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Sensitivity Analysis of Physiographic Parameters in Eastern Region of Bangladesh

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Abstract: *Discharge estimation from rainfall event is a very difficult task due to various influencing factors. Various physiographic parameters play a vital role for surface and channel flow. Actual field values of several hydrological event parameters are sometimes impossible to ascertain in developing country like Bangladesh. Hydrological model can be used to measure the discharge and physiographic parameter. Discharge for Khowai river basin, one of the important basin in Bangladesh is simulated for period 1995-2016 using a semi-distributed model Soil and water Assessment Tool (SWAT). Model calibration and validation have been performed for daily time periods using Sequential Uncertainty Fitting version 2(SUFI-2) algorithm within SWAT-CUP (SWAT Calibration Uncertainty program) using 22 physiographic parameters. Our calibration outputs for the period 2000-2008 showed good correlation between observed and model simulated values with NSE=0.81 and R^2=0.86. During Validation period from 2009-2016 the NSE and R^2 were 0.69 and 0.78 respectively which are reasonable. Sensitivity analysis is an integral part of model development and involves analytical examination of input parameters to aid in model validation and provide guidance for future research. Sensitivities of 22 input parameters have been analyzed using SUFI-2 algorithm in SWAT-CUP. It is done by global and one-at-a-time sensitivity procedures. For Khowai river four parameters show most sensitive for both of global and one-at-a-time sensitivity procedures. They are SCS surface runoff curve (CN2.mgt), base flow alpha factor for bank storage (ALPHA_BNK.rte), ground water delay time (GW_DELAY.gw), Soil evaporation and compensation factor (ESCO.hru). From the study that focusing on sensitive parameters can lead to a better understanding and to better estimated values and thus reduced uncertainty of model and it helped to simulate reliable local hydrology of watershed of Bangladesh.*

Keywords: SWAT, SUFI 2, Khowai River, Calibration and Validation

1. Introduction

Bangladesh is a riverine country and highly vulnerable to climatic extremes [1]. South Asian country Bangladesh is located between 20°34′ to 26°38′ north latitude and 88°01′ to 92°42′ east longitude, with an area of 1,47,610 sqkm. The eastern region of Bangladesh is unique due to its hydro-ecological characteristics such as heavy rainfall, temperature effect, soil and land use change and humidity [2]. This region is also known for its many small streams and rivers. Khowai is one of the small river systems in eastern region of Bangladesh. The course of Khowai is from its origination in the eastern part of Atharamura hills of Tripura in India and enters the Bangladesh in Ballah area of Sylhet district [3]. With the entry into Sylhet in Bangladesh, the course continues into eastern side of Bangladesh through crossing the eastside Habiganj town before falls into Kushiyara at Kishorgonj district. Because of the flows, physiographic features, and their sensitivity, the Khowai River is worth researching. Once it crosses India's borders in the northeastern area, the scenario changes. The Khowai River is limelight for typical roles in Bangladesh and India for causing floods. According to the source of water development board, Bangladesh, water of the Khowai River was flowing 270 cm above danger level at Masuli point in Habigonj on June 20, 2017. The river often causes natural calamities there. It should be noted that agriculture and irrigation of that region depend on the behavior of the river. Attempts have also been made to reorganize those areas through which Khowai River passes to ensure that areas avail maximum advantages. Worse consequence is also there at the same juncture but steps are taken to suppress them. The rate of channel migration of Khowai river basin is assessed and variation of sinuosity index and radius of curvature also calculated [4]. Flash flood risk assessment for upper Teesta River basin is studied by Mandal et al [5] by using the hydrological modeling system (HEC-HMS) software to simulate the hydraulics characteristics of the Teesta Basin for a flash flood. Khadiza et al [6] used a semi distributed model to measure river discharge for Meghna River basin in eastern region of Bangladesh. The flow characteristics of the Teesta River were analyzed by calculating monthly maximum and minimum water levels and discharges from 1985 to 2006 by Mondal et al [7] and observed discharge of the Teesta over the last 22 years has been decreasing. Pradhan et al also estimated the Rainfall Runoff using Remote Sensing and GIS in and around Singtam, East Sikkim [8], but there are not so many studies to sensitivity analysis of physiographic parameters by using SWAT-CUP in Bangladeshi river basin where the SWAT model has been successfully applied in agricultural watersheds across many US states and other continents. [9-15]. The purpose of the study is to measure the discharge of the Khowai River basin along with soil type, land use and others hydrological and meteorological data corresponds with by using different software and then compare the simulated data with observed data. After that we analyzed physiographic parameters which are sensitive to discharge and affect the flow of river and those can be used to measure discharge when observe data are not available.

2. Study area and methods

2.1 Study Area

Khowai River is a trans-boundary river that originates from the eastern part of the Atharamura Hills of Tripura in India. It is the third longest river of Tripura. Khowai has a length of 224 km of which 91 km lies within Bangladesh. Average width is 106 meter and flow path of the river is spiral. Flowing north-west, it leaves India at Khowai, and enters Bangladesh at Balla in Habiganj District. The river passes east of Habiganj town. North of town it turns west, and joins the Kushiyara river in Astagram Upozilla, Kishorgonj District. Khowai is one of the major tributaries of Meghna river basin. This river supports other rivers or streams through tributaries. Khowai river basin is surrounding by Meghna river basin in the north and west in Bangladesh, Gumti river basin in the south and Dhalai river basin in the east in India. The specific area of Khowai river basin for study area is shown in Figure 1.

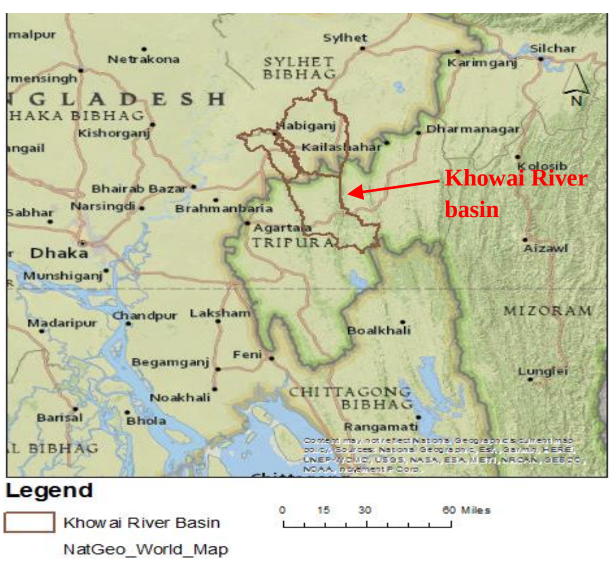

Figure 1: Khowai basin, the light red transparent line marks basin boundary

2.2 Methods

The Soil and Water Assessment Tool (SWAT) model is physically based and provides distributed descriptions of hydrologic process at sub-basin scale developed by United States Department of Agriculture (USDA) [16-18]. SWAT model performance can be optimized by assigning parameter values based on hydrological characteristics. Some of parameters can be fixed on the basis of pre-existing catchment data or knowledge gained in other studies. However, values for other parameters need to assigned during a calibration process as a result of complex spatial and temporal variations that are not readily captured either through measurements or within the model algorithms themselves [19]. The hydrologic cycle as simulated by SWAT is based on the water balance equation

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{sep} - Q_{gw}\right)$$

where t is the time in days, SW_t and SW_0 are the final and initial soil water content on day i (mm H_2O) respectively, Q_{surf} is the amount of surface runoff on the day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{sep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O). Surface runoff can be estimated by the model using Soil Conversation Service (SCS) curve number method [20]. This method is widely used for the predicting the approximate amount of runoff from a given rainfall event. Soil properties, land use and hydrologic condition are the main factors to evaluate runoff from this method. The SCS curve number equation is

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$

where R_{day} is the rainfall depth for the day (mm) and S is the retention parameter (mm). The retention parameter and perdition of lateral flow by SWAT model are computed as bellow

$$S = 25.4\left(\frac{100}{CN} - 10\right)$$

where CN is the curve number. Lateral flow is computed as

$$q_{lat} = 0.024\frac{2SSCsin\alpha}{\theta_d L}$$

where q_{lat} is later flow (mm/day), S is drainable volume of soil water per unit of saturated thickness (mm/day), SC is saturated hydraulic conductivity (mm/h), α is slope of the land, θ_d is drainable porosity, L is flow length (m).

A large number of specialized and time series datasets are required to simulate the water balance of a watershed using the SWAT model to establish the water balance [21]. For developing hydrological model different types of data are used such as:

- DEM (Digital Elevation Model)
- Land-use Data
- Soil data

- Climate data (Precipitation, Temperature, Humidity, Wind speed, Solar radiation)
- Hydrological data (River discharge, Water level, Water temperature, Water pressure)

These data are required for developing SWAT model which are collected from different sources such as Bangladesh Meteorological Department (BMD), Bangladesh Water Development Board (BWDB), United States of Geological Survey (USGS), Food and Agriculture Organization (FAO) etc. Data used for SWAT model development and corresponding data sources are given in the following table.

Table 1: Data used for SWAT model development and the data sources

Variable Name	Data Source
Digital Elevation Model	STRM
Land use Map	GLOBCOVER
Soil Map	FAO-UNESCO
Climate	BMD
Discharge Data	BWDB
Stream Network Data	USGS Hydro-SHEDS

2.2.1 Digital Elevation Model

The SRTM (Suttle Radar Topography Mission) 90m resolution Digital Elevation Model is used in this work. It is downloading from open source of (http://srtm.csi.cgiar.org/). Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution [22]. DEM (Digital Elevation Model) was processed according to study area for input and then by using river shape extracted the flow direction, flow accumulation, stream network generation and delineation of the watershed and sub-basins. There are 3 sub-basins were produced and DEM ranges from 0 m to 462 m (**Fig. 2**)

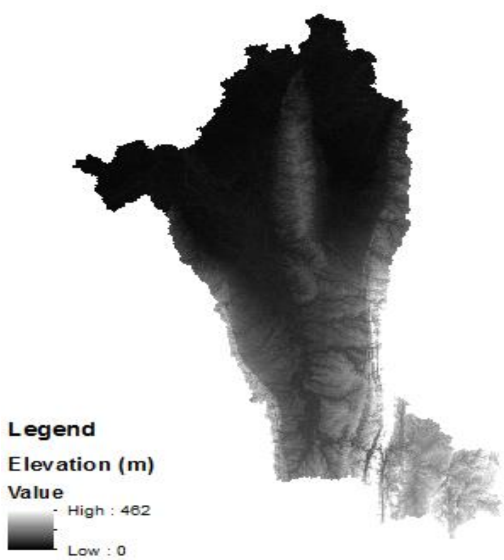

Figure 2: DEM for Khowai River Basin

2.2.2 Stream Network

The digital stream network is necessary for watershed delineation. The digital stream network data is available from United States Geological Survey (USGS) Hydro-SHEDS at http://hydrosheds.cr.usgs.gov/index.php. Hydro-SHEDS deliver data in various regional extents, types, and

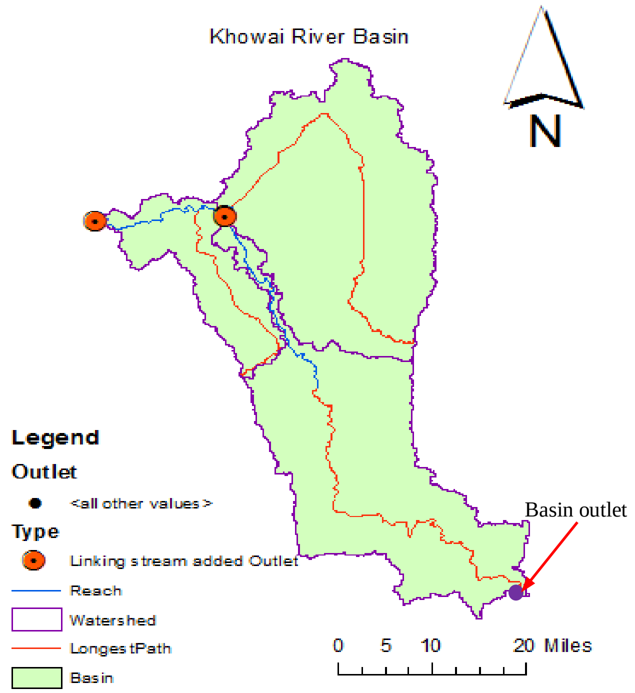

Figure 3: Watershed and outlet for Khowai river basin

resolutions. For this study the used data resolution was 15s. The watershed is delineated using watershed delineation tool in SWAT with using DEM and stream network as an input in the SWAT model. Khowai River basin is divided into 3 sub-basins and sub-basins are divided into 31 HRUs based on soil type, land use and slope classes that allow a high level of spatial detail simulation (Fig. 3). We have taken the basin outlet to measure simulated discharge which is used for measuring river flow. The Figure 3 reveals the watershed and outlet of Khowai River basin. The red dots are indicated the linking stream added outlets and purple dot is indicated the manually added outlet of basin.

2.2.3 Land Use

Land-use changes have a great impact on flooding and water cycle. Land use is one of the most important factors that affect surface erosion, runoff, and evapotranspiration in a watershed [23]. Land cover data was taken from ESA (European Space Agency) Glob-cover Project with resolution of 300 m. The data is available at http://due.esrin.esa.int/page_globcover.php.

Table 2 represents the value and label of the land use classification in study area. The data input as raster file and also define as lookup table. The Global land cover has about

80 classifications grouped into eight major categories [24]. For Khowai basin the dominate categories of classes are post-flooding or irrigation croplands (or aquatic) and closed to open (>15%) mixed broadleaved and needle leaved forest and lowest is closed (> 40%) broadleaved deciduous forest (> 5m), Open (15-40%) broadleaved deciduous forest/woodland (>5m) and water body. So, the area is agricultural dominant area. The land use patterns of the study area is presented in Figure 4.

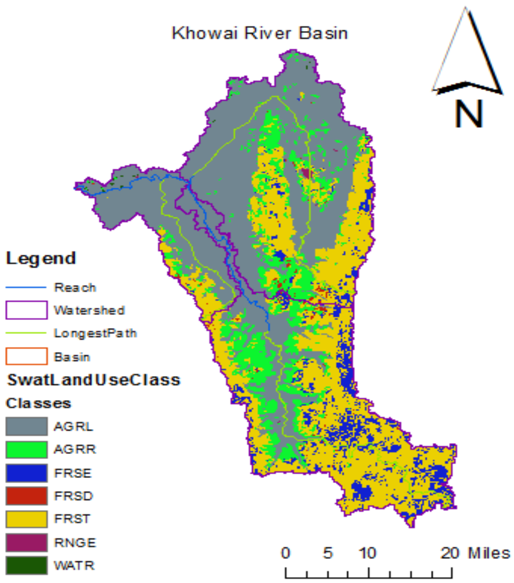

Figure 4: Major Land-Use in Khowai River Basin

Table 2 represents the value and label of the of the land use classification in study area. The data input as raster file and define as lookup table. In Khowai River basin there are 7 types of different land use (Table 2). Most of the land (47.05%) is covered by Agricultural Land Generic followed by forest-mixed (32.25%), Agricultural Land-Row Crops (12.31%) and so on. The lowest portion of land is used for water bodies (0.09%).

Table 2: Land use of Khowai River Basin

Code	Land-use	Percentage of area (%)
AGRL	Agricultural Land-Generic	47.05
AGRR	Agricultural Land-Row Crops	12.31
FRSE	Forest-Evergreen	7.55
FRSD	Forest-Deciduous	0.6
FRST	Forest-Mixed	32.25
RNGE	Range-Grasses	0.14
WATR	Water bodies	0.09

2.2.4 Soil Data

Soil data is significant for the SWAT model; SWAT model requires physiochemical properties and soil textures of different types. Soil data input as a shape file and collected from FAO-UNESCO Soil Map of the world at htt://www.fao.org/soils-portal/. The scale of digitized soil map is 1:5.000.000 scale range. After input soil shape file then by lookup table use SNUM, a sequential code number that ranges from 1 to 6,997, unique for each soil mapping. Depending on hydraulic conductivity soil are divided into four hydrologic groups. They are Hydrologic group A, B, C and D. Two types of soil were found in Khowai basin area as, Bd61-2c-3665, Ge51-2a-3707 which is shown in Figure 5.

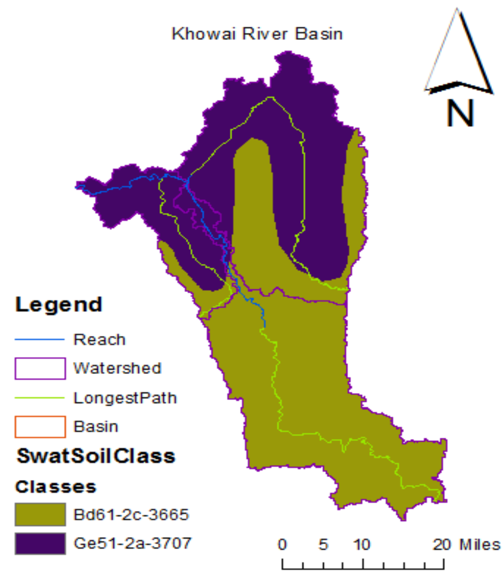

Figure 5: FAO soil types in the Khowai River Basin

Hydrologic group A having highly infiltration rates, group B having moderate infiltration rates, group C having slow infiltration rates and group D having very slow infiltration rates even when thoroughly wetted. Surface flow depends on soil initial condition and soil texture. In a barren land surface soil is easily eroded and soil erosion is less in forest land. Soil profile of Khowai flood plain in the upstream found most of the plain land is sandy soil or sandy loam. The soil is mainly formed by sedimentation and currents of Khowai River. Soil has great impact to store precipitation; different soil has different capacities to absorb rainfall. Sandy soil holds less water than clay soil and loamy soil. Clay soil holds more water than sandy soil. Sand absorbs less water than clay. Table 3 reveals the FAO soil types of Khowai River Basin with hydrologic code, texture, percentage of total watershed area and the quantity of Clay, Silt, Sand and Rock.

Table 3: FAO soil description

SNUM (Sequential code)	Hydrologic group	Texture	CLAY (%)	SILT (%)	SAND (%)	ROCK (%)	Percentage of area (%)
Bd61-2c-3665	C	LOAM	22	34	44	0	57.2
Ge51-2a-3707	C	LOAM	24	36	40	0	42.8

2.2.5 Meteorological Data

SWAT model require a large amount of meteorological data for model run. The meteorological data are collected from Bangladesh Meteorological Department (BMD) [25]. For SWAT model precipitation, temperature (max and min), solar radiation, wind speed, and humidity data are required to run the model where the records of precipitation and temperature are the minimum mandatory inputs and the other parameters are optional [26]. One of the main sets of input for simulating the watershed in SWAT is weather data [27]. Meteorological data of Srimangal station which latitude is 24.30N and longitude is 91.73E are used from 1995 to 2016 for this study. SWAT use Meteorological data for simulation performed for the watershed in a short listed below:

- Input data time Series: Daily data
- Simulation period: (1995-2016)
- Precipitation: Daily (mm)
- Temperature: Maximum and Minimum (Daily)
- Relative Humidity (%): Daily
- Wind Speed (m/s): Daily

In SWAT model the weather data definition dialog is divided in six tabs: Weather Generator data, Rainfall data, Temperature data, Solar Radiation data, Wind speed data and Relative Humidity data. Weather station location and weather generator data are obtained from two sources: one of the built-in US databases or the User Weather Stations database. In SWAT model we have used temperature and precipitation as weather data from period: 1995-2016. The model can read these inputs directly from the file or generate the value using daily averaged data analyzed for a number of years. It includes the WGEN weather generator model [28] to generate climate data or to fill in gaps in measured records. The weather generator first independently generates precipitation for the day, followed by generation of maximum and minimum temperature, wind speed and relative humidity.

2.2.6 Hydrological Data

Hydrological data water level and discharge are the main input of SWAT model. They are collected from Bangladesh Water Development Board [29]. Daily discharge data from 2000-2016 of Shaistaganj station of Habiganj are used for model simulation.

3. Observed Results

Precipitation, temperature, wind speed, relative humidity and solar radiation data in the period 1995-2016 are used to run SWAT model. But some limitation of observed discharge data, we have simulated the model from 2000 to 2016.

3.1 Temperature

The Temperature data has been calculated as daily based and considered as averaged Maximum-Minimum temperature. The maximum temperature occurs in the month of July, August and sometimes in April where the minimum temperature occurs in the month of November to January. The daily averaged maximum-minimum temperature is shown in the following Figure 6.

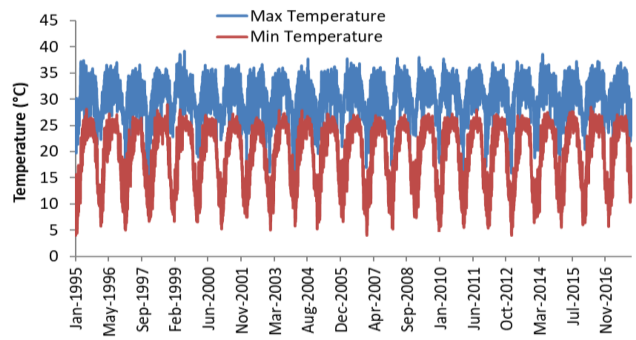

Figure 6: Daily average maximum and minimum temperature

3.2 Discharge with Precipitation

One of the main factors of discharge is precipitation. There are some similarities between observed discharge and precipitation, typically as precipitation increases, discharge increases as well. Peak discharge normally happens during periods of heavy precipitation. Figure 7 below displays the discharge and precipitation data for the Khowai basin from 2000 to 2016.

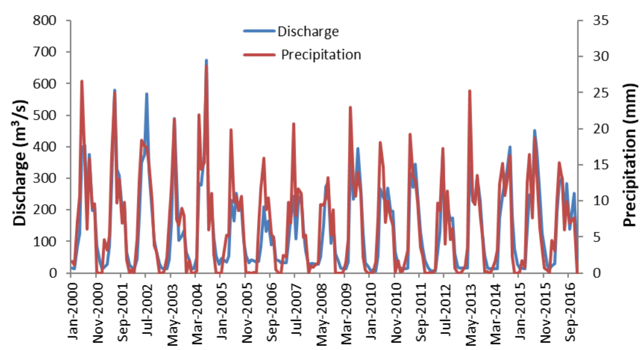

Figure 7: Comparison between observed discharge and precipitation

From Figure 7 we can easily see that peak discharge is occurred at the time of high precipitation and vice versa. In addition, we observed that there is some lag between peak precipitation and peak discharge, it is because there need sometimes to occur surface or river flow after precipitation, and it is called lag time.

4. SWAT-CUP for Calibration and Validation

Calibration means adjustment of the model parameters so that simulated and observed data will match within the desired accuracy. Model parameters may require adjustment due to a number of reasons. There are numerous parameters in hydrological models which can be classified as physical parameters (i.e., parameters that can be physically measurable from the properties of watershed) and process parameters (i.e, parameters represent properties which are not directly measurable) [30]. In reality, all models require some degree of calibration to fine tune the predictive ability of the model. For calibration and validation SWAT-CUP 2012 version was used. SWAT-CUP is a computer program and it helps for sensitivity analysis, calibration and validation and uncertainty analysis of SWAT model [31]. Calibration and validation of the model were done using the SUFI-2 approach within SWAT-CUP considering 22 key hydrological parameters. Then, each parameter was set to default lower and upper values as suggested by the SWAT expert group [32]. Finally, the best fitted parameter values obtained from SWAT-CUP were incorporated into the SWAT database for stream discharge simulations. The model performance was evaluated using Nash-Sutcliffe efficiency (NSE) [33], coefficient of determination (R^2) and percentage of bias (PBIAS), RMSE-observations standard deviation ratio (RSR) [34]. The calibration and validation periods have been selected from 2000 to 2008 and from 2009 to 2016 respectively. Some parameters had greater influence on the shape and magnitude of the output hydrographs.

5. Evaluation of Model Efficiency

The calibration and validation were carried out with four different statistical methods, coefficient of determination (R^2), the Nash and Sutcliffe efficiency (NSE), Percent Bias and RMSE-observation standard deviation ratio (RSR). The R^2 value is an indicator of the strength of the linear relationship between the observed and simulated values. The NSE is a normalized statistic method used for the prediction of relative amount of noise compared with information. If the R^2 and NSE values are less than or very close to zero, the model prediction is unacceptable or poor. When the values are one, the model's prediction is accurate [35]. Model simulation is generally considered to be satisfactory if R^2 >0.75 [36] and NSE > 0.50 for stream flow [37]. R^2 and NSE are statistically defined as follows

$$R^2 = \left(\frac{\sum_{i=0}^{n}(Q_{0bs} - \bar{Q}_{obs})(Q_{sim} - \bar{Q}_{sim})}{\sqrt{\sum_{i=0}^{n}(Q_{obs} - \bar{Q}_{obs})^2}\sqrt{\sum_{i=0}^{n}(Q_{sim} - \bar{Q}_{sim})^2}} \right)^2$$

and

$$NSE = 1 - \frac{\sum_{i=0}^{n}(Q_{obs} - \bar{Q}_{sim})^2}{\sum_{i=0}^{n}(Q_{sim} - \bar{Q}_{obs})^2}$$

where Q_{obs} is the observed data on day i, Q_{sim} is the simulated output on day i, $\bar{Q}_{obs}$ is the mean observed data during study period, $\bar{Q}_{sim}$ is the mean simulated data during study period and n is the total number of observed data.

Percent Bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts [38]. PBIAS values 0 is the optimum value; the small value is more preferred. Positive values indicate model overestimation bias, and negative values indicate underestimation model bias. The PBIAS is calculated with the following equation:

$$PBIAS = 100 \times \frac{\sum_{i=0}^{n}(Q_{obs} - Q_{sim})}{\sum_{i=0}^{n}(Q_{obs})}$$

One of the most used error index statistics is RMSE [39-41]. RSR is calculated as the ratio of the RMSE and standard deviation of observation data, is shown in the following equation

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=0}^{n}(Q_{obs} - Q_{sim})^2}}{\sqrt{\sum_{i=0}^{n}(Q_{obs} - \bar{Q}_{sim})^2}}$$

RSR varies from the optimal value of 0 (perfect model simulation) to a large positive value. The lower RSR, the lower the RMSE, and the better the model simulation performance.

6. Results and Discussion

Hydrological model SWAT have been used for measuring discharge of Khowai river basin. Model calibration and validation is very important for evaluating model performance. Sensitivity analysis is an integral part of model development. Sensitivities of 22 parameters have been analyzed using the SUFI-2 algorithm in SWAT_CUP. For Khowai basin four input parameters show the most sensitive for both of one-at-a-time and global sensitivity procedure, including SCS runoff curve number (CN2.mgt), baseflow alpha factor for bank storage (ALPHA_BNK.rte), groundwater delay time (GW_DELAY.gw), soil evaporation compensation factor (ESCO.hru).

6.1 Parameter Sensitivity

We have used two methods for analyzing sensitivity of parameters: 1) one-at-a-time and 2) Global sensitivity method. The result of local (one-at-a-time) and global sensitivity are shown and discussed in the following subsections.

6.1.1 One-at-a-time sensitivity

The One-at-a-time sensitivity demonstrates the sensitivity of a variable to the changes in a parameter if all other parameters are kept constant at some value. For one at a time sensitivity analysis, the SCS runoff curve number (CN2) was found most sensitive parameter fo Khowai river basin. Parameter like a groundwater delay (GW_DELAY) and base flow alpha factor for bank storage (ALPHA_BNK) showed higher sensitivity as well. The effective hydraulic conductivity in main channel alluvium (CH_K2.rte) was evaluated the very sensitive input parameter using one at a time sensitivity analysis.

The dashed line is the observed discharge and simulated discharged is plotted for five values of CN2.mgt keeping others fixed within the specified range of calibration by SUFI-2 process in SWAT-CUP. We can see that, CN2 is highly sensitive because for different values of CN2 simulated discharge curve is different. If CN2 is increasing, then simulated discharge curve is increasing and if CN2 is decreasing then simulated discharge curve is decreasing. So CN2 is one of the sensitive parameters influences simulated discharge.

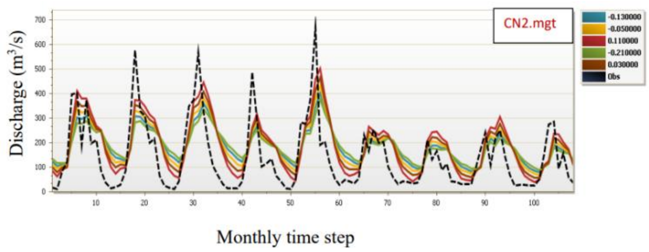

Figure 8: Sensitivity of CN2 on discharge for five different values in one-at-a-time method

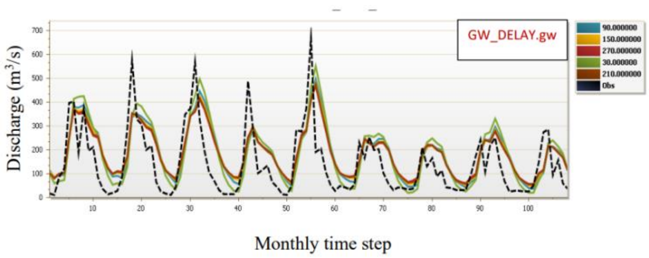

Figure 9: Sensitivity of GW_DELAY on discharge for five different values in one-at-a-time method

The dashed line is the observed discharge and simulated discharged is plotted for five values of GW_DELAY.gw keeping others fixed within the specified range of calibration by SUFI-2 process in SWAT-CUP. From Figure 8 we see that, GW_DELAY is sensitive in dry and rainy season and shows opposite characteristic in two seasons. In dry season, simulated discharge increases when GW_DELAY increases and simulated discharge decreases when GW_DELAY decreases. In rainy season, simulated discharge increases when GW_DELAY decreases. Clearly, GW_DELAY is also sensitive as the simulated graph varies when GW_DELAY value changes.

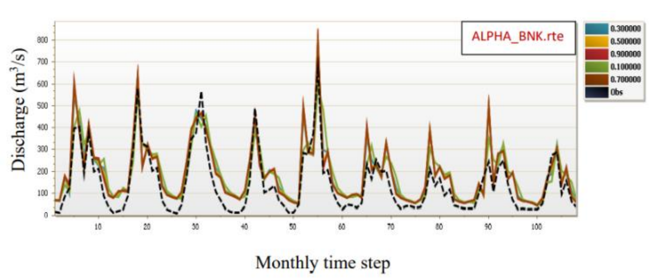

Figure 10: Sensitivity of ALPHA_BNK on discharge for five different values in one-at-a-time method

Similarly, ALPHA_BNK.rte is sensitive as the simulated graph varies when ALPHA_BNK value changes. Simulated discharge increases when ALPHA_BNK value decreases and vise-versa.

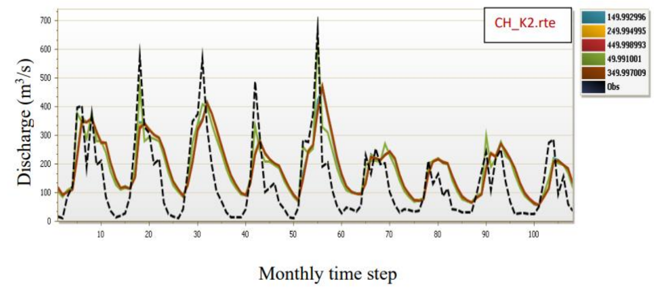

Figure 11: Sensitivity of CH_K2 on discharge for five different values in one-at-a-time method

Figure 11 shows that, CH_K2.rte have great impact on the simulated discharge graph. We can see that, in pre-monsoon, simulated discharge is increasing when CH_K2 is decreasing and vise-versa. In post-monsoon, simulated discharge is increasing when CH_K2 is increasing. So, CH_K2 is sensitive parameter in one-at-a-time analysis.

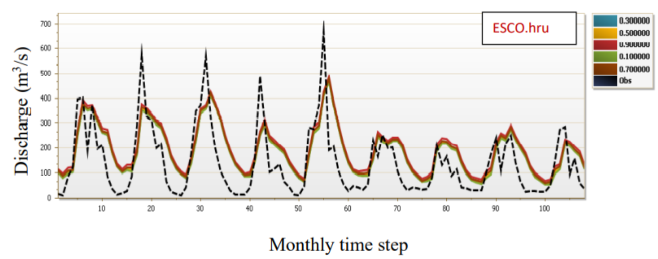

Figure 12: Sensitivity of ESCO on discharge for five different values in one-at-a-time method

Here also dashed line is the observed discharge and simulated discharged is plotted for five values ESCO.hru keeping others fixed within the specified range of calibration by SUFI-2 process in SWAT-CUP. We can see that, ESCO influences the simulated discharge slightly. Thus CN2, GW_DELAY, ALPHA_BNK, CH_K2 and ESCO are sensitive and other parameters are not so sensitive under one at a time sensitivity analysis because they do not influence so much the simulated discharge.

6.1.2 Global sensitivity

The most sensitive input parameter was identified on the basis of t-stat and p-value of global sensitivity analysis in the Figure 13. In this analysis, the larger in absolute value of t stat and the smaller the p-value, the more sensitive the parameter [31].

The output of assessment of global sensitivity procedure shows that about seven parameters are considered sensitive in the study area. The output is highlighted in Table 4. Base flow alpha factor for bank storage (ALPHA_BNK), Soil evaporation compensation factor (ESCO), Groundwater delay time (GW_DELAY), SCS runoff curve number (CN2) are top four input parameter in the study area.

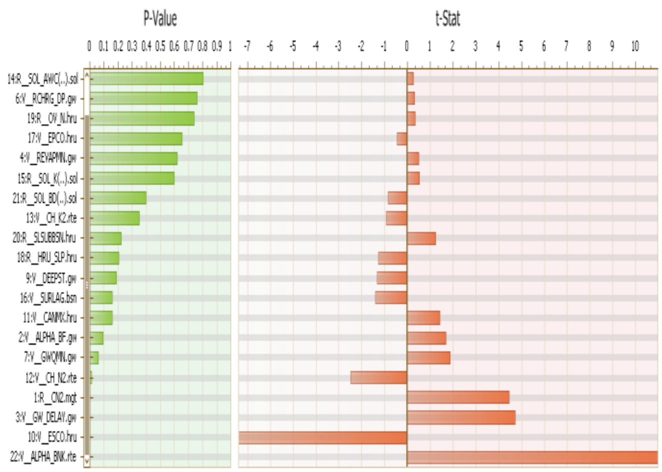

Figure 13: Global sensitivity by t-stat and p-value

Table 4: Summary of the global sensitivity analysis

No.	SWAT input parameter	Global sensitivity		
		t-stat	p-value	Ranking
1	CN2.mgt	4.4425	0	4
2	ALPHA_BF	1.6839	0.0927	7
3	GW_DELAY.gw	4.7091	0	3
4	REVAPMN.gw	0.4958	0.6201	17
5	GW_REVAP.gw	0.2055	0.8371	21
6	RCHRG_DP.gw	0.3071	0.7588	19
7	GWQMN.gw	1.8762	0.0611	6
8	SHALLST.gw	-0.2	0.8413	22
9	DEEPST.gw	-1.314	0.1892	11
10	ESCO.hru	-7.391	0	2
11	CANMX.hru	1.4189	0.1564	8
12	CH_N2.rte	-2.484	0.0132	5
13	CH_K2.rte	-0.937	0.349	14
14	SOL_AWC.sol	0.2499	0.8026	20
15	SOL_K.sol	0.5278	0.5978	16
16	SURLAG.bsn	-1.411	0.1588	10
17	EPCO.hru	-0.448	0.6543	18
18	HRU_SLP.hru	-1.274	0.2032	12
19	OV_N.hru	0.3338	0.7386	18
20	SLSUBBSN.hru	1.2251	0.221	13
21	SOL_BD.sol	-0.849	0.3959	15
22	ALPHA_BNK.rte	10.972	0	1

The overall results of one at a time and global sensitivity can be discussed in few steps. From global sensitivity analysis, we see that very sensitive input parameters fall between rank 1 to 7 and the higher rank reflects the insensitive parameters. Four parameters show stable and sensitive in both case, inclusive of CN2.mgt, ALPHA_BNK.rte, GW_DELAY.gw, ESCO.hru. CN2.mgt is the most sensitive parameter in local sensitivity analysis. On the other hand, ALPHA_BNK.rte is the rank 1 sensitive parameter in global sensitivity analysis. There are four parameters are sensitive in only one technique. CH_K2.rte is very sensitive in one-at-a-time technique but ranking as no 17 in global sensitivity technique. CH_N2.rte, GWQMN.gw, ALPHA_BF.gw are well sensitive in global sensitivity technique but poor in one at a time sensitivity analysis. Other parameters are medium sensitive in global methods but insensitive in one at a time sensitivity. These parameters are CANMX.hru, SURLAG.bsn, DEEPST.gw, HRU_SLP.hru, SLSUBBSN.hru. The other parameters are not sensitive even using both of the techniques

6.2 Calibration and Validation result in daily simulation

Calibration processes provide the best possible fit values amongst the observed and simulated stream flows for a particular calibration period. The calibration graph for the time period 2000-2008 along with observed data and simulated has been shown in following figure 14.

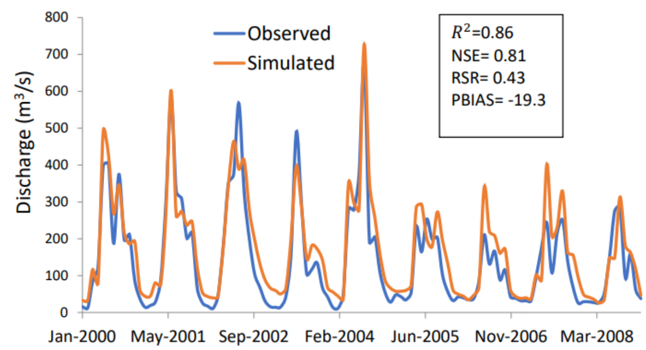

Figure 14: Daily discharge calibration period (2000-2008)

The statistics for model efficiency during calibration periods are the coefficient of determination, R^2=0.86 $(0 \leq R^2 \leq 1)$ and NSE= 0.81 $(0 \leq NSE \leq 1)$ which are very good. RMSE-observation standard deviation ratio (RSR) = 0.43 and Percent Bias (PBIAS) = -19.3 are in satisfactory limit. Form Figure 12 it is observed that model simulated discharge is higher than observed discharge. The results of PBIAS also indicates that the model overestimate the simulated value.

The evaluation of the performance of the model was done by comparing the observed and simulated stream flow for Khowai river basin at Shaistagonj station for validation period 2009 to 2016 years. The validation graph for 2009-2016 along with observed data has been shown in following figure 15.

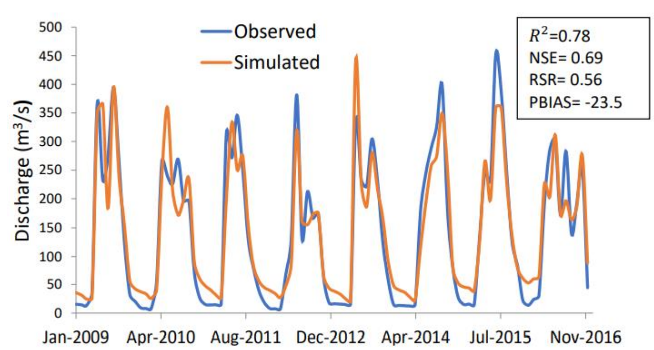

Figure 15: Daily discharge validation period (2009-2016)

From the above figure we can say that most of the times model simulated value agrees with observed value but in dry (November-February) and rainy season (May-October) there looks some overestimation of model simulated value. We can say that the validation result is good because the coefficient of determination, R^2=0.78 $(0 \leq R^2 \leq 1)$ and NSE= 0.69 $(0 \leq NSE \leq 1)$. RMSE-observation standard deviation ratio (RSR)= 0.56 and Percent Bias (PBIAS) = -23.5 are in satisfactory limit.

Table 5: Model performance statistics for calibration and validation period of Khowai basin

Station name	CALIBRATION				VALIDATION			
	NSE	R^2	RSR	PBIAS	NSE	R^2	RSR	PBIAS
Shaistagonj Station	0.81	0.86	0.43	-19.3	0.69	0.78	0.56	-23.5

Table 6: General performance ratings of statistical test [37]

Performance Rating	R^2	NSE	RSR	PBIAS
Very good	$0.75 < R^2 \leq 1$	$0.75 < NSE \leq 1$	$0.0 < RSR \leq 0.5$	PBIAS < ±10
Good	$0.65 < R^2 \leq 0.75$	$0.65 < NSE \leq 0.75$	$0.5 < RSR \leq 0.6$	±10 ≤ PBIAS < ±15
Satisfactory	$0.5 < R^2 \leq 0.65$	$0.5 < NSE \leq 0.65$	$0.6 < RSR \leq 0.7$	±15 ≤ PBIAS < ±25
Unsatisfactory	$R^2 \leq 0.5$	$NSE \leq 0.5$	$RSR > 0.7$	PBIAS ≥ ±25

Comparing Table 5 and Table 6 we see that in calibration and validation model performance statistics R^2, NSE, RSR, PBIAS are in acceptable range**.** Model performance test values indicate that the model results are very good that we can use. So, calibration and validation outputs revealed that model is very good in simulating the discharge data.

7. Conclusions

Arc-GIS enable SWAT model is used to simulate discharge for Khowai basin using many hydrologic parameters which is most important basin for the eastern part of Bangladesh. This research exercises the use of hydrological data with Arc-SWAT in combination of SWATCUP software to indicate model performance which can produce acceptable results. In this study, different satellite-based data and organization open-source data were used. Besides, there are many different parameters of the governing equation were used for adjusting value. Most of the time the model agrees with observed value and some time it over estimates and some time under estimates the value. The statistical fitting values were well matched every time but sometime it deviated from the best fit value. The SWAT-CUP programs were proven good in conducting sensitivity analysis in the study area. For Khowai river basin CN2.mgt, ALPHA_BNK.rte, GW_DELAY.gw, ESCO.hru were evaluated to be the most sensitive parameters in both case global and local sensitivity. CH_N2.rte, GWQMN.gw, ALPHA_BF.gw are well sensitive in global sensitivity technique but poor in one-at-a-time-sensitivity analysis. CH_K2.rte is very sensitive in one-at-a-time but insensitive in global sensitivity technique. Thus, for khowai basin CN2.mgt, ALPHA_BNK.rte, GW_DELAY.gw, ESCO.hru show most sensitive parameters. These parameters are also recommended to utilize for the similar spatial pattern of others tropical watershed. It also indicates flood frequency analysis which enabled us to predict future flood. The SWAT-CUP calibrate the stream flow simulations and analyze sensitivity of parameter to reduce the uncertainty and increase user confidence in its predicative abilities which makes the application of model effective. Finally, it can be concluded that this model can be used to predict discharge of Khowai river when measurement of discharge is not possible because of lack of money or expert to measure discharge. This model can also be used for others river basin of Bangladesh. So, this model is very compatible for Bangladesh.

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