RUN-OFF ESTIMATION FOR THE KARJAN RIVER BASIN USING NRCS CN METHOD

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In a large watershed the surface runoff generated may significantly affects environment, agriculture, and the availability of flood potential (Jayswal *et al*., 2021) The runoff generated from the watershed runoff determines the soil erosion condition and other hydraulic properties of soil and also potential runoff availability for the water management. The runoff from a watershed can be measured using different methods and empirical models based on daily, monthly or annually depending on rainfall pattern, infiltration rate and the morphometric characteristics of the watershed (Sondarva *et al.* 2023). There are several hydrological models available for estimation of runoff out of which most of the models requires large number of input data. The Natural Resources Conservation Service Curve Number (NRCS-CN) method which is formerly known as Soil conservation Service Curve Number (SCS-CN), is the one of the most reliable and oldest method for the estimation of runoff from precipitation. It can be used very effectively in the ArcGIS. When runoff estimation deals with the ungauged watershed, where such detailed information is seldom available. Perhaps the most popular technique for meeting this need is the curve number method developed by the U.S. Department of Agriculture (USDA). The Curve Number method estimates the direct runoff from storm rainfall based on data from watershed. This method is most relevant and it considers the physiographic and hydrologic condition of the watershed (Bans ode *et al*. 2014). One of the most significant advantages of this method is that it relies on single conceptual parameter called as maximum potential retention (S) or corresponding Curve Number. However, the CN method cannot respond to the differences in storm intensity and Antecedent Moisture Condition (AMC). The error made in the selection of CN can reflect many folds in the estimation of runoff.

METHODOLOGY and DATA COLLECTION

Location of the study area

The study area is located at 73.20’ to 74.00’ East Longitude and 21.20’ to 22.00’ North Latitude. As shown in the Fig. 1, Karjan watershed falls in the Narmada, Vadodara, Surat district of the Gujarat state in which the major part of watershed is covered by Narmada district which is situated in the Southern part of the Gujarat state. In the Karjan river basin out of total area 33.52% area was covered under forest cover. The catchment area is about 1538.38 km^2. The area having Rajpipla hills, which is merging with the Saputara and Shyadri ranges.

The area was delineated using Bhuvan portal online shape file tool and verified with the Survey of India Toposheet NF 43-10.

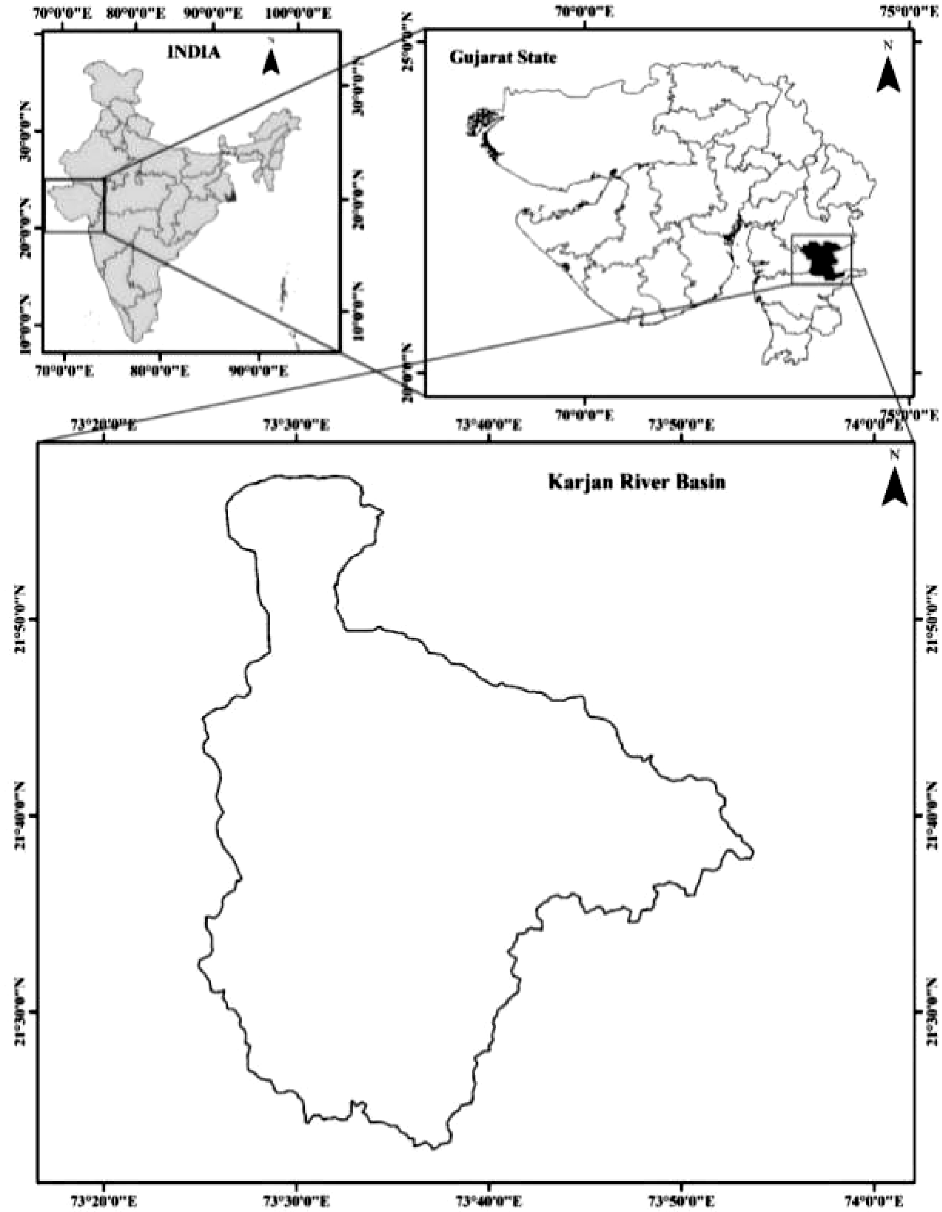

Fig. 1 Location map of Karjan River basin

NRCS-CN model for runoff estimation

A. ***Rainfall***

The rainfall data from the year 1999 to year 2021 were collected from State Water Data Center for the Karjan River basin. Seven raingauge sations falling under the Karjan watershed i.e., Rajpipla, Bitda, Juna Mosda, Dumkhal, Thava, Dediapada and Dhanmoli. The area covered under each station are 14.97, 19.52, 10.59, 23.78, 30.83 and 0.32 percentage respectively for the raingauge stations Rajpipla, Bitda, Juna Mosda, Dumkhal, Thava, Dediapada and Dhanmoli.

B. *Potential maximum retention (S)*

Potential maximum soil water retention of Karjan watershed was estimated by SCS-CN method. It is mainly depending on the hydrological soil group and land use type of the area, as CN is a function of the land use and hydrologic soil group.

C. *Curve number*

The Karjan watershed has four types of hydrologic soil groups (HSG), Table 4.8, the major soil group is of D type followed by B and C, D type of soil has highest runoff potential as it is having very less infiltration capacity. The weighted curve number was calculated based on the area wise land use and hydrological soil group, as SCS-CN method gives good result when the area is not much. The AMC was selected based on the preceding 5-day rainfall.

D. *Hydrologic Soil Groups of Karjan Watershed*

Soil properties influence the generation of runoff from rainfall in the methods of runoff estimation. Soil map prepared by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and soil report of the study area have been used for classifying various soils into hydrologic soil groups. Soil classification system developed by SCS-CN is widely useful for the determination of hydrological soil groups and it has been followed while classifying soils into different hydrologic soil groups for the Karjan watershed area.

According to this hydrological soil group classification system, soils of the Karjan watershed area are classified into A, B, C or D hydrologic soil group depending on their properties. Category "A" has lowest runoff potential whereas category "D" has highest runoff potential. The percent of total area under particular soil hydrologic group is given in Table 1. Only Dhanmoli polygon of the watershed fully covered in the D group of HSG while Rajpipla polygon contains all kind of HSG. Overall, most area in the Karjan river basin is covered with Hydrologic soil group B and D.

Table. 1 Percentage area covered under Hydrologic Soil group for different polygons under Karjan watershed

Sr No.	Polygon	Percent Area of the Karjan river basin (%)			
		HSG-A	HSG-B	HSG-C	HSG-D
1	Rajpipla	6.68	40.08	0.13	53.11
2	Bitda	-	8.05	-	91.95
3	Dumkhal	-	-	0.17	99.82
4	Juna Mosda	-	3.34	8.30	88.35
5	Thava	-	59.71	-	40.28
6	Dediapada	-	41.10	-	58.89
7	Dhanmoli	-	-	-	100

E. *Land use Land cover in Karjan Watershed*

Land use/land cover is dynamic in nature and it gives very precise information about the relationship between anthropogenic activities with the environment (Prakasam, 2010; Yadav *et al.*, 2012). Land use is an essential basic characteristic of watershed that affects hydrological events like infiltration, surface storage, runoff and soil erosion during simulation (Neitsch et al, 2005). As shown in

Fig. 2 and 3, Land use/ land cover map for two years was prepared for the year 1999 and 2009 with the help of ERDAS Imagine software and used in the NRCS CN method. The images were classified in five land use/land cover classes, i.e., Agricultural land, Forest land, Urban land, Fallow land, and Water bodies.

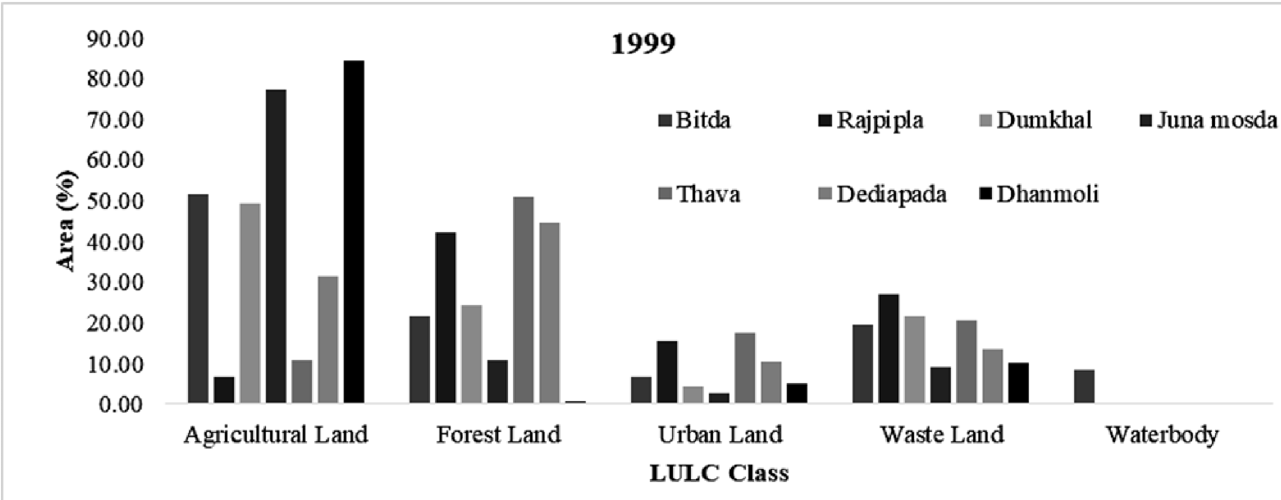

Fig. 2 Land-use Land cover class for the year 1999 of Karjan River basin.

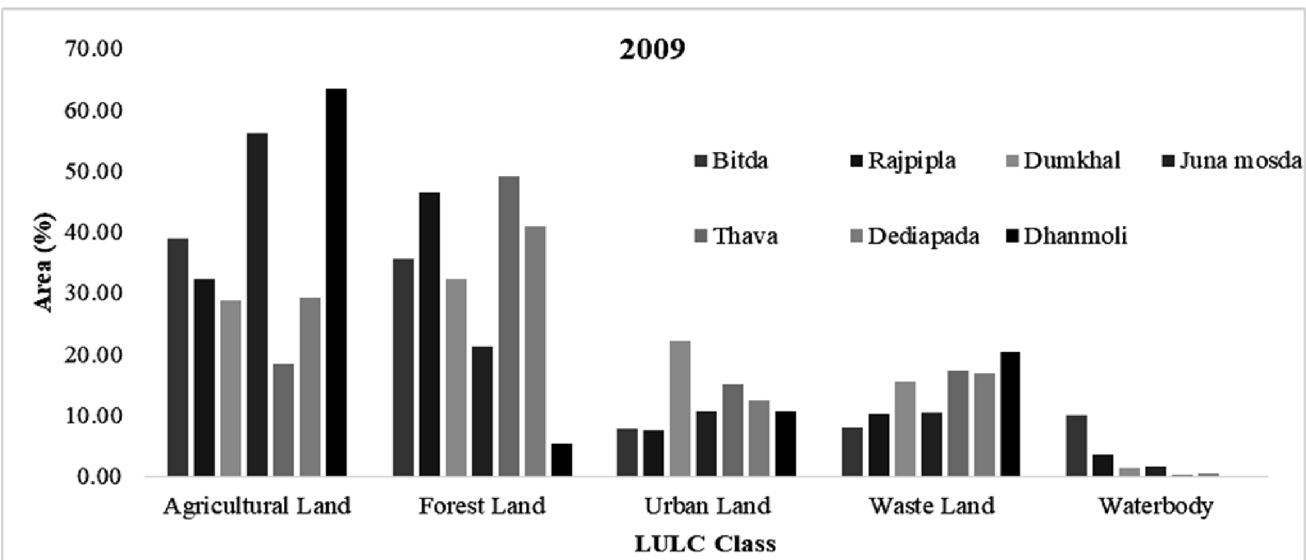

Fig. 3 Land-use Land cover class for the year 2009 of Karjan River basin.

It was found that the forest cover decreased from 514.2 km^2 to 502.20 km^2 from year 1999 to 2009, while agricultural land, residential land was increased from 560.53 km^2 to 571.16 km^2 and 156.03 km^2 to 200.20 km^2 respectively. The similar results were obtained by Sondarva, *et al.* 2023 for the lower Tapi river basin. As the forest cover decreased it shows the impact on the surface runoff. Surface runoff is increased in 2009 and onwards.

Structure of SCS-CN model

The NRCS CN method formerly known as SCS curve number method is based on the water balance equation. There are various parameters i.e., rainfall, curve number, land use land cover, hydrological soil group and antecedent moisture condition used for the estimation of runoff by this method.

The NRCS-CN method, expressed in equation below

$$Q = \frac{(p - la)^2}{(p - la + S)} \qquad ...(1)$$

Where $I_a = 0.2$ S

Q = Accumulated storm runoff, m;

P = Accumulated storm rainfall, mm,

S = Potential maximum retention of surface water by the soil,

Ia = Initial quantity of interception, depression and infiltration

Substituting in equation (1), the equation becomes

$$Q = \frac{(p - 0.2S)^2}{(pa - 0.8S)} \qquad ...(2)$$

Which is valid for P >0.2S, otherwise runoff (Q) will be zero

Potential retention of water (S) can be determined from the P - Q data. Generally, S is derived from a equation expressed in terms of the curve number (CN):

$$S = \frac{25400}{CN} - 254 \qquad ...(3)$$

Where CN is a dimensionless parameter. It is the function of watershed hydrologic land use/land cover units hydrologic soil groups antecedent moisture condition. The value of varies between 0 to 100. CN is 0 when surface runoff is 0 and CN is 100 when all rainfall becomes runoff, S=100. CN values can be obtained for different land uses and hydrologic condition from the standard Table CN values for AMC-I and III can be obtained using the equations (2) and equation (3).

RESULTS AND DISCUSSION

Runoff estimation using NRCS CN method

The Karjan River basin has 7 rain gauge stations i.e., Rajpipla, Bitda, Juna Mosda, Dumkhal, Thava, Dediapada and Dhanmoli, covering 14.97, 19.52, 10.59, 23.78, 30.83 and 0.32 percentage area of Karjan watershed respectively. The mean rainfall of the Karjan watershed was estimated by Thiessen polygon method. The average annual rainfall of the Karjan River basin was found to be 1205 mm for the duration of 23 years i.e., from 1999 to 2021.

The seasonal distribution of the rainfall is given in fir. 4. As per the seasonal distribution of rainfall analysis, it was observed that the maximum rainfall among the annual rainfall values was in July month, followed by, August, September, and June during 1999 to 2021. Looking to the percentage distribution of rainfall during the season, it was observed that the highest and lowest percent of annual rainfall occurred in July month, 67.56% in 2009, and 4.28% in 2002. The highest and lowest percentage of annual rainfall for August month was observed as 63.83 % in 2020 and 6.69 % in 2015 respectively. The highest and lowest percentage of annual rainfall for September month was observed as 45.89 % in 2021 and 2.37 % in 2001. The highest and lowest percentage of annual rainfall for June month was observed as 35.71 in 2002 and 2.72 % in 2012.

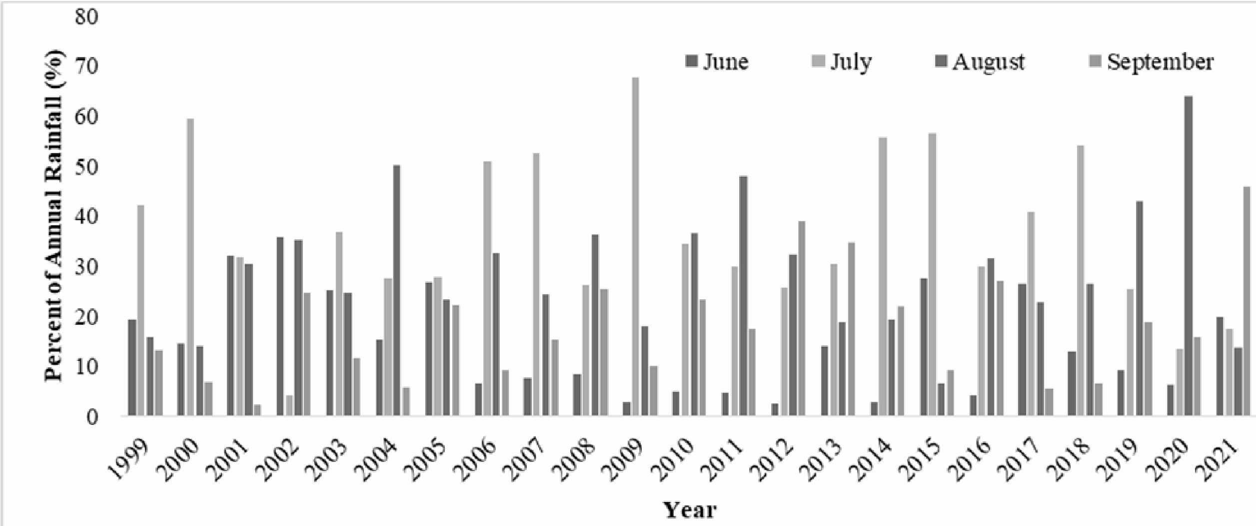

Fig. 4 Seasonal Rainfall over the Karjan Watershed from year 1999-2021

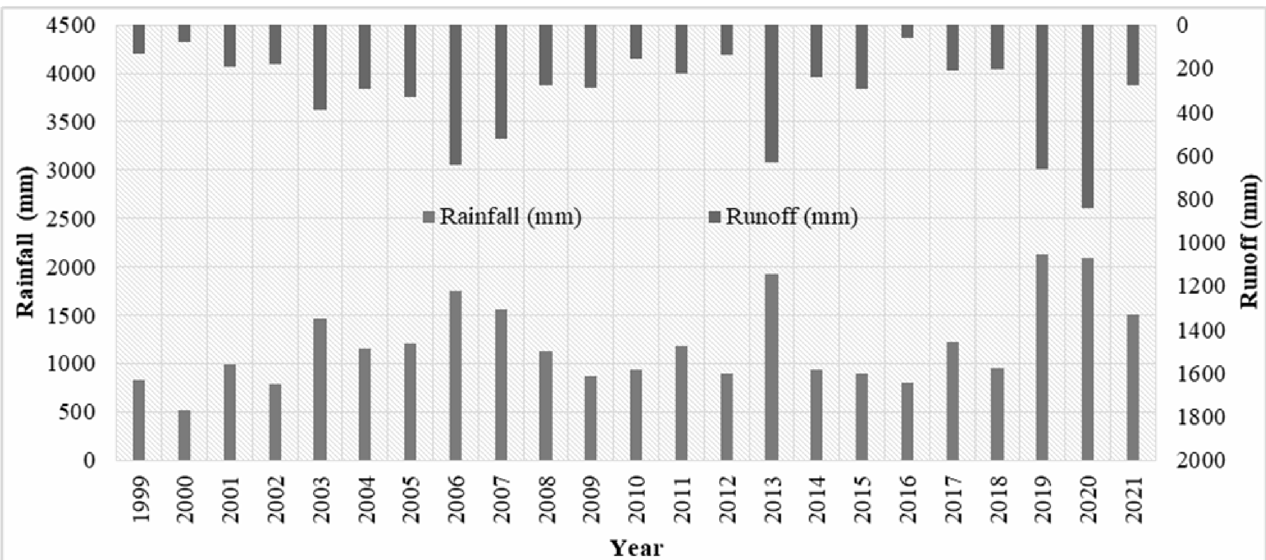

Fig. 5 Annual Rainfall and NRCS-CN estimated Runoff for year 1999 to 2021

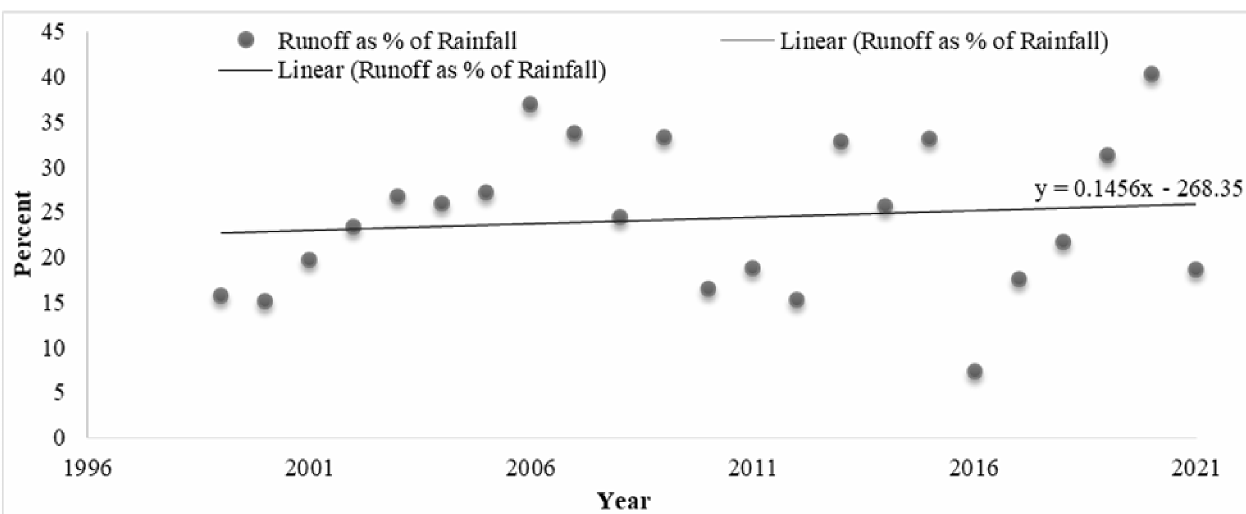

Fig. 6 Estimated Runoff using SCS-CN Method as percent of rainfall

The estimated runoff using NRCS- CN method is shown in Fig. 5 and the percentage contribution of the rainfall into runoff is presented in 6. It was observed that the highest runoff was observed in the year of 2020 as 842.11 mm and the lowest runoff was observed in the year of 2016 as 57.85 mm. The highest rainfall contribution to runoff was observed in the year of 2020 as 40.29 percent and the lowest contribution of rainfall to runoff was observed in the year of 2016 as 7.25 percent. It was observed in year 2020 throughout the monsoon season 37.78 percent period having rainfall and the AMC I, II and III conditions were prevailed for 15.44%, 35.57% and 37.78% and in year 2016, 34.44 percent days having rainfall with AMC I, II and III of 16.11, 22.15 and 34.44 respectively. AMC II and III having high influence in runoff generation which was higher in year 2020. AMC I cause more rainwater to infiltrate in to the soil which was higher in year 2016.Runoff contribution was found to be increased from year 1999 -2009 -2020, it may be due to deforestation and increase in the urban area in the Karjan watershed.

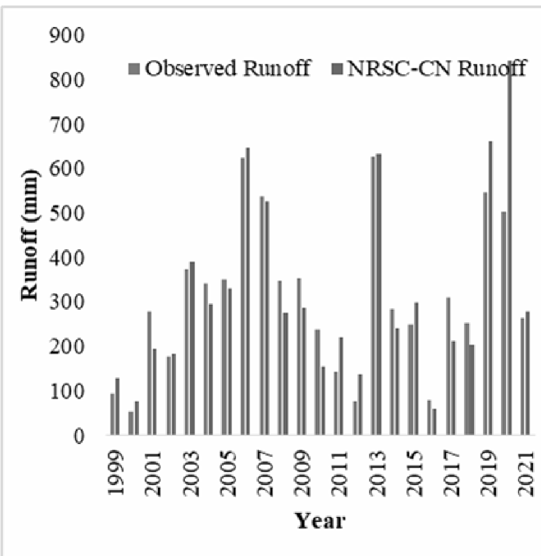

Fig. 7 Observed and Simulated runoff

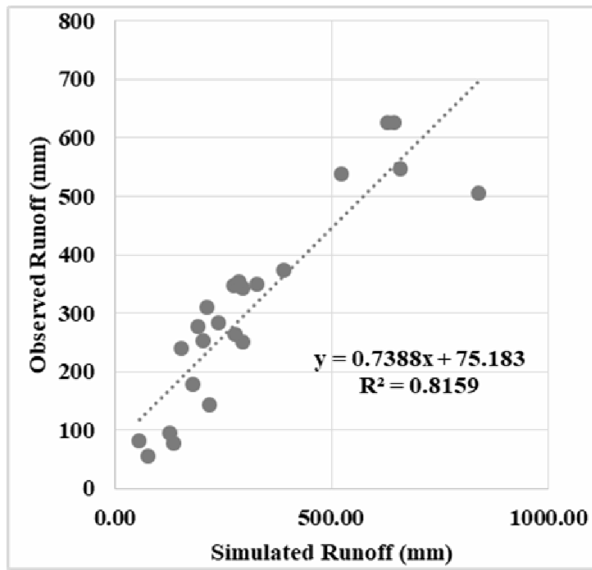

Fig. 8 Observed runoff Vs Simulated runoff

Performance evaluation of NRCS-CN model

The criteria used to evaluate the performance of the models are the overall agreement between observed and estimated runoff volumes. Coefficient of determination (R^2) and Nash-Sutclife simulation efficiency (NSE) were the goodness of fit measures used to evaluate model predictions. The R^2 value is an indication of strength of the relationship between the observed runoff and the estimated runoff values. The R^2 value ranges from 0 to 1, generally values more than 0.5 shows acceptability or results also R^2 value moving towards 1 indicates decreasing error variance (Santhi *et al*., 2001, Van Liew *et al.,* 2003; Nyeko, 2010) and the NSE which is the normalized statistics that determines the relative magnitude to the residual variance to the measured data variance (Nash and Sutctclife, 1970; Nyeko, 2010). This objective function can best reflect the overall fit of a hydrograph (Sevat and Dezetter 1991). The Nash-Sutclife simulation efficiency, NSE indicates how well the plot of the same as all predicted ENS is 1. If the NSE is between 0 and 1 which indicates deviations between the observed and estimated values. If NSE is negative, predictions are very poor, and the average value of output is a better estimate than the model predictions (Nash, Sutclife, 1970). By plotting 1:1 line between observed versus simulated data, NSE reflects the degree of fitness (Moriasi *et al*., 2007; Abbaspour, 2012). Based on the values of the performance parameters, the performance of the Karjan watershed simulation model is given in Table 4.13.

The coefficient of determination (R^2) is obtained from the regression analysis (scattered plot) of the observed runoff values (mm) and estimated runoff value (mm) and it was found 0.816 which shows good correlation between observed and estimated values of runoff for the year 1999 to 2021. It can be seen from the Fig. 8, that the points obtained by plotting the estimated runoff values against observed runoff values are very close to a straight line indicates that the differences between them are not significant. The best fit line between the data has high coefficient of determination (R^2) which shows that they are related by a straight line. The value of the RSR was found to be 0.536 which is under category of good model performance, similarly percent of bias (%) was found to be -0.489 which is under very good model performance category and Nash-Sutclife model efficiency (NSE) values were found to be 0.781 under very good model performance.

CONCLUSION

The mean runoff potential of the Karjan River basin using NRCS CN method is about 316mm from the 1205 mm mean annual rainfall and the weighted CN for the Karjan River basin is 70.94. The NRCS CN method can be efficiently use for the runoff estimation in the Karjan river basin.

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