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Estimation of Runoff for Aji basinusing SWAT model based on SCS-CN method

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Abstract: *Runoff is a very important factor in hydrological cycle and it is relevant for the watershed management programme for conservation and development or natural resources and its management. And Water resource planning and management is important and critical issue in arid and semi-arid regions.And availability of accurate information on runoff is very rare. Here three different bias corrected data scenarios are there (1961-2000), (2046-2064) and (2081-2100). Soil and Water Assessment Tool (SWAT) is a physical based model developed for predict the runoff, erosion, sediment and nutrient transport from the watershed Runoff from a watershed affected by several geo-morphological parameters and for a particular watershed land use change can affect the runoff volume and runoff rate significantly. Here bias corrected data applied in SWAT model and SCS-CN method. Present study was undertaken to estimate surface runoff in the Aji basin situated in Rajkot, Gujarat, India using SWAT model and SCS-CN method. The Weight curve number for the Aji basin is 72.00. The coefficient of determination (R^2) for the daily and monthly runoff was obtained according to the SCS-CN and SWAT model are 0.852 and 0.947 respectively during 1961-2000. 0.88 and 0.964 respectively for the 2046-2064.Similarly 0.98 and 0.95 respectively for the 2081-2100.In this study found that SCS-curve number method along with SWAT MODEL can be used successfully in semi-arid region to simulate rainfall runoff and to estimate total surface water.*

Keywords:Hydrological modeling, Bias correction, Arc GIS, SWAT model, Runoff estimation, Curve number.

INTRODUCTION

Water is a transparent fluid which forms the streams, lakes, ocean and rain and is one of the major constituents of the fluids of living beings. Hydrological research deals with the distribution and circulation of water with environment. Agricultural systems in India need improved management strategies to increase their level of self-sufficiency in terms of food production. An increase in food production can only come from four sources such as capturing local rain, horizontal expansion of agriculture, food imports, or lower calories diets[9].

The SWAT is a semi-physically distributed hydrological model, operated on daily time step to simulate runoff and sediment at watershed scale[1, 2, 6]. The Soil and Assessment tool (SWAT) with Arc GIS interface can used for estimating the surface runoff. Different studies have shown that climate change significantly affects the hydrologic cycle and alters runoff regimes and water availability in different regions across the nation.The term 'bias correction' describes the process of re-scaling climate model output to reduce the effects of systematic errors in the climate models[10]. Future climate

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changes associated with specific emission scenarios can be projected using Global Climate Models (GCMs). GCMs' output data can be used regionally, after disaggregation, to force hydrological models to simulate projected runoff. Traditional method for runoff estimation by composite CNs. And compare with SWAT Model Output to Estimate Runoff.

The conventional SCS-curve number method is widely used for estimate the direct runoff volume. United State Department of Agriculture has developed the SCS-Curve number method. Due to its simplicity, that became the most popular method for small watershed[4]. Explained its concept with its capabilities, drawbacks and uses after critical examination of its conceptual and empirical basis and provided area of research in future.[7]discussed the changes of Curve Numbers Effects on Estimates of Storm Runoff Depths evaluated that the effect of spatial variability of Curve numbers on runoff estimation. SCS model with using land use/land cover, soil map and rainfall value for estimating runoff [8]. Estimated runoff of a catchment using SCS-CN method in Damodar sub catchment [5].

The weighted curve number of a watershed using the RS and GIS techniques. From the Darewadi watershed carried out a case study for highlighting the role of GIS and RS in SCS- curve number method for estimation of direct surface runoff [7]. The objective of the present study are to compare the weight curve number for the basin area and to estimate surface runoff by SWAT model in three different scenarios ((1961-2000), (2046-2064), (2081-2100)) in the Aji basin situated in Rajkot, Gujarat, India.

STUDY AREA

Aji is the most important river of Saurashtra. The Ajiriver passes through the city of Rajkot. The Aji-I project is built for the water supply to Rajkot city. It is situated between latitude 21^o to 22^{o}N and longitude of 70^o to 71^o E. Aji river length is 164 km with 2130 km^2 catchment area. Some of the major tributaries of Aji are the Nyari, Lalapari, Khokaldadi, Banked and the Dondi. The River originating from hills of sardhar near Atkot, to its mouth at the Gulf of Kutch in Ranjitparaof Jamnagar district.There are four dams on Aji River. Aji-I, Aji-II, Aji-III, &Aji-IV dams are situated on Aji River having catchment area 142 km^2, 452 km^2, 1378 km^2 and 1772 km^2 respectively.

January is the coldest month with mean monthly temperature varying from 4^{o}C to 15^{o}C and

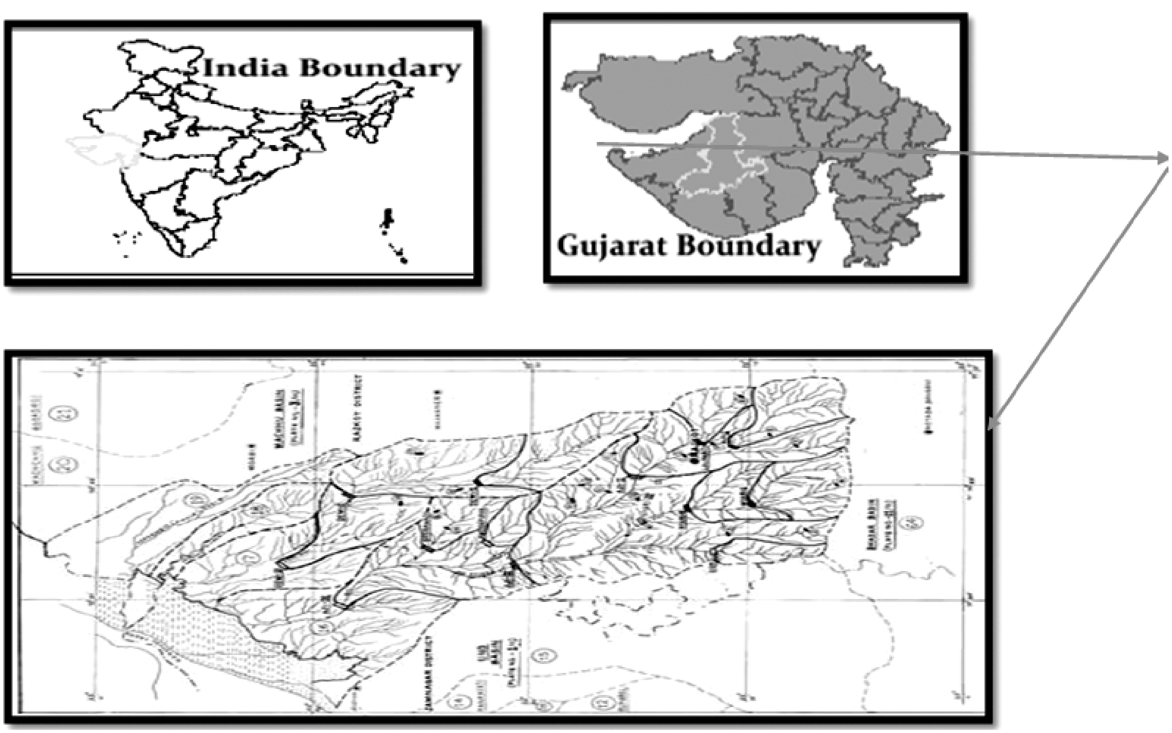

Figure 1. Location map of Aji basin

maximum monthly temperature varies between 40°C to 46°C in the month of May. Agriculture is the main occupation in the area. Groundwater is the main source of irrigation in study area. Major area falls under irrigated agriculture with groundnut, cotton and pulses as main kharif crop and wheat, garlic and onion as Rabi crop. The location map of study area is shown in Fig. 1.

METHODOLOGY

The methodology to achieve the goals and objectives of the present study is shown in this Fig. 2. The various steps involved in the experiment are as follows:

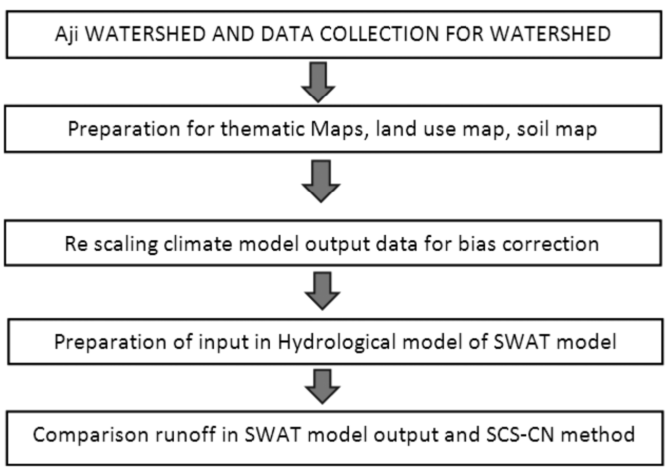

Figure 2. Flowchart for the model development

Bias Correction

The term 'bias correction' describes the process of re-scaling climate model output to reduce the effects of systematic errors in the climate models.In hydrological climate-change impact studies, large-scale climate variables for current and future conditions are generally provided by global climate models (GCMs). To resolve processes and features relevant to hydrology at the catchment scale, regional climate models (RCMs) are commonly used to transfer coarse-resolution GCM data to a higher resolution. Various methods are used to RCMs simulations. Among these, a power transformation method was used for the precipitations data and liner scaling and variance scaling were used for the temperature data. The observed data of the meteorological station nearest to the grid points and in the study area was compared with RCMs (RCM1 grid point (70.75, 22.75) and RCM2 grid point (70.75, 22.25)) grid data of the baseline/control period (1961-2000). This study has performed the bias correction of daily meteorological data such as temperature, rainfall from the RCM model for the Aji River Basin. The 'bias correction' refers exclusively to post-processing RCM output in the context of this study.

SCS-Curve Number Method

Curve number method is developed by the United States Department of Agriculture (USDA) the Soil Conservation Service (SCS) for estimating the direct runoff volume. SCS-Curve number method is based on the below relationship between rainfall, P (mm), and runoff, Q (mm) (USDA-SCS 1985).

$$\begin{cases} \dfrac{(P-I_a)^2}{P-I_a+S} & P>I_a \\ 0 & P \le I_a \end{cases}$$

Where S (mm) is maximum potential retention. The empirical relationship between initial abstraction (I_a) and maximum potential retention (S) is as given as $I_a = 0.1S$ for Antecedent moisture contact (AMC) II, III and $I_a = 0.3S$ for the AMC I. Bhattacharya (1998) found that $I_a = 0.2S$ has been produce a good results for several watershed of India, with varying types of soils, rainfall and land cover conditions.

In this study to calculating the direct runoff depth first to remove initial abstraction. The empirical combination of maximum potential retention and rainfall, based on $I_a = 0.2S$ gives as

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \tag{4.2}$$

The maximum potential retention (S), is varies with antecedent soil moisture and other variables and it calculated using the curve number values. The relationship of maximum potential retention (S) and curve number (CN) is given as,

$$S = \frac{25400}{CN} - 254 \tag{4.3}$$

The Curve number (CN) is dimensionless and values vary from 0 to 100. The curve number calculated on the basis of land use/land cover, soil type and antecedent moisture content. A high curve number value indicates the layer is impermeable. If the curve number value 100 indicates that the all rainfall resultant in runoff.

Surface Water Harvesting

Available surface water storage capacity of different water harvesting structures can be calculated by,

$$V = C \cdot A \cdot H \tag{6}$$

Where, V = Volume of water that can be held by the structure, A = Submerged area (m^2), H = Maximum water depth (m) and C = Constant value of storage Capacity.

RESULTS AND DISCUSSION

Thematic Maps of Aji basin

The maps of watershed boundary, drainage pattern/network, land use, soils were digitized and processed under GIS environment using ArcGIS software in the study area.

Land use map

The GIS analysis of the land use showed that area of 70.05%, 2.66%, and 3.54% were found under Agriculture, built up, water body respectively. The Fig. 3 shows that the dominant land uses are under agriculture.

Soil Map

The soil map of the basin is presented in Fig. 4 and the soil texture pattern is shown in Table 1. The GIS

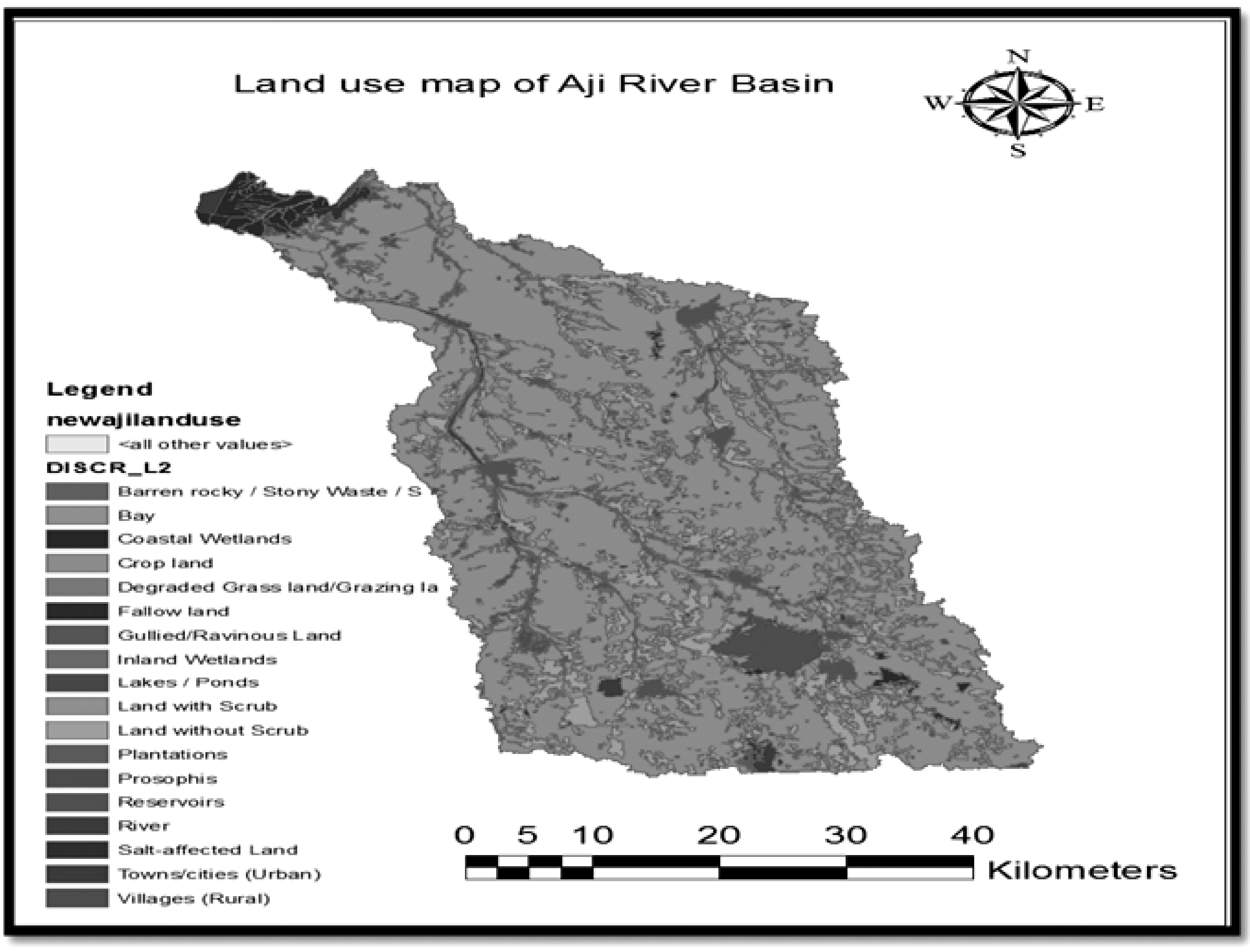

Figure 3. Land use map of Aji basin.

Table 1
Soil texture pattern of Aji river basin

Sr. No	*Area (%)*	*Texture*	*Description*	
1	35.16	Fine	Fine, Montmorillonitic, Hydperthermic, Calcareous, VerticUstochrepts	Inceptisols and Vertisols
2	62.41	clayey	Clayey, Montmorillonitic, Hyperthermic, calcareous, verticUstochrepts	Vertisols
3	2.42	Fine Loamy	Fine, Montmorillonitic, Hyperthermic, calcareous, VerticUstochrepts	Inceptisols

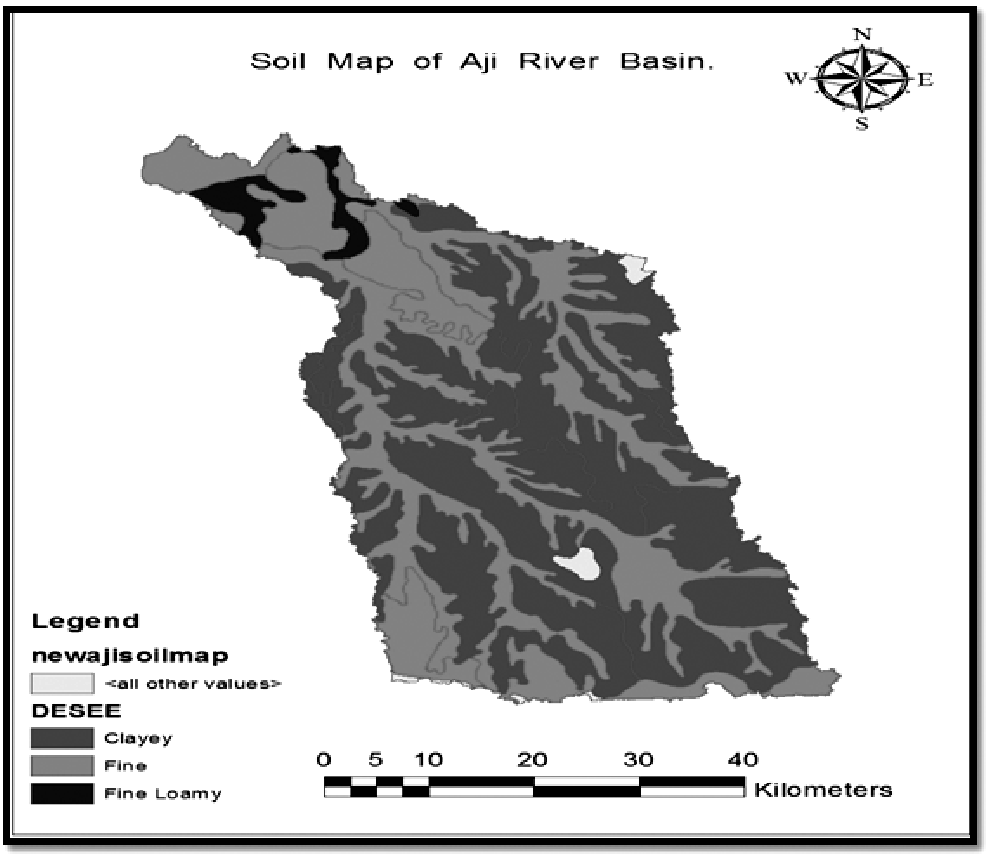

Figure 4. Soil map ofAji basin.

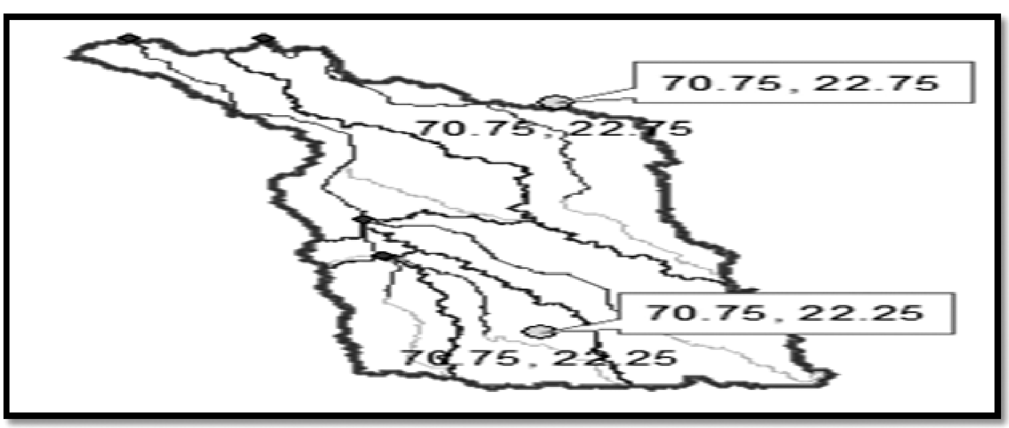

Figure 5. Watershed Map of Aji basin

analysis showed that 35.16%, 62.41% and 2.42% area having soil type of fine, clayey, fine loamy, respectively. It was seen that the clayey soil exist in major part of the basin.

RESULT AND DISCUSSION

Runoff for 1961-2000

The daily runoff was obtained from the SWAT run simulation results using the daily rainfall data from 1961 to 2000. It was also estimated by SCS curve number techniques for the comparison. The comparison of runoff obtained by SWAT model and SCS curve number method are presented in Fig. 6. The Fig 4.16 shows that the runoff estimated by SWAT model is higher than that of SCS curve number techniques. The reason is that the curve number used in the SCS curve number technique is applicable for the 5% slope only while SWAT model corporate the modified SCS curve number techniques using the slope adjusted curve number.

Therefore, it can be said that the surface water potential in basin can be created by the tune of 15 MCM as per the SWAT model estimation if the entire runoff water is harvested and managed properly. That created surface water resources are able to irrigate 3000ha cropped area. Therefore, about 19% area of the basin can be irrigated in one season from these surface water resources.

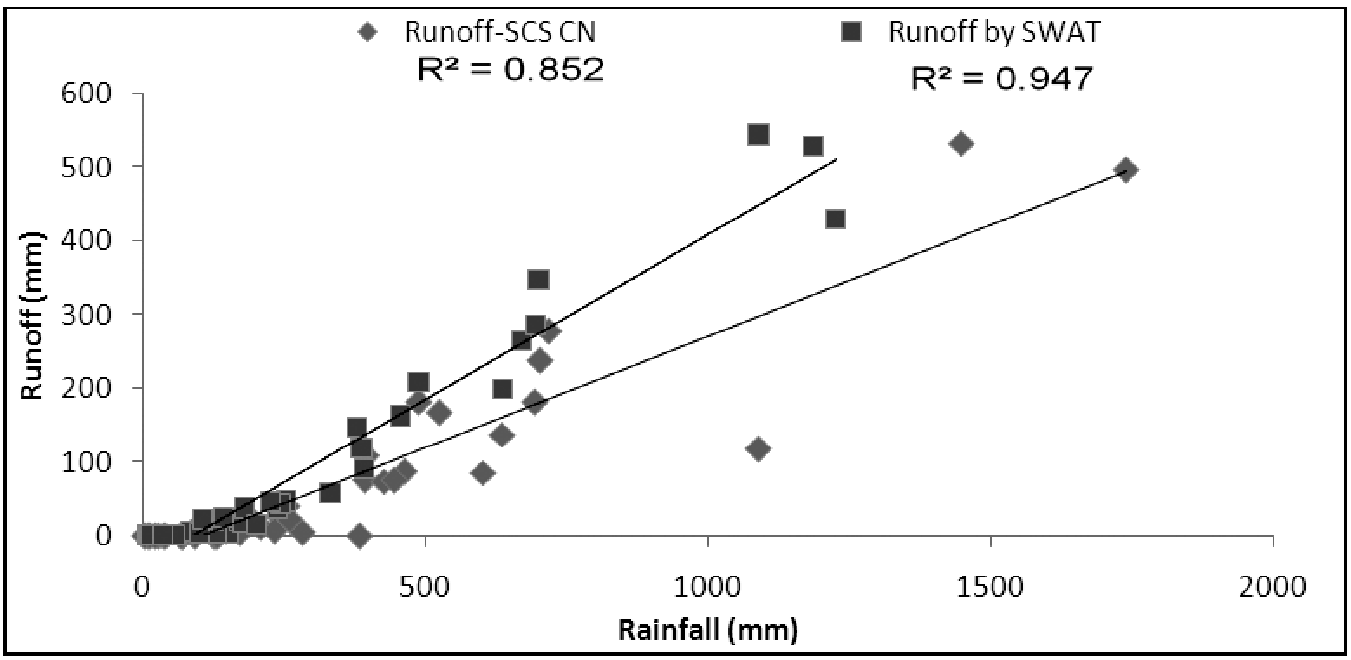

Figure 6. Comparison of runoff estimation by different methods (1961-2000).

The following rainfall-runoff relationships could be found best fit as stated under Eqn. 1 for the SCS method and Eqn. 2 for the SWAT model. The value of goodness of fit was found good.

$$R = 0.302\,P - 32.05 \quad (R^2 = 0.85) \qquad (1)$$

$$R = 0.448\,P - 39.44 \quad (R^2 = 0.94) \qquad (2)$$

Where, R is the seasonal runoff (mm) and P is the seasonal rainfall (mm). The eqn. 1 and 2 shows that the runoff can be generated if seasonal rainfall amount is more than 108 mm and 88 mm by SCS-CN method and SWAT model.

Runoff for 2046-2064

The average monsoon runoff estimated for the basin is 138.78 mm and 215.40 mm by SCS-CN method and SWAT model respectively. The comparison of runoff obtained by SWAT model and SCS curve number method are presented in Fig. 6. Therefore, it can be said that the surface water potential in basin can be created by the tune of 33.8 MCM as per the

SWAT model estimation if the entire runoff water is harvested and managed properly. That created surface water resources are able to irrigate 68 sq.km cropped area in one season which is 43% area of the basin.

The following rainfall-runoff relationships could be found best fit as stated under Eqn. 3 for the SCS method and Eqn. 4 for the SWAT model. The value of goodness of fit was found good.

$$R = 0.436\ P - 44.58 (R^2 = 0.88) \quad (3)$$

$$R = 0.482\ P - 55.77\ (R^2 = 0.96) \quad (4)$$

Where, R is the seasonal runoff (mm) and P is the seasonal rainfall (mm). The eqn. 3 and 4 shows that the runoff can be generated if seasonal rainfall amount is more than 102 mm and 116 mm by SCS-CN method and SWAT model.

Runoff for 2081-2100

The average monsoon runoff estimated for the basin is 496.24 mm and 204.49 mm by SCS-CN method and SWAT model respectively. The comparison of runoff obtained by SWAT model and SCS curve number method are presented in Fig.7. Therefore, it can be said that the surface water potential in basin can be created by the tune of 32 MCM as per the SWAT model estimation if the entire runoff water is harvested and managed properly. That created surface water resources are able to irrigate 6400ha cropped area which is 40% area of the basin.

The following rainfall-runoff relationships could be found best fit as stated under Eqn. 5 for the SCS method and Eqn. 6 for the SWAT model. The value of goodness of fit was found good.

$$R = 0.704\ P - 29.78\ (R^2 = 0.98) \quad (5)$$

$$R = 0.484\ P - 43.89\ (R^2 = 0.95) \quad (6)$$

Where, R is the seasonal runoff (mm) and P is the seasonal rainfall (mm). The eqn. 5 and 6 shows that the runoff can be generated if seasonal rainfall amount is more than 42.3 mm and 90 mm by SCS-CN method and SWAT model.

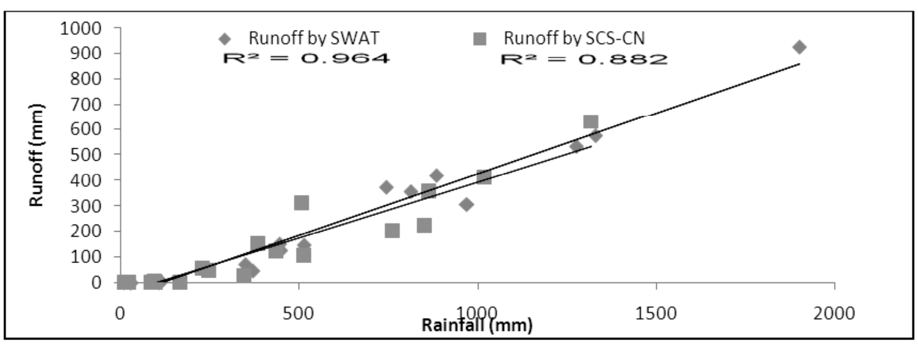

Figure 7. Comparison of runoff estimation by different methods (2046-2064)

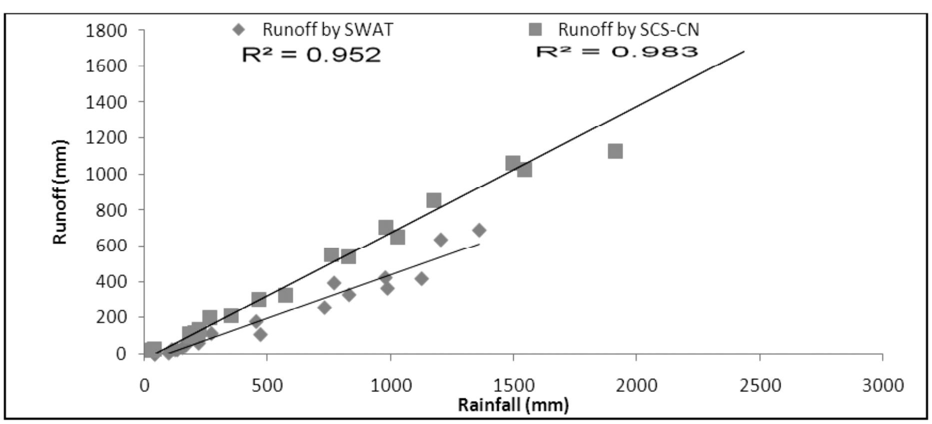

Figure 8. Comparison of runoff estimation by different methods (2081-2100).

CONCLUSION

Rainfall runoff simulation is important for the water resources planning, development and management requires assessment of different components of hydrological cycle, like rainfall, runoff, ground water recharge and evapotranspiration from crop field, forest, grassland/pasture and evaporation from wasteland, bare field and free water bodies. This study is undertaken to estimate the surface runoff and flow volume using SWAT model and compare with traditional SCS-CN methodinAji basin. Estimation of Runoff by SWAT model was carried out with extracted geo-morphological data such as land use, soil type etc under the environment of RS and GIS. In this study it is found that SWAT model combination of curve number method with environment RS and GIS can improve the model performance significantly.To find out the weighted curve number for antecedent moisture condition-II for the scenario 1961-2000 that was found out as 72 for the Aji basin. It is to be noted that SCS-CN method was formulated for humid catchments, yet it is found to be a suitable method for semi-arid regions of Gujarat. The surface water potential in basin can be created by the tune of 15 MCM, 33.8 MCM and 32 MCM as per the SWAT model simulation during the period of 1961-2000, 2046-2064, 2081-2100 respectively. The runoff estimated by SWAT model is higher than SCS-CN method because the SCS-CN method does not account the slope adjusted curve number. The overall scenarios of 1961-2000, 2046-64 and 2081-2100 shows that the monsoon seasonal rainfall, runoff are increasing at 24.12mm/decade and 11.55 mm/decade. Overall it is found in this study that curve number method along with SWAT model is very efficient and accurate for modelling rainfall-runoff and to estimate total surface runoff.

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