff (Q1) is generated (Eqn. 9) while other part enters into lower ground water box with delay where from base flow (Q2) (Eqn. 10) is generated. Delay here is the model parameter which needs to be calibrated. PERC [mm d-1] defines the maximum percolation rate from the upper to the lower groundwater box (SLZ (mm)). Runoff from the groundwater boxes is computed as the sum of two outflow equations (K1 and K2 (d-1)) (Eqn. 9 & Eqn. 10) depending on whether SUZ is above a threshold value, UZL (mm), or not. In routing routine this runoff is finally transformed by a triangular weighting function defined by the parameter MAXBAS (d).

$$Q1 = \min(\boldsymbol{K1} \cdot SUZ^{1+\alpha}, SUZ)......................[Eqn.9]$$

$$Q2 = \boldsymbol{K2} \cdot SLZ..............[Eqn.10]$$

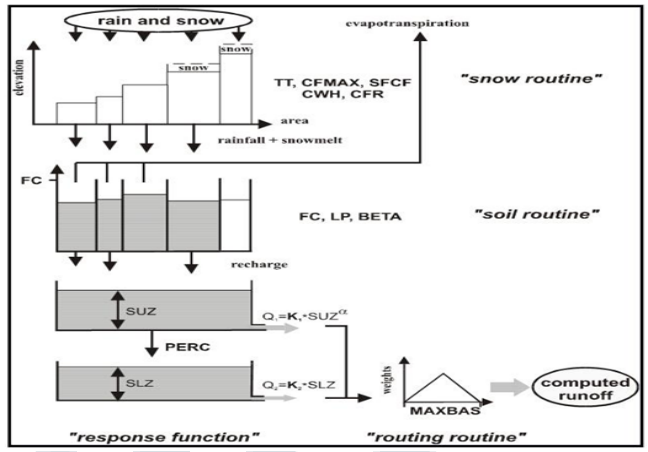

Fig. 4 Structure of HBV model (taken from help menu of HBV – Light v4.0.0.10). Notations have been described in the text.

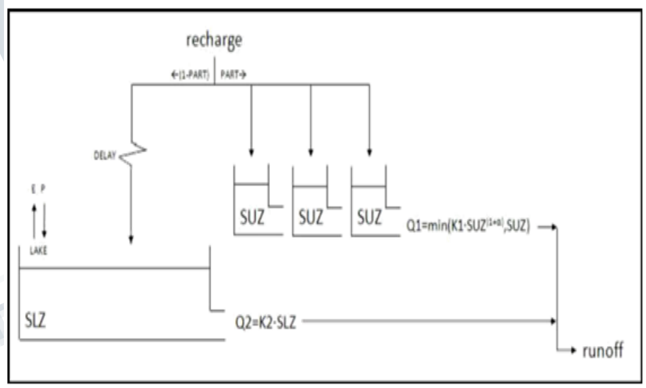

Fig. 5 Response function module of HBV model (taken from help menu of HBV – Light v4.0.0.10). Note that this sub-model has distributed structure. Notations have been described in the text.

$$Q_{sim}(t) = \sum_{i=1}^{MAXBAS} c(i) \cdot (Q1 + Q2) \cdot (t - i + 1)......[Eqn.11]$$

$$where, c(i) = \int_{i-1}^{i} \frac{2}{MAXBAS} - \left| u - \frac{MAXBAS}{2} \right| \cdot \frac{4}{MAXBAS^2} du$$

Table 1 shows the input and output variables for each module of HBV model. It is to be noted that the HBV-Light v4.0.0.10 that has been used in the present study uses all the input data on daily basis except potential evaporation which can be used on daily or monthly basis. Table shows the model parameters along with their calibrated values.

Table 1: Input and output variables of four modules of HBV model

Module	Input data	Output data
Snow routine	Precipitation, Temp.	Snow pack, Snow melt
Soil routine	PET, Precipitation, Snowmelt	AET, SM, GW Recharge
Response function	Groundwater recharge, PET	Runoff, GW level
Routing routine	Runoff	Simulated runoff

Source: Seibert, 2005

Table 2 Model parameters and their calibrated values

Parameter	Explanation	Unit	Valid range	Calibrated value
Snow Routine				
TT	Threshold Temperature	°C	[-2,0.5]	-0.3
CFMAX	Degree-day factor	mm °C^{-1} day^{-1}	[0.5,4]	2.384
SFCF	Snowfall correction factor	-	[0.5,0.9]	0.732
CHW	Water holding capacity	-	0.1 (Constant)	0.1
CFR	Refreezing coefficient	-	0.05 (Constant)	0.05
Soil Moisture Routine				
FC	Max. SM	mm	[100,550]	549.999
LP	SM threshold for reduction of Evap.	-	[0.3,1]	0.321
BETA	Shape coefficient	-	[1,5]	1
Response Routine				
Alpha	Non-linearity coefficient	-	[0,infinite]	0.168
K₁	Recession coefficient 1	day^{-1}	[0.001,0.2]	0.089
K₂	Recession coefficient 2	day^{-1}	[0.00005,0.1]	0.091
Routing Routine				
MAXBAS	Length of triangular weighting function	day	[1,100]	1.301
Others				
PART	Portion of recharge which is added to GW-Box 1	-	[0,1]	0.504
DELAY	Time period over which recharge is evenly distributed	t	[0,infinite]	4.293

Source: Help menu of HBV – Light software v4.0.0.1. The calibrated values are output of optimization of model parameters by GAP method.

B. Model Calibration and Validation

Model calibration is simply the process of optimization of a set of parameters of the model parameters while validation is the measures of the output of model fit to real world scenario. Calibration and validation of conceptual runoff models usually are limited to comparing simulated with observed stream flow at the basin outlet [30]. In present model structure there are fourteen parameters to be calibrated. The software HBV – Light v4.0.0.1 provides the options of two methods for calibration. One is Monte Carlo while the other one is Genetic Algorithm Powel Optimization (GAP) method. Author has given a trial of using both the methods but Monte Carlo method produces somewhat poor result in comparison to output of GAP method. Hence, finally GAP method has been applied for parameter optimization. The model has been calibrated for the period 24 June, 2003 to 31 October, 2008 while it is run for the period 1 January, 2000 to 31 December, 2015. The objective functions used here for judging the goodness of fit of the model are R2 and Nash-Sutcliff Coefficient [31] here called Coefficient of Efficiency (Reff) which is of the form:

$$R_{eff} = 1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \bar{Q}_{obs})^2} \text{................}[Eqn.12]$$

Here Qobs and Qsim are the observed and simulated runoff respectively. Its value ranges from (–) infinity to 1. The model is considered to be perfectly fitted if Reff =1; as good (poor) as the constant-value prediction if Reff = 0 and very poor fit if Reff <0.

VI. RESULT AND DISCUSSION

The value of objective functions (R2 = 0.901 and Reff = 0.867) indicates that the model is well capable of representing the real world hydrologic system pertaining to the district of Dakshin Dinajpur. Model performance generally depends upon two factors – the calibration efficiency of user and accuracy in preparing input data for the model. Table 3 shows the result of multiple linear regression model formulated for estimation of missing discharge data where square root of rainfall and normalized antecedent precipitation index (NAPI) are used as explanatory variables. Here p-value is quite satisfactory at 95% significance level while R2 and adjusted R2 value indicate that model is on and average acceptable. The result of data generation by applying HBV model and that of subsequent analysis using multiple linear regression have been presented in Table 4 to Table 6 and in Fig. 6.

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Table 3: The result of multiple linear regression model formulated for estimation of missing discharge data

Explanatory Variable	Coefficient	p-value	R^2	Adj R^2
Intercept	- 56.08	0.01	0.716	0.713
$Rainfall^{0.5}$	21.167	0.00		
NAPI	240.13	0.00		

Table 4: Output of HBV model run

Year	Rainfall	Runoff Total	Direct Runoff	Base Flow	AET[1]	SM[2]	Recharge
2000	1703.7	700.9	353.3	347.5	1151.4	60156.9	655.2
2001	1798.5	760.8	383.4	377.3	944.0	57383.1	761.6
2002	1657.3	635.2	320.1	315.1	1087.6	59357.7	634.5
2003	1688.0	624.9	315.0	309.9	1045.3	57089.2	626.6
2004	1612.9	593.8	299.2	294.6	1025.5	54859.4	592.5
2005	1647.2	680.0	342.7	337.2	926.1	57638.5	680.1
2006	1121.5	292.7	147.5	145.2	899.0	42095.9	292.7
2007	1517.6	611.8	308.3	303.4	917.8	51587.5	612.0
2008	1372.4	466.2	234.9	231.2	918.8	45585.1	466.1
2009	1181.7	377.3	190.1	187.1	783.2	40320.6	377.4
2010	1634.6	682.5	344.0	338.5	912.3	55555.1	683.0
2011	1462.6	524.8	264.5	260.3	983.0	50917.8	524.7
2012	1230.3	431.5	217.4	214.0	805.7	42189.9	431.2
2013	1431.4	482.6	243.2	239.3	895.3	47239.6	482.6
2014	1364.6	497.9	250.9	247.0	908.6	48688.3	498.3
2015	1572.1	575.0	289.8	285.2	992.2	52174.6	575.0

The statistical analysis (Table 6) shows that runoff total, base flow and ground water recharge on annual basis are influenced by two factors together; one is annual rainfall while the other is annual groundwater draft for irrigation. The former is positively related to them while there is negative impact of ground water withdrawal on hydrologic variables mentioned. The rainfall, on other hand, again has been identified as the sole influential factor for direct alteration of surface runoff, actual evaporation and soil moisture storage on annual basis. Increase or decrease in one unit of rainfall causes respectively increase or decrease in runoff total by 0.661 units, surface runoff by 0.31 units, base flow by 0.328 units, actual evaporation by 0.337 units, ground water recharge by 0.634 units and soil moisture storage by 30.924 units

Table 5: Result of Mann-Kendall Test

Variable	Time Step	Z_s	Sen's Estimator	Interpretation	Remarks
Rainfall	Annual	-2.57	-22.95	Sig. Decreasing	Test has been applied at 95% significance level
Rainy Day	Annual	-2.16	-1.2	Sig. Decreasing	
Runoff Total	Annual	-2.03	-13.57	Sig. Decreasing	
Direct Runoff	Annual	-2.03	-6.84	Sig. Decreasing	
Base Flow	Annual	-2.03	-6.73	Sig. Decreasing	
AET[1]	Annual	-2.39	-11.12	Sig. Decreasing	
Soil Moisture	Annual	-2.39	-795.31	Sig. Decreasing	
Recharge	Annual	-1.85	-12.03	No Trend	
GW Irri. Area[2]	Annual	-0.68	-0.34	No Trend	

Note: 1. Actual evaporation, 2. Groundwater irrigated area

Table 6: Result of Multiple Linear Regression formulated to assess the impact of natural and human factor on hydrologic processes

Response Variable	Explanatory Variables	Co-efficient	p-value	VIF	Adjusted R Square
Runoff Total	(Constant)	-395.295	0.000		0.953
	Rainfall	0.661	0.000	1.265	
	GW Irrigated Area	-1.751	0.027	1.265	
Direct Runoff	(Constant)	-183.939	0.000		0.936
	Rainfall	0.31	0.000	1	
Base Flow	(Constant)	-196.011	0.000		0.953
	Rainfall	0.328	0.000	1.265	
	GW Irrigated Area	-0.868	0.027	1.265	
Actual Evaporation	(Constant)	444.04	0.005		0.468
	Rainfall	0.337	0.002	1.000	
Groundwater Recharge	(Constant)	-373.809	0.000		0.946
	Rainfall	0.643	0.000	1.265	
	GW Irrigated Area	-1.619	0.047	1.265	
Soil Moisture Storage	(Constant)	5048.849	0.189		0.916
	Rainfall	30.924	0.000	1.000	

on annual basis (Table 6). Fourteen variables (including land use, crop occupied area etc.) were entered in the model and using stepwise method those variables which are proved to be insignificant have been excluded from the model. Rainfall and groundwater irrigation area have been accepted as influential for alteration of hydrologic processes base on p-value (accepted when it is <0.05) which are quite satisfactory (Table 6) at 95% significance level while VIF explain the existence of multi co-linearity in the data series. Those variables have been excluded from the model against which value of VIF is >1.75. It has earlier been stated that to substantiate the result of impact analysis of natural and human factor on hydrologic system Mann-Kendall test is used since the number of data point in time series generated by HBV model is sixteen only. The Mann-Kendall test result shows (Table 5) that all the hydrologic variables have been proved to be significantly decreasing over time on annual basis except ground water recharge. The groundwater irrigation area that

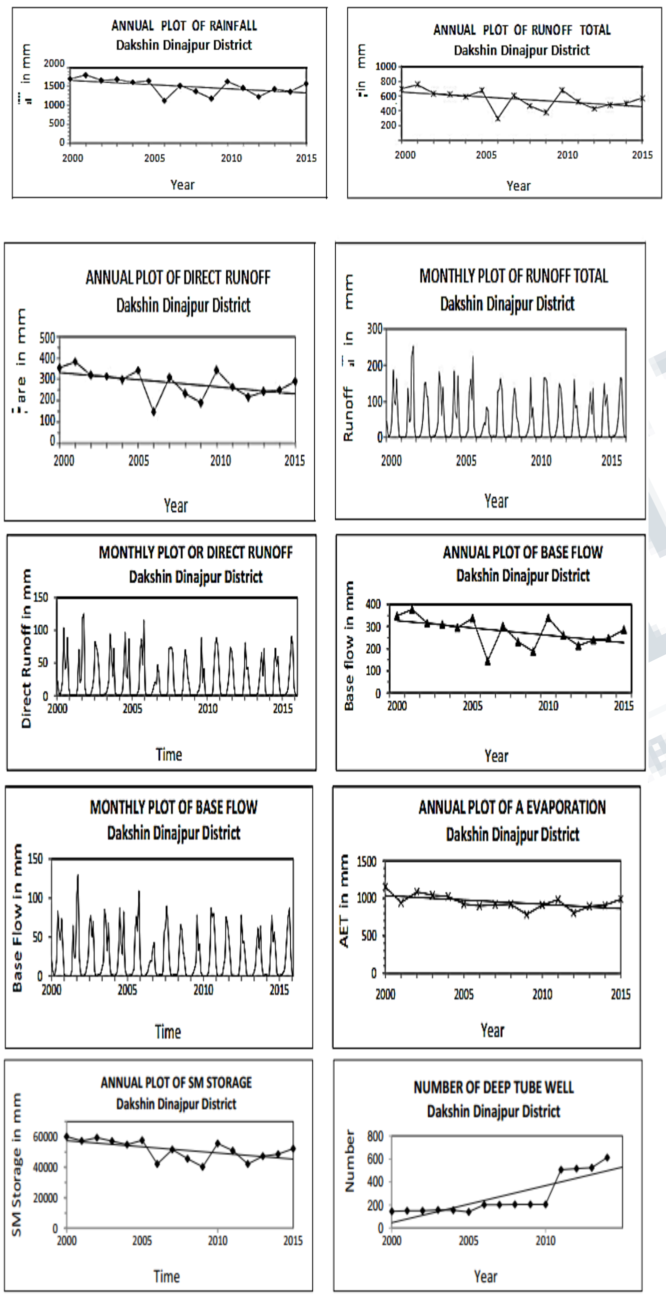

Fig. 6 Graphical presentation of variables generated as output of HBV model run while plot of tube well data is not related to the mode. The straight lines are the trend lines otherwise the lines show changing pattern of concerned variable over time.

has been the proved to be the sole human factor to exert influence on hydrologic process also shows no significant trend over time.

In last one and half decade there has been reduction in annual rainfall by about 22.61% with respect to base year in 2000. As the Sen's estimator value shows (Table 5), the annual rainfall is declining in the study area at the rate of 22.95 mm per year. Direct runoff on the other hand is decreasing at the rate of 6.84 mm per year. There is 29% reduction in direct runoff in last sixteen years. Base flow is also declining at the rate of 6.73 mm per year and it has been reduced on an average by about 30.76% with respect to its estimated value in the base year 2000. There is also declining trend of actual evaporation over the time at the rate of 11.12 mm per year. On an average it has been reduced in last sixteen years by about 14.56%. The soil moisture storage is declining at the rate of 795.3 mm per year which is much alarming. This parameter has been reduced by about 21% in last sixteen year. Reduction in rainfall can well explain the declining trend of base flow since former is positively related to latter but unchanged status of ground water irrigation area is not in compliance with that of base flow with which it is inversely related. The another event which seems to be discrepant is that in spite of declining trend of rainfall the ground water recharge remains unchanged.

To address this problem the attempt has been made to assess the trend of hydrologic variables for two separate periods – monsoon and non-monsoon. It is observed that monsoon rain that takes a share of about 73% of annual total remains almost same while non-monsoon rainfall is decreasing. In the study area recharge occurs directly from monsoon rain in four wet months starting from June ending at September. During October or sometime in November recharge occurs from depression storage. Non-monsoon rainfall cannot cause groundwater recharge since during this period almost all the rain water is spent in satisfying the interception zone and soil moisture zone. Direct runoff (here the term surface runoff is also used interchangeably with the term direct runoff) that is generated from monsoon rain is decreasing though the latter remains same. It might be due to fact that shortfall in rain during eight months of dry period results in depletion of soil moisture storage and also depletion of storage in other zones like interception zone and hence after long period of dryness when rain comes an increased portion of it goes to saturate the interception zone, soil moisture zone etc. i.e. initial abstraction loss might has been increased. Base flow on the other hand decreases due to increased dependency on groundwater for irrigation in lean season that is substantiated by the time series of data on number of deep tube well that shows increasing trend (Fig. 6)

VII. CONCLUSION

The hydrological processes in Dakshin Dinajpur distric is gradually changing in response to change in rainfall coupled with human interference through increased utilization of groundwater for irrigation use in lean season. There are two important outcomes of the present study: First, Annual rainfall is gradually decreasing in response to which runoff total, direct runoff, base flow, soil moisture, actual evaporation are declining day by day while groundwater recharge remains more or less uniform over last one and half decades. Groundwater recharge occurs directly from rainfall during monsoon period that starts at second week of June and ends at last week of September. Groundwater recharge continues even after withdrawal of monsoon and goes up to October and during this one month duration it occurs from depression storage like pond, natural water body etc. The ground water recharge remains unchanged since the monsoon rainfall remains almost same while decreasing rainfall portion is of non-monsoon period that cannot make groundwater recharge. Decrease in non-monsoon rainfall causes decrease in soil moisture storage and this shortfall in dry season rainfall also acts as limiting factor for actual evaporation. Now question arises why direct runoff that occurs mostly due to monsoon rain is decreasing while about 73% of total rain occurs during south west monsoon. It might be the cause that since there is short fall in dry period rainfall the soil moisture zone goes dry through most part of the year and hence a lion share of monsoon rain is used to satisfy the soil moisture zone initial abstraction loss is increasing that result in decrease in direct runoff. This assumption needs to be proved or disproved taking into consideration of abstraction loss in various zones like interception zone, soil moisture zone etc. and here lies the scope of further research. Second, important outcome is that for dry season crop cultivation farmers are compelled to withdraw more groundwater for its use in irrigation as indicated by the tube well data and this causes decrease in base flow (lean flow) of the rivers in the district. In experience of local people in general and farmers in particulars the four major rivers those were once perennial are now becoming intermittent ones. Farmers should go for cultivation of drought resistant traditional crop during dry season, otherwise the present rivers and water body will go dry in near future and there might be scarcity of even drinking water in coming era. So, not only proper planning in water resource management but that also in agriculture is the urgent need for the district. The database generated in present study is not sufficient for this purpose and this study assesses the phenomenon for very short period (only sixteen year). Further research is needed considering time series of long duration and also considering more variables like interception zone storage, irrigation intensity, population pressure etc. to address the problems.

REFERENCES

[1]. A. AghaKouchak and E. Habib, "Application of a conceptual hydrologic model in teaching hydrological processes", International Journal of Engineering Education, vol. 26, no. 4, pp. 963-973, 2010.

[2]. B. Bates, Z. W. Kundzewicz, Shaohong Wu and J. Palutikof, (ed.) "Climate change and water", Technical Paper of the Intergovernmental Panel on Climate Change (Geneva: IPCC Secretariat). pp 210-214, June, 2008.

[3]. I.M. Ferguson and R.M. Maxwell, "The role of groundwater in watershed response and land surface feedbacks under climate change", Water Resources and Research. 46: W00F02, 2010.

[4]. Kevin E. Trenberth, Aiguo Dai, Roy M. Rasmussen, and David B. Parsons, "The changing character of precipitation", Bulletin of American Meteorological Society, vol. 84, pp. 1205-17, September, 2003.

[5]. Claudia C. Faunt, Kenneth Belitz, and Randall T. Hanson,"GroundwaterAvailabilityin California's Central Valley" in "Groundwater availabililty of the Central Valley aquifer" (edited by C.C. Faunt), California.United States Geological Survey Professinal Paper 1766 (Reston, VA: USGS), pp. 59-120, 2009.

[6]. Enli Wang, Qiang Yu,Dingrong Wu,Jun Xia, "Climate, agricultural production and hydrological balance in the North China Plain", International Journal of Climatology, vol. 28, pp. 1959-1970, March, 2008.

[7]. E.P. Odum and G.W. Barrett, "Fundamentals of Ecology", Thomson Business Information India Pvt. Ltd., India, ISBN: 81-315-0020-9; pp. 10-11, 2005.

[8]. E.L. Ndulue, C.C. Mbajiorgu, S.N. Ugwu, V. Ogwo and K.N. Ogbu, "Assessment of land use/cover impacts on runoff and sediment yield using hydrologic models: A review", Journal of Ecology and Natural Environment, vol. 7, no. 2, pp. 46-55, 2015.

[9]. V.P. Sing and D.A. Woolhiser, "Mathematical Modeling of Watershed Hydrology", J. Hydrol. Eng. ASCE, vol. 7 no. 4, pp. 269-343, 2002.

[10]. Anonymous, "Estimation of direct runoff from storm rainfall", in Chapter:10, National Engineering Handbook, Part-630 (Hydrology), Natural Resources Conservation Service, USDA, pp. 10.1-10.20, July, 2004.

[11]. R.K. Paul, "Impact of natural and man-induced factors on alteration of runoff: a case study in Dakshin Dinajpur district of West Bengal", Geo-Analyst, pp. 1-12, December, 2015

[12]. Anonymous, "District Resource Map, South Dinajpur, West Bengal", GSI, Govt. of India, 2009.

[13]. India Meteorological Department "Climate of West Bengal", Controller of Publications, Department of Publications, Govt. of India, Civil Lines, New Delhi-54, 2008.

[14]. D.C. Nayak, D. Sarkar, M. Velayutham, "Soil Series of West Bengal", NBSS Pub. No. 89, NBSS&LUP, Nagpur, 2001

[15]. Govt. of India "District Census Handbook, Dakshin Dinajpur, Village and Town Directory, Series: 20, Part-XII-A", Directorate of Census Operations, West Bengal, 2011.

[16]. Govt. of West Bengal, "District Statistical Hand Book, Dakshin Dinajpur", Bureau of Applied Economics and Statistics, Govt. of West Begnal, (of several year, 2000-2014).

[17]. Anonymous, "Indian Road Congress Special Publication No. 13", 2004.

[18]. P.J.R Reddy, "A Textbook of Hydrology", Third Edition, University Science Press, New Delhi. pp. 131, 2011.

[19]. Anonymous, "Crop evaporation - Guidelines for computing crop water requirements", FAO – Food and Agriculture Organization of the United Nations (Ed.), FAO Irrigation and drainage paper No. 56, Rome: FAO, 1998

[20]. S.K. Garg, "Hydrology and Water Resources Engineering" (seventh edn), Khanna Publishers, New Delhi, India, 1987.

[21]. S. Bergström, "Utvechling och tillämpning av en digital avrinningsmodell" (Development and application of a digital runoff model, in Swedish), SMHI (Swedish Meteorological and Hydrological Institute), Notiser och preliminära rapporter, serie HYDROLOGI, No. 22, Norrköping, 1972.

[22]. S. Bergström, "Development and application of a conceptual runoff model for Scandinavian catchments", SMHI RHO 7, Norrköping, pp.134, 1976.

[23]. S. Bergström, "Parametervärden för HBV-modelleni Sverige, Erfarenheter från modelkalibreringar under perioden 1975-1989" (Parametervalues for the HBV model in Sweden, in Swedish), SMHI Hydrologi, No.28, Norrköping, pp.35, 1990.

[24]. S. Bergström, "The HBV model - its structure and applications", SMHI RH No 4. Norrköping, pp. 35, 1992.

[25]. W.H. Press, Brian P. Flannery, Saul A. Teukolsky, William T. Vetterling, "Numerical recipes in FORTRAN: The art of scientific computing", 2nd edition, Cambridge University Press, Cambridge, Great Britain, 1992.

[26]. G. Lindström, and S. Bergström, "Improving the HBV and PULSE-models by use of temperature anomalies", Vannet I Norden 1, pp.16–23, 1992.

[27]. J. Seibert, "User's Manual of HBV light version 2", Dept. of Physical Geography and Quaternary Geology, Stockholm University, Sweden, 2005.

[28]. K. Stahl, et al. "Coupled modelling of glacier and stream flow response to future climate scenarios", Water Resour. Res., vol. 42, no. 2, p. 13, 2008.

[29]. J. Seibert, "Estimation of parameter uncertainty in the HBV model", Nordic Hydrology, vo. 28, no. 4/5, pp. 247-262, 1997.

[30]. J. Seibert, "Multi-criteria calibration of a conceptual runoff model using a genetic algorithm", Hydrology and Earth System Science, vol. 4, no. 2, pp. 215-224, 2000.

[31]. J.E. Nash and J.V. Sutcliffe, "River flow forecasting through conceptual models, part 1-a discussion of principles", Journal of Hydrology., vol. 10, pp. 282-290, 1970.

