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Sensitivity Analysis of Runoff Model by SWAT to Meteorological Parameters: A Case Study of Kasillian Watershed, Mazandaran, Iran

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Abstract: *To design and construct mosthydraulic structures, e.g. dams, it is essential to determine watershed runoff. If a watershed lacks any gaging station, thenhydrologic models can be utilized to estimate runoff. The Soil Water Assessment Tool (SWAT) is one of the most widelyusedcomputerwatershed models. In this model, we need to input meteorological data, such as precipitation, temperature, wind speed, solar radiation, and relative humidity;as well as watershed data, including curvenumberandroughness coefficient, to calculate the watershed runoff. Some watershedshave weather stations, but there is a risk that the recordeddataof a station do not represent the whole watershed and the use of such data may cause error. Consequently, the error of estimated runoff error needs to be determined. This study deals with the sensitivity of runoff estimatedusing the SWAT model to the variations in meteorological parameters, such as precipitation, solar radiation, wind, humidity, and temperature. Results indicate that with a 30% decrease in the average monthly precipitation, sunshine, relative humidity, wind and temperature, we witness,respectively,a 64.27% decrease, 114.67% increase, 45.93% decrease, 126.12% increase, and 39.21% increase in the estimated runoff.. Runoff estimation is found to be most sensitive to wind speed and solar radiation,and least sensitive to temperature.*

Keywords: *meteorological parameters, rainfall runoff, sensitivity analysis, SWAT, watershed yield*

1. INTRODUCTION

In order to build a dam, it is vital to determinemonthly and annauwatershedyieldssothe volume of storage and the height of dam can be evaluated.. A gage station can measure the input of water to the dam. In the absence of the gage station, a computermodel, e.g. SWAT, can be used to estimate current and historical watershed runoff. However, the model requires meteorological data, such as precipitation, temperature, wind speed, solar radiation and relative humidity on one hand, and watershed charactersitics, such as curve number and roughness coefficient on the other hand. Because of the limited number of weather stations in some watersheds, the measured values of a station may not represent the whole watershed. There is therefore a need to calculate the error in runoff estimation.Thisstudy is based on, aims to investigate the sensitivity of watershed runoff estimated by SWAT to variations in meteorological parameters, such as precipitation, solar radiation, wind, humidity, and temperature.

2. LITERATURE REVIEW

Behtarinejad (2012) employed SWAT to investigate sedimentation and the waste of nutrients east of Gorganrood watershed.The was verified from 1999 to 2006.Datafrom 2007 to 2010 was used to validate the results which were found satisfactory. The SWAT model possesses the capability to produce diverse scenariosfordifferent management options. Gholami (2004) used SWAT to stimulate the average monthly runoff ofEmameh watershed (a sub-basin of Jajrood watershed). Results exhibited a higher sensitivity of the model to overland roughness coefficient [1-12]. Omani et al. (2007) used SWAT to stimulaterunoffin the Gharesar sub-basin northwest of the Karkheh River. They found a higher sensitivity to curve number [3-15].

Saadati (2003) stimulated daily discharge and water balance in Kasillianwatershed.Resultsshowed that the model was sensitive to the annual and monthly periods and yielded more reasonable results in comparison with the daily period (Saadati 2003).Behtarinejad (2012) and Alavinia&Nasiri-saleh (2011)employed the SWAT model to estimate the discharge and advocated its efficiency. Applying to Ghareh-sarwatershed,Omani et al. (2008 concluded that the SWAT model was capable of stimulating hydrologic components [6-7].

Simulating runoff from Behestabad watershed (one of the sub-basins of Northern Karoon), Rostamian (2006) concluded that the SWAT model was not able to stimulatemaximumvalues [8-9].

Poorabdollah and Tajrishi (2009) employed SWAT in Emameh (a sub-basin of Latian Dam watershed) and fpimdthe model to be efficient for runoff estimation [10].

Chu and Shirmohammade (2004) used SWAT to estimate overlandflow from a 33.4 square kilometer watershed located in Maryland. Results showed that themodel was notaccurateduring very wet years. When wet years were omitted, monthly runoff was estimated satisfactorily Behtarinejad 2012, Chu &Shirmohammade 2004) [11].

Hatou et al. (2004) concluded that the runoff values estimated by SWAT agreed with the values measured in Lershi watershed [12]. Schuol et al. (2006) argued that SWAT was capable of stimulating the hydrological balance [13-18].

Santhi et al. (2001) satisfactorily forecasted the Bask River watershed runoff by SWAT [18-34].

2.1. Material

The case study is limited to Kasillian watershed (located in Northern forests of Alborzmountain in Iran) that included Sangdeh, Darzikela, Sootkela, Valikchal and Valikbon villages. The area of Kasillian watershed is approximately 66.81 square kilometers and the main river stretches for 16.8 kilometers. The geographical coordinates of the watershed are: latitude from 36˚-02’ to 36˚-11’ N, and longitude from 53˚-10’ to 53˚-26’ E. There is a gage station on KasillianRiver at Valikbon. The station, built in 1970, is located at longitude of 53˚-17’ and latitude 36˚-10’ to measure river discharge. Fig. 1 shows the location of Kasillian watershed.

The SWAT model uses precipitation, temperature, solar radiation, wind speed and relative humiditydata which was available from January 1978 till January 1989. The statistical parameters were retrieved from Pol-e-sefidcineoptic, Sangdeh and Darzikelaclimatology, Valikchalprecipitation-gauge, and Valik hydrometer stations.

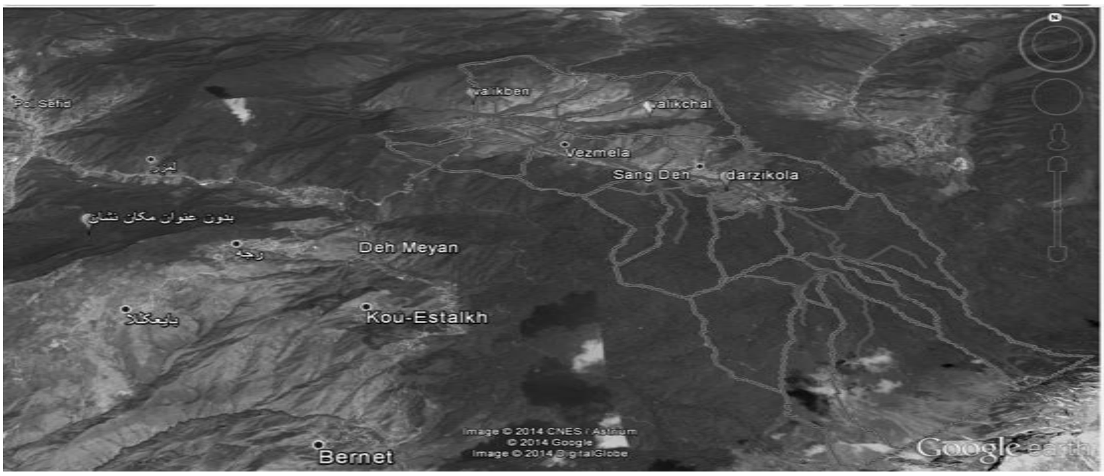

Fig1. *Location of Kasilian Watershed until Valik hydrometer Station.*

2.2. SWAT Model

SWAT was developed by the Grassland Water and Soil Research Laboratory,Temple, Texas, of the U.S. Department of Agriculture, Agricultural Research Service. This model stimulates watershed runoff and requires climatic data such as precipitation, temperature, solar radiation, wind speed and relative humidity. At least temperature and precipitation data needed to be specified and the model is able to stimulateotherdata. It also needs land map, land application, and the digital elevation model. Arc GIS software runs the SWAT model [35-66].

2.3. Formulas and Tables

The Soil Conservation Service (SCS) curve number is a function of soil permeability, land use,andantecedent soil moisture. Different curve numbers were considered for antecedent soil moisturecondition II in diverse types of land use from 67 to 76 based on the SWAT formulas and the optimum number for the region was obtained as 67 [67-82].

SCS runoff equation estimates runoff for different land uses and different types of soil [83-89].Equ.1 shows the runoff equation as (SCS 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (1)$$

Where Q_{surf} is the accumulated runoff or the excess of precipitation (mm),R_{day} is the amount of precipitation per day (mm),I_a is the initial abstraction of the surface reserve, the diffusion before runoff (mm), and S is the maximum soil moisture retention (mm). A changeinthe S parameter results from change in the soiltype, land use, management, slope and soil content. The Sparameteris defined in Equ.2 (SWAT Theoretical Documentation Version 2009):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (2)$$

where CN is the curve number for day. I_a is approximately estimated as 0.2 and fed into Equ.1.to obtain Equ.3 (SWAT Theoretical Documentation Version 2009):

$$Q_{surf} = \frac{(R_{day} - 0.2s)^2}{(R_{day} + 0.8s)} \quad (3)$$

Runoff occurs onlyif $R_{day} > I_a$. The graphical solutions for Equ.3 with the numerical values of different curves are presented in Fig.2 (SWAT Theoretical Documentation Version 2009). As evident in Fig.2, the higher the curve number, the more precipitationbecomesrunoff. The runoff resulting from precipitationvarieswith a curve according to the curvenumber.

The SCS curve defines three antecedent moisture conditions: 1- dry (wilting point), 2- average antecedent moisture, and 3- wet (soil capacity). The humidity condition 1 (dry) possesses the lowest value in the daily curve number. The curve numbers for antecedent moisture conditions 1 & 2 are calculated based on equations 4& 5 (SWAT Theoretical Documentation Version 2009):

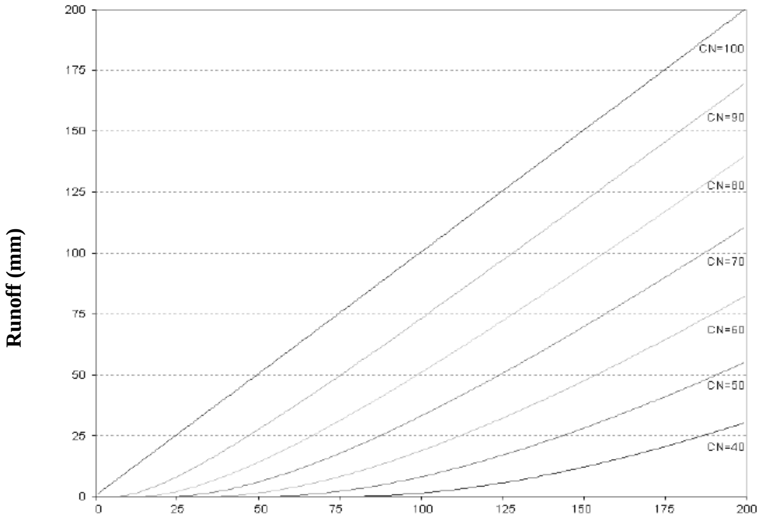

Fig2. *Relationship of runoff to rainfall in SCS Curve number method.(SWAT Theoretical Documentation Version 2009*

$$\mathbf{CN_1} = \mathbf{CN_2} - \frac{\mathbf{20.\ (100-CN_2)}}{\mathbf{(100-CN_2+exp[2.533-0.0636.(100-CN_2)])}} \tag{4}$$

$$\mathbf{CN_3} = \mathbf{CN_2.exp[0.00673.(100-CN_2)]} \tag{5}$$

Where CN_1, CN_2 and CN_3 are the curvenumbers for antecedent soil moisture conditions 1, 2 and 3, respectively.

Williams (1995) developed a curve number equation for different slopes as Equ.6 (SWAT Theoretical Documentation Version 2009):

$$\mathbf{CN_{2s}} = \frac{\mathbf{(CN_3-CN_2)}}{\mathbf{3}}\mathbf{.[1-2.exp(-13.86.slp)]+CN_2} \tag{6}$$

Where CN_{2s} (for the antecdedent soil moisture condition II) is set for the slope, CN_3 (for the antecedent soil moisture condition III) is for a 5% slope, CN_2 (for the antecedent soil moisture condition II) is for a 5% slope and SLP is the average slope of sub-basins. SWAT does not set the curve numbers for the slope. Setting is done before entering the curve number and through the input file management. SWAT input variables, utilizing the curve number method, affects the overland runoff calculation as in table1 (SWAT Theoretical Documentation Version 2009):

Table1. *SWAT input variables that pertain to surface runoff calculated with the SCS curve number method.(SWAT Theoretical Documentation Version, 2009*)

Variable Name	Definition	Input File
IEVENT	Rainfall, runoff , routing option.	.bsn
ICN	Daily curve number calculation method:0 caculate daily CN value as a function of soil moisture ؛ 1 calculate daily CN value as a function of plant evapotranspiration	.bsn
CNCOEF	Cncoef: Weihghting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant evapotranspiration	.bsn
PERCIPITATION	R_{day}: Daily precipitation (mm H_2O)	.pcp
CN_2	CN_2: Moisture condition II curve number	.mgt
CNOP	CN_2: Moisture condition II curve number	.mgt

The Manning overland roughness coefficient values for the intended watershed region and related SWAT tables are in the range of .05 to .2. The optimum value for this region was calculated as 1 [90-114].

The overland concentration timet_{ov} was calculated by Equ.7 (SWAT Theoretical Documentation Version 2009):

$$t_{ov} = \frac{L_{slp}}{3600 . v_{ov}} \tag{7}$$

Where L_{slp} is the length of sub-basin slope,v_{ov} is the velocity of overland flow (m/s), and 3600 is the unit conversion factor. The velocity of overland flow was estimated based on Equ.8 or Manning equation (SWAT Theoretical Documentation Version 2009):

$$v_{ov} = \frac{q^{0.4}{}_{ov} . slp^{0.3}}{n^{0.6}} \tag{8}$$

Where q_{ov} is the average of the land current (cubic meter per second),slp is the mean slope of sub-basin, and n is the Manning roughness coefficient for the sub-basin. The rate of current is assumed as 6.35 mm/h and unit conversion was done through Equs. 9 and 10 (SWAT Theoretical Documentation Version 2009).

$$v_{ov} = \frac{0.005 . L_{slp}^{0.4} . slp^{0.3}}{n^{0.6}} \tag{9}$$

$$t_{ov} = \frac{L_{slp}^{0.6} . n^{0.6}}{18 . slp^{0.3}} \tag{10}$$

2.4. Soil Type

In this study, we used the optimum curve number and overland roughness coefficient. The precipitation data was chosen from different meteorological stations to obtain the optimum curve number and overland roughness coefficient. SWAT was initially run with the curve number CN_2=67and the overlandroughness coefficient of 0.1. Results are presented in fig. 3.

To optimize parameters, different values of the curve numberand roughness coefficient were utilized and the correlation of discharge variation with each parameter introduced in tables 2 and 3is represented in figures 4 to 7. By comparisonof runoff amounts registered at the hydrometer station with the calculated amount, the most optimum curve number was found to be 67 and the roughness coefficient as .1. Subsequently, based on thesevalues, variations in the SWAT input parameters were used to simulatethewatershed runoff. The effect of variation in each of meteorological parameters on runoff was calculated and compared with the observed runoff. It should be mentioned that in this stage of calculations only precipitation data were fed into the model [115-127].

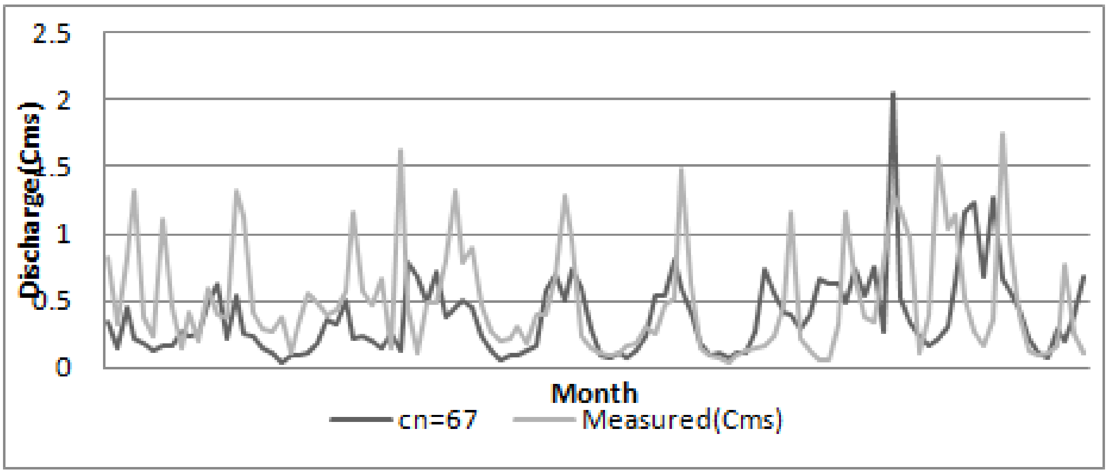

Fig3. *Comparison ofMonthly Simulated Discharge of the SWAT with Measured Discharge.*

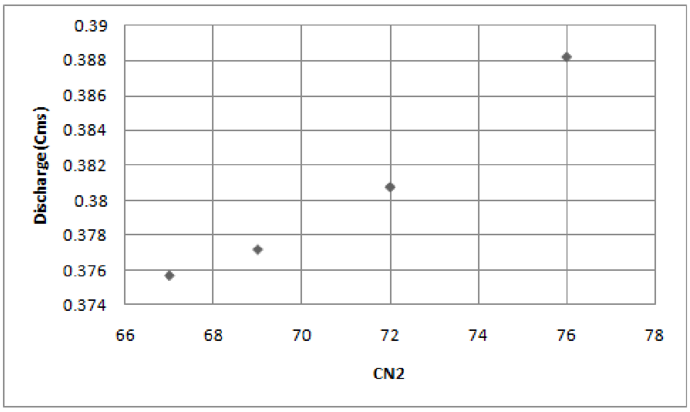

Fig4. *Simulated discharge for different values of* CN_2

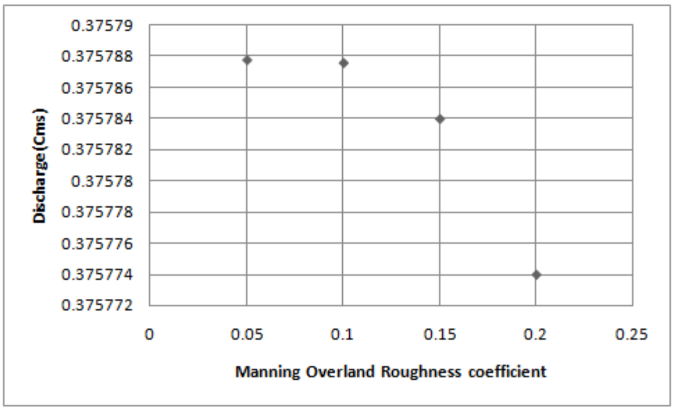

Fig5. *Simulated discharge for difference Manning overland roughness coefficient values*

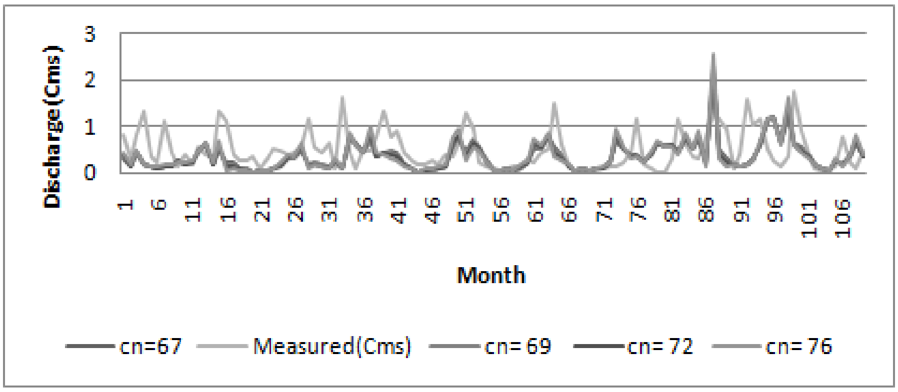

Fig6.*Comparison of simulated discharge river with different CN values with measured discharge*

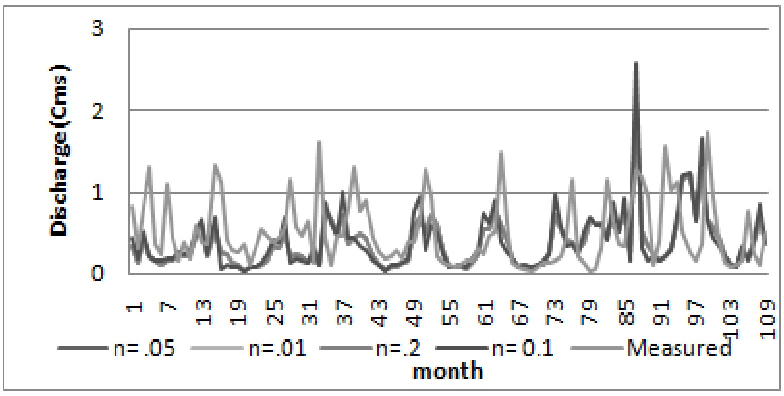

Fig7. *Comparison of simulated discharge with different Manning overland eoughness coefficient values with maesured discharge*

Table2. *Effect of CN on averagesimulated discharge*

CN	67	69	72	76
Average Simulated Discharge (m^3/s)	0.375787	0.377227	0.38084	0.388203
Average Measured Discharge (m^3/s)	0.498953	0.498953	0.498953	0.498953
Error (m^3/s)	0.123166	0.121726	0.118113	0.11075
Percent change or variable	0	0.3992%	1.3574%	3.3271%

2.5. Sensitivity Analysis of Watershed Runoff to Meteorological Parameters

Required meteorological parameters, including temperature, relative humidity, wind speed,solar radiation, and precipitation were fed into SWAT and average runoff, as is shown in the third row of table 4, was calculated as 0.5704 cubic meters per second.

Table4. *Simulated discharge for varing preiciptation*

Precipitation(mm)	Average Simulated Discharge (m^3/s)	Average Measured Discharge (m^3/s)	Difference Average Maesured Discharge and Simulated Discharge (m^3/s)	Percent variable Simulated Discharge
PCP×1.5=3.11181	1.285224074	0.49895304	0.7863	125.31%
PCP×0.7=1.452178	0.203889444	0.49895304	0.2951	-64.27%
PCP=2.07454	0.5704225	0.49895304	0.0715	0

2.6. Effect of Precipitation

In order to evaluate the sensitivity of runoff estimated by the SWAT model to precipitation, initially all precipitation values were multipliedby 1.5 and runoff was calculated. The real amount of precipitation was used to obtain the average long-term runoff (.570). With a 50% increase in precipitation, runoff increased to 1.285 (a 125% increase). With a 30% decrease in precipitation, the average runoff decreased by 64% (.204 cubic meters per second). Consequently, we obtained a .7148 increase and a .3666 decrease in monthly runoff. As evident in Fig.8, the monthly runoff trend was ascending based on precipitation. With a 50% increase and a 30% decrease in input precipitation, the stimulated runoff was .79 and .29 whichwere higher and lower than the average observed monthly runoff, respectively [128-143].

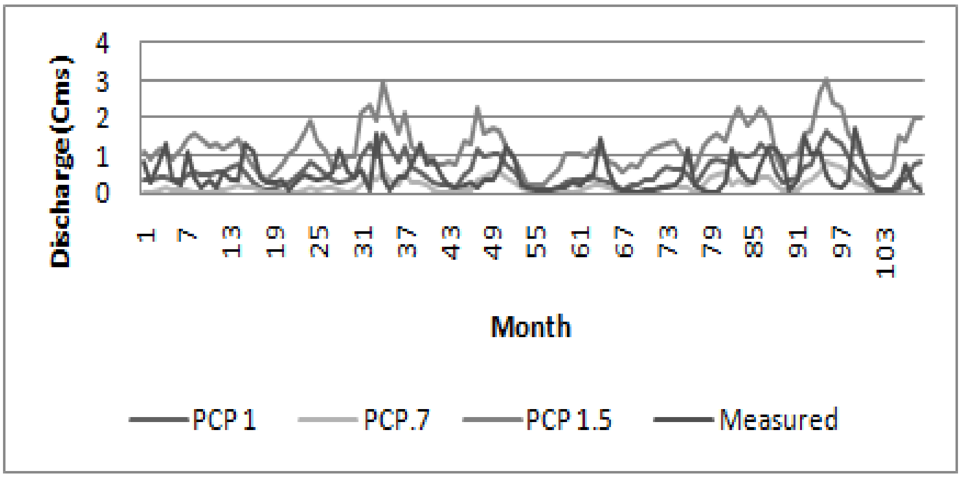

Fig8. *Simulated Discharge for varying precipitation*

2.7. Effect of Solar Radiation

For a 20% increase and a 30% decrease in solar radiation, the simulated runoff varied from 0.57 cubic meters per second to 0.59 and 1.22 cubic meters per second, respectively. The monthly variations are presented in table 5 and figures 10 and 11, with a 20% increase and a 30% decrease in solar radiation, the simulated runoff increased by 0.09 and 0.73 cubic meters per second, repectively [144-159].

Table5. *Simulated Discharge for different solar radiation values*

Average Solar Radiation) MJ/(m^2/ (Day)	Average Simulated Discharge (m^3/s)	Average Measured Discharge (m^3/s)	Difference Average Measured Discharge and Simulated Discharge (m^3/s)	Percent variable Simulated Discharge
solar ×1.2= 22.16	0.59279263	0.498653704	0.0938	3.9095%
solar ×0.7= 12.901	1.224596	0.498653704	0.7256	114.67%
solar= 18.43	0.5704225	0.498653704	0.0715	0

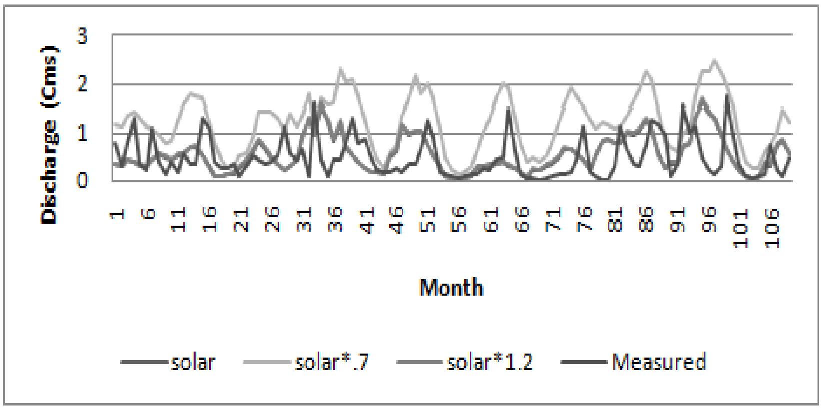

Fig10. *Simulated Discharge for different solar radiation*

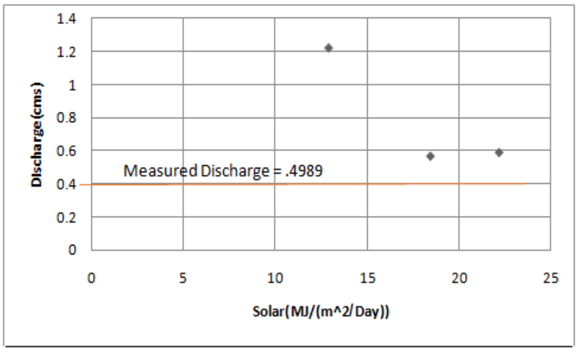

Fig11. *Average monthly simulated discharge for different solar radiation values*

2.8. Effect of Relative

With a 20% increase and a 30% decrease in relative humidity, the average monthly runoff changed from .5704 to .6947 and .3084, respectively. The 21.79% increase and 45% decrease are presented in table 6and figures 12 and 13. With a 20% increase and 30% decrease in relative humidity, the simulated runoff was 39.25% higher, and 38.18% lower than average measured monthly runoff, respectively [160-178].

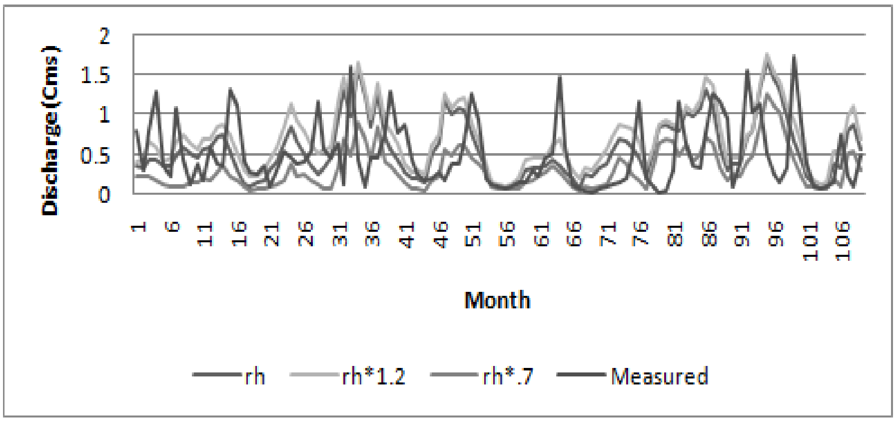

Fig12. *Average monthly simulated discharge with varying relative humidity*

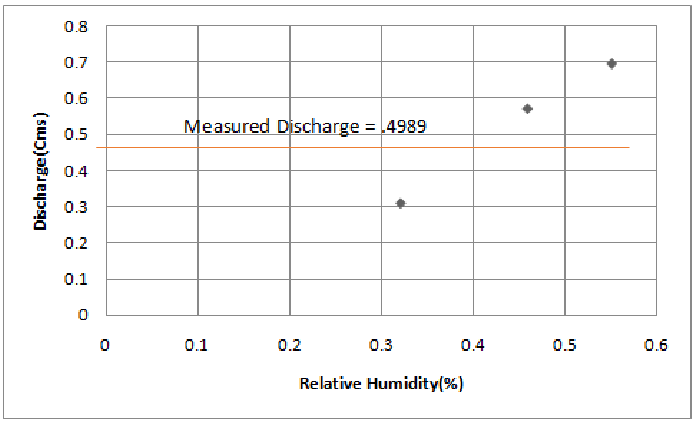

Fig13. *Simulated discharge for varying relative humidity*

Table6. *Simulated Discharge with varying relative humidity*

Average Humidity(%)	Average Simulated Discharge (m^3/s)	Average Measured Discharge (m^3/s)	Difference Average Measured Dsicharge and Simulated Dsicharge (m^3/s)	Percent Difference Simulated Discharge
Rh =0.4591	0.5704225	0.498953	0.0715	0
Rh×1.2=0.5509	0.694742037	0.498953	0.1958	21.79%
0.7Rh×=0.3213	0.308425093	0.498953	0.1905	-45.93%

2.9. Effect of Wind Speed

With a 50% increase and a 30% decrease in wind speed, the average monthly runoff was 1.23 and 1.28 cubic meters per second. The simulated values were .74 and .79 higher than the observed average monthly runoff (figures 14 & 15, table 7).

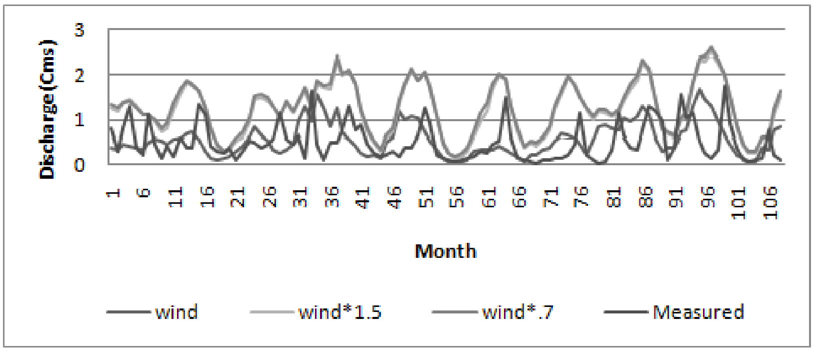

Fig14. *Simulated discharge for varying wind speed*

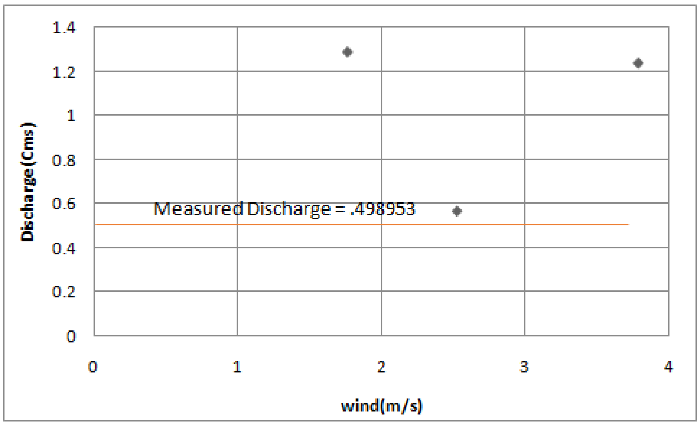

Fig15. *Simulated discharge for varying wind speed*

Table7. *Measureddischarge and simulateddischargefor different wind speed*

Average Wind Speed(m/s)	Average Simulated Discharge (m^3/s)	Average Measured Discharge (m^3/s)	Difference Average Maesured Discharge and Simulated Discharge(m^3/s)	Percent variable Simulated Discharge
0.7wind×=1.764	1.2898388	0.498953704	0.7909	126.12%
1.5 wind× =3.78	1.23933713	0.498953704	0.7404	117.26%
Wind=2.52	0.5704225	0.498953704	0.0715	0

2.10. Effect of Temperature

With a 50% increase and a 30% decrease in temperature, the average monthly runoff varied from .570 to .242 and .794, that is, a 57.56% increase and a 39.21% decrease in monthly runoff. The Simulated results were 51% lower and 61.22% higher than the measuredaveragemonthly runoff (figures 16 & 17, table 8).

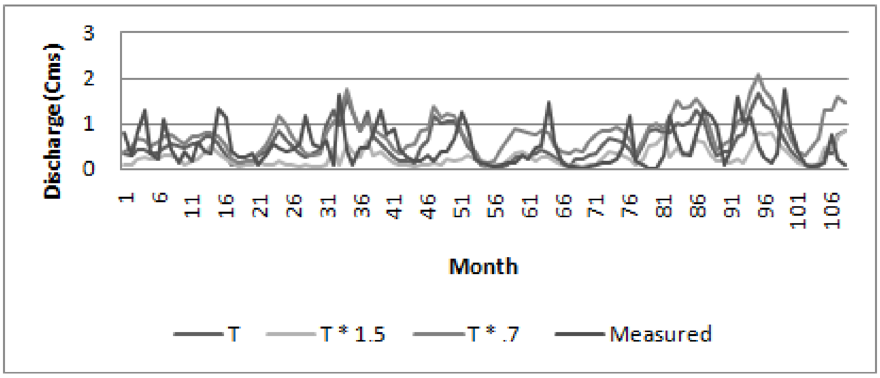

Fig16. *Simulated discharge for varying temperature*

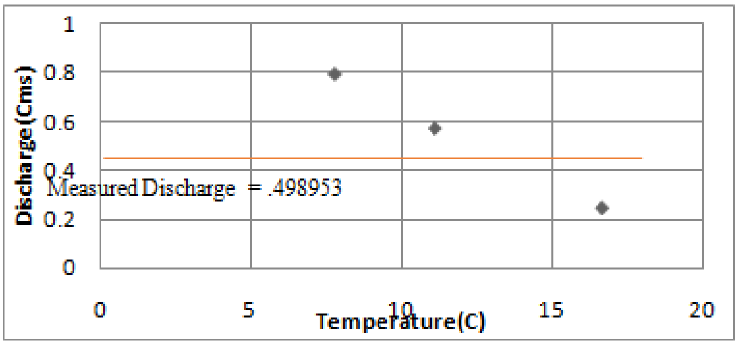

Fig17. *Simulated discharge for varyingtemperature*

Table8. *Simulated discharge for varying temperature*

Temperature(C)	Average Simulated Discharge (m^3/s)	Average Measured Discharge (m^3/s)	Difference Average Measured Discharge and Simulated Discharge (m^3/s)	Percent variable Simulated Discharge
T×0.7 =7.7627395	0.79410463	0.498953704	0.2952	39.21%
T×1.5 =16.635587	0.242062685	0.498953704	0.2569	-57.57%
T= 11.08963	0.5704225	0.498953704	0.0715	0

3. RESULTS

1. With a 13.43% increase in the curve number, the simulated average monthly runoff would be 2.51% close to the measured average runoff. With a 1.5% increase in the roughness coefficient of watershed, the simulated runoff would come .01% closer to the measured discharge.

2. A 30% decrease in average monthly precipitation, solar radiation, relative humidity, wind and temperature would cause a 64.27% decrease, 114.67% increase, 45.93% decrease, 126.12% increase and 39.21% increase in average monthly runoff, respectively. It is evident that precipitation and relative humidity produce the most decreases. The most increase in runoff was a function of wind, then solar radiation and finally temperature.
3. With a 50% increase in the average monthly precipitation, a 20% increase in radiation and relative humidity and a 50% increase in wind and temperature, the runoff amount would experience a 125.31% increase, 3.9095% increase, 21.79% increase, 117.26% increase and 57.57% decrease, respectively. Precipitation then wind and relative humidity cause the most increases. Runoff is least sensitive to solar radiation.

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