INTERNATIONAL JOURNAL OF BIO-RESOURCE, ENVIRONMENT AND AGRICULTURAL SCIENCES (IJBEAS)
Vol. 2(2) :322-332, 2016
www.sbear.in // ISSN 2454-3551

SWAT SIMULATION MODEL FOR CLIMATE CHANGE IMPACT ON RUNOFF

Kishore Chandra Swain[1*], Chiranjit Singha[1] and Dinesh Kumar Rusia[2]

[1]Department of ASEPAN, Institute of Agriculture, Visva-Bharati, Sriniketan, Birbhum, West Bengal 731236
[2]Department of Agricultural Engineering, Birsa Agricultural University, Kanke, Ranchi, Jharkhand.
[*]Corresponding author: swainkc@yahoo.com.

Received: March 2016 Revised accepted: May 2016

ABSTRACT

SWAT has proven to be an effective method of evaluating alternative land use effects on runoff, sediment and pollutant losses for simulation of hypothetical, real and future scenarios. This capability has been strengthened via the integration of GIS-SWAT with LULC simulation models in watershed management for sustainable agricultural planning programme. The assessment of climate change impact on water resources is still subject to great uncertainty. One of the major uncertainties is the climate projection, which has a marked influence on the simulated runoff in the context of future hydrology. In addition, the application of hydrological models involves uncertainty at various levels as the models are simplified conceptualizations of a real-world system. SWAT has been used as a tool for managing the runoff in the watershed involving future weather parameters from climate models, land use/land cover patterns, soil series information etc. The paper highlighted the contribution of various researchers for runoff estimations in national and international scenarios.

Keywords: SWAT, ArcSWAT, climate change, watershed, land use/land cover

INTRODUCTION

Since the beginning of industrial revolution the influence of human activity has begun to extend to a global scale. Today, environmental issue becomes the biggest concern of mankind because of the increasing concentration of greenhouse gases in the atmosphere and the changing climate of the earth and recently at global scale temperature is increasing and the amount and distribution of rainfall is being altered (Cubasch et al., 2001).Climate change is one of the most important global environmental challenges, which affects the overall system by affecting food production, water supply, health, energy, etc. Impact of climate change poses a high threat to the water resources of the globe. Climate variability and change are expected to alter regional hydrologic conditions and result in variety of impacts on water resource systems throughout the world. Potential impacts may include changes in hydrological processes such as evapotranspiration, soil moisture, water temperature, stream flow volume, timing and magnitude of runoff, and frequency and severity of floods (Zierland Bugmann, 2005; Zhang et al., 2005). This is arising due to the increasing concentration of greenhouse gases in the atmosphere since the pre-industrial times. Intergovernmental Panel on Climate Change (IPCC) concluded that it is more than 90% likely that accelerated warming of the past 50-60 years is caused by the anthropogenic release of greenhouse gases, such as CO_2 (Wang et al.,2011). Climate change affects the hydrologic cycle of a region through changes in the timing, amount and form of precipitation, evaporation and transpiration rates and soil moisture. This has touched all parts of the world including India. The effects of climate change on hydrological regimes have become a priority area for water and catchment management strategies. The terrestrial hydrology driven by monsoon rainfall plays a crucial role in shaping the agriculture, surface and ground water scenario in India. Thus, it is imperative to assess the impact of the changing climatic scenario projected under various climate change scenario towards the hydrological aspects for India. Runoff is one of the key parameters used as an indicator of hydrological process.

Global warming and the increasingly large-scale of human activities (IPCC, 2007) are causing major changes to hydrological cycles of river basins and affecting their physical conditions on a regional scale. In recent decades, hydrological studies have focused on runoff, in particular (Fraiture, 2007; Hejazi and Moglen, 2007). IPCC's Fourth Assessment Report concludes that climate change is becoming a present day reality as warming of the climate system has become unequivocal (IPCC, 2007). All general circulation models (GCMs) predict an enhanced hydrological cycle and an increase in area-averaged annual mean rainfall. According to the IPCC (2007), GCMs are currently the most advanced tools available for simulating the response of the global climate system to changing atmospheric composition. The climate change projected by IPCC includes predictions on deviations of temperature and precipitation from past and current conditions. Those changes could have significant impact on the hydrological characteristics and response of watersheds. The climate change is a main parameter which affects the element of hydrological cycle especially runoff. Changes in the climatology of precipitation, evapotranspiration, and, soil moisture leads lot of changes in runoff and stream flow. The results present that the effect of temperature change cannot be clearly presented on the change of runoff while the rainfall, relative humidity and evaporation are the parameters for the considering of runoff change. If there are the increase of rainfall and relative humidity, there is also the increase of runoff. On the other hand, if there is the increasing of evaporation, there is the decreasing of runoff. Climate-induced increase in surface temperatures can impact hydrologic processes of a watershed system that climate change can have significant effects on stream flow, also influences the timing and magnitude of runoff.

ArcSWAT (Arc Soil and Water Assessment Tool) is a physically-based, semi-distributed hydrologic model, which has proven to be an effective tool for assessing water resource for predicting surface run off and non-point source pollution problems for a wide range of scales and environmental conditions across the globe (Neitsch et al., 2011). It has emerged as a powerful tool to quantify the effects of climate change on water resources (Jha et al., 2006). To accurately estimate future supplies for water resources management plans, the effects of global climate change on runoff should be considered because the runoff is the main element of hydrology and water resources management. Since runoff is affected by the climate change, the purpose of this study is to determine the effects of the climate change on surface runoff.

HYDROLOGICAL MODEL

Hydrological models can be defined as mathematical formulations that determine the runoff signal that leaves a river basin from the rainfall signal received by the watershed. Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the infiltration rate is usually very high. Runoff volumes in a catchment are known to be influenced by numerous factors, including climatic variables (particularly precipitation), human activities, subsurface drainage patterns and various other geographical and hydrological variables (Chen, 2007; Zhang et al., 2008; Kumar et al., 2005). Hydrological models provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources systems.

Quantifying the impact of climate change on runoff is relatively straightforward, using either traditional regression methods or more complex hydrological models, such as SWAT (Yao et al., 2008).

The water balance equation simulated in hydrologic cycle is presented as Equation 1:

$$S_f=S_i+\sum_{i=1}^{t}(P-Q_s-ET-w-Q_g)\ldots\ (1)$$

Where, S_f: Final soil water content (mm H_2O), S_i: Initial soil water content (mm H_2O), t: Time (days),P: Precipitation on day i (mm H_2O), Q_s: Surface runoff on day i (mm H_2O), ET: Evapotranspiration on day i (mm H_2O), w: Water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_g: Return flow on day i (mm H_2O), (Kosa and Sukwimolseree,2014).SWAT is a physically based distributed parameter model which has been developed to predict runoff, erosion, sediment and nutrient transport from agricultural watersheds under different management practices. SWAT is a basin-scale, continuous model that operates on a daily time step. The model is physically based, computationally efficient and capable of continuous simulation over long periods.

Surface runoff is one of the major causes of erosion of the earth's surface and the location of high runoff generating areas is very important for making better land management practices. The location of runoff production in a watershed depends on the mechanism by which runoff is generated. Infiltration excess occurs when the rainfall intensities exceed to the soil infiltration rate or any depression storage has been already filled. Soil infiltration rates are controlled by soil characteristics, vegetation cover and land use practices. Rainfall runoff models are classified as deterministic (physical), parametric (empirical) and mathematical models (Dawson and Wilby, 2001). The SCS curve number method is used for runoff, daily rainfall and evapotranspiration rate but peak runoff is calculated using a modification of the Rational Formula (Allen et al., 1989).

Arnold et al. (1995) of United States Department of Agriculture (USDA) Agricultural Research Service (ARS) developed a river basin model using SWAT. The model is comprehensive and was developed to assess the impact of land management practices on water, sediment and agricultural chemical yields in large complex basins with varying soil types, land use and management conditions. The inbuilt algorithms of SWAT model are useful tools for generating missing climate data for basins (Sharpley and Williams, 1990).

CLIMATE CHANGE IMPACT OVER RUNOFF

The runoff have been addressed by the assessment of various global, regional and national scales (Lettenmaier et al., 1999; Arora et al., 2001).Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. Later stage, surface run off occurs. The climate change is a main parameter which affects the element of hydrological cycle especially runoff. Climate change, especially the change of rainfall and temperature, will largely determine the future runoff of a basin, (Wang et al., 2009).An implementation of a 2041-2060 climate change scenario by (Gosain et al., 2006) on 12 major river basins in India resulted in a general decrease of surface runoff and an increase in flood and droughts. The hydrologic cycle as simulated by SWAT is based on the water balance equation. Since the model maintains a continuous water balance, complex basins are subdivided to reflect differences in ET for various crops, soils, etc. Thus, runoff is predicted separately for each sub-area and routed to obtain the total runoff for the basin. This increases accuracy and gives a much better physical description of the water balance. Liu and Cui (2011) investigated runoff change induced by precipitation and potential evapotranspiration (PET) in the Yellow River Basin. The SWAT model estimates runoff volume by using the Soil Conservation Service (SCS) curve number (CN) technique (USDA, 1972).Improved SWAT hydrologic predictions could potentially be obtained through modifications in the curve number methodology and/or incorporation of more complex routines. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt (1911) infiltration method.

Soil Conservation Service (SCS)

The surface runoff is calculated using the SCS runoff curve number and daily rainfall while the evapotranspiration is computed using (Hargreaves, 1975; Allen et al., 1989) depended on data available. The SCS curve number method is a rainfall runoff model that was designed for computing excess rainfall (direct runoff). The CREAMS model, runoff volume is estimated with a modification of the SCS curve number method (USDA Soil Conservation Service, 1972).The SCS runoff equation is an empirical model that came into common use in the1950s. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981). The Soil Conservation Service (SCS, 1985) curve number method, which is a versatile and widely used approach for quick runoff estimation and also relatively easy to use with minimum data and give adequate results (USDA, 1986; Chatterjee et al., 2001; Bhuyan et al., 2003) was used.

The SCS curve number (Equation2) is (SCS, 1972):

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)^2}{\left(R_{day} - I_a + S\right)} \qquad (2)$$

Where, Q_{surf}: Accumulated runoff or rainfall excess (mm H_2O), R_{day}: Rainfall depth for the day (mm H_2O), I_a: Initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H_2O), and $S$is the retention parameter (mm H_2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as Equation 3:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad (3)$$

Where, CN: Curve number for the day. The initial abstractions (I_a) is commonly approximated as $0.2S$and Equation 4 as

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)} \qquad (4)$$

Runoff will only occur when $R_{day} > I_a$.
SCS model has been used to estimate runoff over mainland of India using normal (1951-1980) and projected climatic (2080; A2 scenario) rainfall along with other inputs like soil and hydrological land cover. This model gives quick estimate of generated runoff in a particular location with reasonably good accuracy. Rainfall to runoff conversion was high (48.3 %) for normal year as compared to low (42.8 %) for the projected climate scenario (Gupta et al., 2014).

Green & Ampt infiltration method

The Green & Ampt equation was developed to predict infiltration assuming excess water at the surface at all times (Green and Ampt, 1911).The Green-Ampt Mein-Larson excess rainfall method was incorporated into SWAT to provide an alternative option for determining surface runoff. This method requires sub-daily precipitation data supplied by the user. The Green-Ampt Mein-Larson infiltration rate is defined as:

$$f_{inf,t} = K_e \cdot \left(1 + \frac{\Psi_{wf} \cdot \Delta\theta_v}{F_{inf,t}}\right) \qquad (5)$$

Where, f_{inf}: Infiltration rate at time t (mm/hr), K_e: Effective hydraulic conductivity (mm/hr), Ψ_{wf}: Wetting front metric potential (mm), $\Delta\theta_v$: Change in volumetric moisture content across the wetting front (mm/mm) and F_{inf} Cumulative infiltration at time t (mm H_2O). SWAT incorporates a surface runoff storage feature to lag a portion of the surface runoff release to the main channel (Neitsch, 2012). Zabaleta et al. (2014) presented an analysis of climate change impacts on runoff and sediment yield for the Axiola watershed by putting climate projections from four climate change projections, representing combinations of two general circulation models (GCMs) and two scenarios, for 2011 to 2100, in SWAT. Three of the GCM-scenario combinations suggested that runoff and sediments would decrease every year from 2011, but the other combination resulted in a predicted increase in runoff and sediments every year from 2011. These variations in annual sediment yield can be attributed to differences in the precipitation estimated between the GCMs in SWAT over view.

SWAT MODEL

SWAT Inputs

SWAT is a comprehensive model that requires a diversity of information in order to run. The SWAT hydrologic model requires input on soils (bulk density, available water capacity, sand, silt, clay, organic matter, and saturated conductivity), land use (crop and rotation), management (tillage, irrigation, nutrient, and pesticide applications), weather (daily precipitation, temperature, and solar radiation), channels (slope, length, bank full width and depth), and the shallow aquifer (specific yield, recession constant, and revap coefficient (Arnold and Allen, 1996). The hydrologic balance of SWAT is driven by several components. Precipitation, infiltration, surface runoff, lateral flow in the soil profile, ET, percolation from the soil profile, and transmission losses all serve as forces driving the hydrologic cycle. The system simulated by SWAT consists of four control volumes that include the: (i) surface, (ii) soil profile or root zone, (iii) shallow aquifer, and (iv) deep aquifer (King et al., 1999).Surface runoff volume is computed using a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) or the Green and Ampt infiltration method (Green and Ampt, 1911).

In SWAT, a watershed is divided into sub-basins, which are then further subdivided into hydrologic response units on the basis of unique combinations of land use, soil and slope class. Climatic data can be input from measured records or generated using the weather generator (or any combination of the two). Overland flow runoff volume is computed using the Natural Resources Conservation Service (NRCS) curve number method. Curve numbers are a function of hydrologic soil group, vegetation, land use, cultivation practice and antecedent moisture conditions (Grohoski et al., 2013). Several studies have been performed that analyzed impacts on SWAT output as a function of: (i) variation in HRU and/or sub-watershed delineations, (ii) different resolutions in topographic, soil, and/or land use data, (iii) effects of spatial and temporal transfers of inputs, (iv) actual and/or hypothetical shifts in land use, and (v) variations in precipitation in puts or ET estimates. These studies serve as further SWAT sensitivity analyses and provide insight into how the model responds to variations in key inputs (Gassman et al., 2014). Gosain and Rao (2006) model outputs included all water-balance components (surface run-off, evapotranspiration, lateral flow, recharge, percolation, sediment yield etc.) at the level of each sub-watershed and at daily, monthly or annual intervals.

SWAT strengths

The worldwide application of SWAT reveals that it is a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decisions. The model will continue to evolve as users determine needed improvements that: (i) will enable more accurate simulation of currently supported processes, (ii) incorporate advancements in scientific knowledge, or (iii) provide new functionality that will expand the SWAT simulation domain (Gassman et al., 2014). Research on the runoff component of the study was reported separately (Chanasyk et al.,2003).

SWAT APPLICATIONS

International scenario

In the *Taoerhe* River basin, China, Li et al. (2012) indicated that climate conditions, especially precipitation, played an important role in runoff variations while land use change during the period 1970-2000 was secondary across the study area. Furthermore, the effects of changes in land use and/or climate conditions on monthly runoff were larger in the wet season. Zeng et al.(2015) estimated the contributions of climate change and human activities to runoff change in the *Luan* River basin, China (during the period 1958-2009) run by hydrological model (SWAT). The effect of climate change on runoff changes is about 28.3-46.8%.Zhang et al.(2012) generalized the characteristics of the human activities to predict future runoff using climate change scenarios, in the *Biliu* River basin, China. Results showed that future annual flow will increase by approximately 10% from 2011 to 2030 under normal human activities and future climate change scenarios, as indicated by climate scenarios with a particularly wet year in the next 20 years. Using the SWAT, the effect of climate change on runoff during 1979 to 2010 is described using the climate parameter contained temperature, rainfall, relative humidity and evaporation as there are increase in rainfall and relative humidity, also increasing in runoff and the increase in evaporation, causes decrease in runoff. Over all the mean monthly runoff was gradually increased from 53% to 73%; in the upper *Mun* river basin is in Northeast Thailand (Kosa and Sukwimolseree, 2014) in Fig. 1.

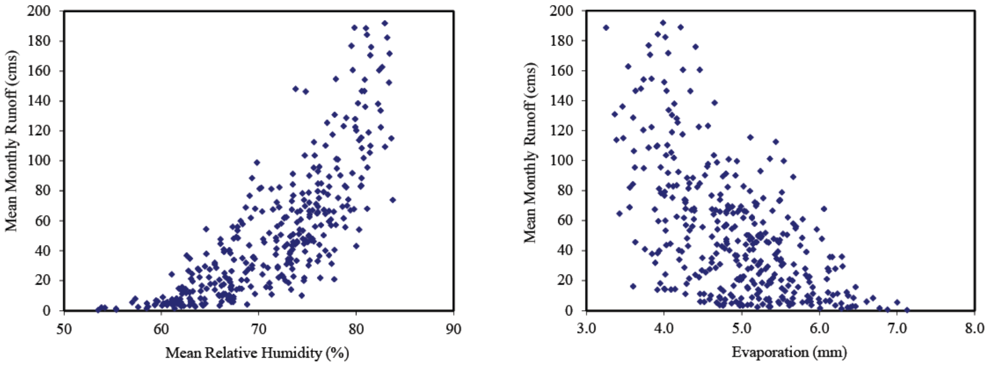


Fig.1. The relationship between mean monthly runoff with mean monthly relative humidity and mean monthly evaporation (Kosa and Sukwimolseree, 2014)

Zeng et al. (2015) used hydrological modelling and climate elasticity approaches to separate the effects of climate change and human activities. The effect of climate change on runoff changes was about 28.3-46.8% and that of human activities accounted for about 53.2-71.7%. indicating that both factors have significant effects on the runoff decline in the in the Luan River basin, China, In the SWAT model, the contribution of human activities to the reduction in run off was 40-70%with a mean value 55%.

The ArcSWAT (2009) program was used to simulate runoff in Bazoft watershed in south western of Iran. The basic input data to SWAT are digital elevation model (DEM), stream network coverage, land use, soil maps, and climate data. The simulation of daily runoff was satisfactory during the calibration period, the model exhibited larger uncertainties in the calibration period. The *P* factor (percentage of data being bracketed by 95PPU) for the calibration period was 0.64, while it was 0.73 for the validation period (Besalatpour et al., 2012) in Table 1.

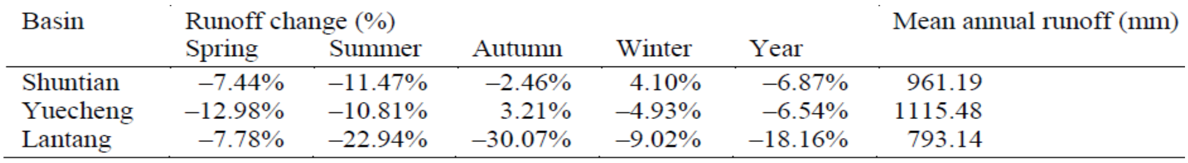
Table 1.Summery statistic results for the daily runoff calibration and validation periods

Evaluation criteria	Calibration	Validation
R^2	0.54	0.48
NS	0.51	0.47
P factor	0.64	0.73

Source:R2: coefficient of determination, NS: Nash-Sutcliff coefficient, and *P* factor: percentage of data being bracketed by 95PPU in Bazoft watershed in south western of Iran, (Besalatpour et al.,2012)

The impact of future climate change on the runoff for the *Dongjiang* River basin, South China, has been investigated with the SWAT. The spatial input data layers required to run the model, include a digital elevation model (DEM), land-use data, soil data and weather data. The results showed that under the future climate change and LUCC scenario, the annual runoff of the three sub-basins all decreased. Its impacts on annual runoff were –6.87%, –6.54%, and –18.16% for the Shuntian, Lantang, and Yuecheng sub-basins respectively, compared with the baseline period 1966–2005 (Lin et al., 2015) in Table 2.

Table 2.The percentage of change of runoff compared to baseline period in the *Dongjiang* River basin, South China (Lin et al., 2015)



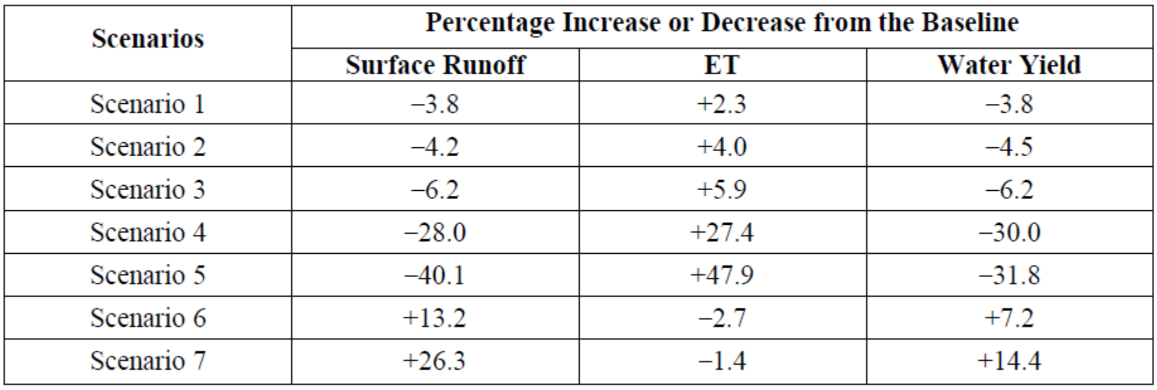
Basin	Runoff change (%)					Mean annual runoff (mm)
	Spring	Summer	Autumn	Winter	Year	
Shuntian	–7.44%	–11.47%	–2.46%	4.10%	–6.87%	961.19
Yuecheng	–12.98%	–10.81%	3.21%	–4.93%	–6.54%	1115.48
Lantang	–7.78%	–22.94%	–30.07%	–9.02%	–18.16%	793.14

SWAT simulated runoff responses to climate change scenarios were non-linear and suggest the basin is highly vulnerable under low (−3 %) and high (+25 %) extremes of projected precipitation changes, but under median projections (+7 %) there is little impact on annual water yields or mean discharge in The Mara River Basin of East Africa. The spatial input data sets were Land use/land cover data, Climate data and Soil data etc. (Mango et al., 2011).

Indian scenario

SWAT studies in India include identification of critical or priority areas for soil and water management in a watershed (Kaur et al., 2004; Tripathi et al., 2003). Gosain et al. (2006) simulated the impacts of a 2041-2060 climate change scenario on the stream flows of 12 major river basins in India, ranging in size from 1,668 to 87,180 km2. Surface runoff was found to generally decrease, and the severity of both floods and droughts increased, in response to the climate change projection. (Uniyal et al., 2015) using the ArcSWAT Model with the input data were three spatial maps in GIS grid format, i.e., digital elevation model, landuse and soil map; weather and measured stream discharge data Comparison of simulation results for different scenarios with the baseline indicated a reduction in surface runoff ranging from 4 to 40% when the temperature was changed from 1 to 5 °C with an increase in rainfall by 5 to 10% results in the increase of surface runoff by 13.2 to 26.3% from the baseline period in the Baitarani River basin (1776.6 km2) of eastern India, Odisha (Table 3).

Table 3.Changes in the mean annual surface runoff, ET and water yield under different scenarios in the *Baitarani River* basin of eastern India, Odisha (Uniyal et al.,2015).



Scenarios	Percentage Increase or Decrease from the Baseline		
	Surface Runoff	ET	Water Yield
Scenario 1	−3.8	+2.3	−3.8
Scenario 2	−4.2	+4.0	−4.5
Scenario 3	−6.2	+5.9	−6.2
Scenario 4	−28.0	+27.4	−30.0
Scenario 5	−40.1	+47.9	−31.8
Scenario 6	+13.2	−2.7	+7.2
Scenario 7	+26.3	−1.4	+14.4

Note: − indicates decrease; + indicates increase; Water Yield = Surface runoff + Baseflow.

The SWAT-2012 model was successfully calibrated and validated in the Middle *Narmada* basin using SUFI-2 algorithm. It is applied to the basin for the modeling of the hydrological water balance and surface runoff. The main input data for simulation of SWAT contained Digital Elevation Model (DEM), land use/land cover (LU/LC), soil type, soil properties and Hydro-climatologically data. The model was simulated for the period of 12 years (1997-2008) and validated with 2009 and 2010 year separately. The results indicated that 46% of the annual precipitation is lost by evapotranspiration in the basin (Diwakar et al., 2014) in Fig. 2.

Tripathi et al. (2006) also found that little variation occurred in predicted surface runoff across three sub-watershed delineation schemes (1, 12, and 22 sub-watersheds) for the 90.2 km^2Nagwan Watershed in Northeast India, but that evapotranspiration, percolation, and soil water content estimates did vary between 5% to 48%, 2% to 26%, and 0.3% to 22%, respectively, between the three configurations. SWAT 2000 was also used in integration with remote sensing and GIS to estimate the surface runoff and sediment yield of an intermediate watershed of the *Satluj* river (up to Kasol). Surface run off is the most important element simulated in this model. Average annual prediction of stream flow is 79.67 mm. The SWAT model has already been calibrated and validated for the study *Nagwan* watershed in Eastern India for the simulation of runoff and sediment yield. Kulkarni and Bansod (2012) used SWAT to simulate the hydrology of the *Krishna* river Basin. The future annual discharge, surface runoff and base flow in the basin show increases over the present as a result of future climate change. Kulkarni et al. (2011, Fig. 3) quantified the impact of climate change on the water resources of the *Bhima* river basin using hydrological model (Precise SWAT); data inputs were DEM, Soil, Land use and weather general data and climate model data. The SWAT model is able to stimulate the future annual discharge, surface runoff and base flow in the basin show increases over the present as a result of future climate change.

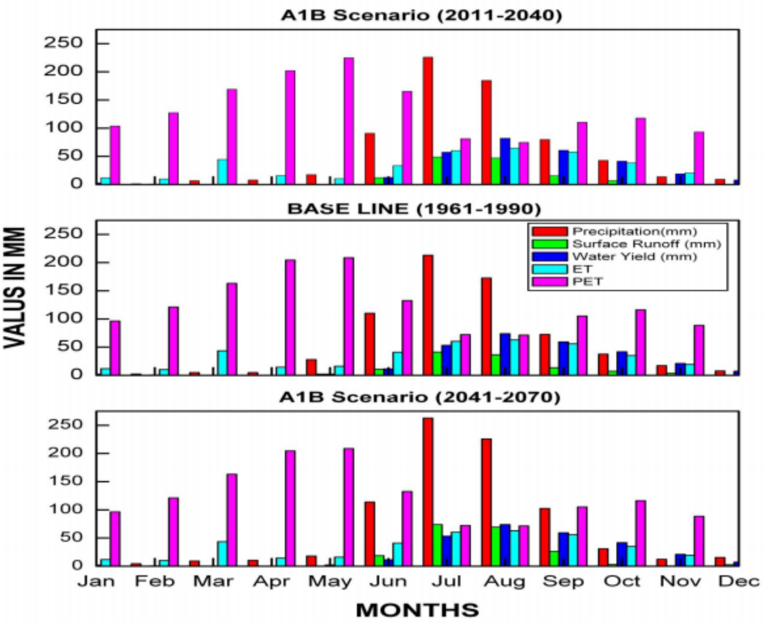
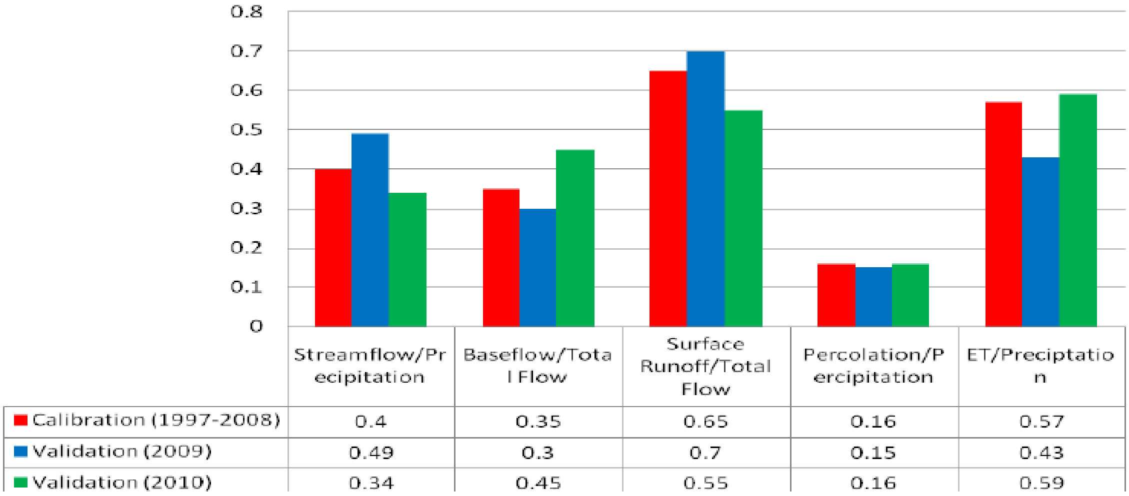


Fig.2.Water balance ratio on an annual average basis over the calibration and validation periods for *MiddleNarmada* basin (Diwakaret al.,2014)



	Streamflow/Precipitation	Baseflow/Total Flow	Surface Runoff/Total Flow	Percolation/Percipitation	ET/Preciptation
🟥 Calibration (1997-2008)	0.4	0.35	0.65	0.16	0.57
🟦 Validation (2009)	0.49	0.3	0.7	0.15	0.43
🟩 Validation (2010)	0.34	0.45	0.55	0.16	0.59

Fig.3.Mean monthly water balance components for control and A1B scenarios stimulate by SWAT the *Bhima* river basin, (Kulkarni et al., 2011).

CONCLUSION

Simulation of hypothetical, real and future scenarios in SWAT has proven to be an effective method of evaluating alternative land use effects on runoff, sediment and pollutant losses. This capability has been strengthened via the integration of GIS-SWAT with LULC simulation models in watershed management for sustainable agricultural planning programme. A key strength of SWAT is its flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer application, cover crops (perennial grasses), filter strips, conservation tillage, irrigation management, flood-prevention structures, grassed waterways, and wetlands. To accurately estimate future supplies for water resources management plans, the effects of global climate change on runoff should be considered because the runoff is the main element of hydrology and water resources management. The assessment of climate change impact on water resources is still subject to great uncertainty. One of the major uncertainties is the climate projection, which has a marked influence on the simulated runoff in the context of future hydrology. In addition, the application of hydrological models (SWAT) involves uncertainty at various levels as the models are simplified conceptualizations of a real-world system. The wide range of SWAT applications that have been described here underscores that the model is a very flexible and robust tool that can be used to simulate a variety of watershed problems.

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