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Impact of Monthly Curve Number and Five-Day Antecedent Rainfall-Runoff Data Set on Performance of SCS-CN Method for Ozat Watershed in India – A Case Study

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Abstract *—The Soil Conservation Service Curve Number (SCS-CN) is a well-established and widely used loss-rate model to estimate surface runoff. It combines watershed and climatic parameters in one entity curve number (CN). Much of the variability in CN has been attributed to antecedent runoff condition (ARC). The (CN) also exhibits an inherent seasonality beyond its spatial variability, which cannot be accounted for by the conventional methods.*
In the present study, CN were determined by three different approaches, standard CN, monthly CN and CN based on five day antecedent rainfall-runoff (ARR) data set using standard asymptotic fit and gauged rainfall-runoff data with an objective to evaluate the impact of monthly CN and five days ARR data set on runoff estimation for Ozat watershed (Gujarat State-India). The significant improvement in performance of SCS-CN method is found on application of CN based on five day ARR data set as compare to monthly CN for Ozat watershed. Refined Willmott's index (d_r) and mean absolute error (MAE) were used to assess and validate the performance of SCS-CN method. For the study region, the CN determined based on five day ARR data set was judged to be more consistent with d_r=0.58 and MAE=0.93 mm for λ=0.05.

Keywords*-soil conservation service curve number method; curve number; seasonal variation; antecedent rainfall; ozat watershed*

I. INTRODUCTION

The SCS-CN method was first introduced in 1954 and which has been now renamed as Natural Resource Conservation Service (NRCS)-CN method. The primary reason for its wide applicability and acceptability lies in the fact that it accounts for major runoff-generating watershed characteristics, namely, soil type, land use/treatment, surface condition and antecedent moisture condition [1-3]. In contrast, the main weaknesses reported in the literature are that it does not consider the impact of rainfall intensity, seasonal variability and the effects of spatial scale.It is highly sensitive to changes in values of its single parameter *CN* and ambiguous considering the effect of antecedent moisture conditions [4, 5]. Nevertheless, the model development has made much progress in last three decades; a need of further improvements has always been experienced to satisfy unresolved challenges.

After the critical examination of the methodology, the SCS-CN method has gained much attention with respect to its modification and investigation. Many researchers [e.g. 6-9] have examined the accuracy of the *CN* method and identify specific unrecognized weaknesses and limitations those were rarely noted in textbooks. Inability to account for the temporal variation in rainfall and runoff is its prime limitation. Recent modifications in determination of *CN* are reported by slope adjustment procedure [10], two-*CN* system approach [11] and composite *CN*-generation [12]. The SCS-CN model implementing with these modifications would have a better simulation performance than the existing original SCS-CN. In *CN* method, parameters those influence the seasonal variation on predicting runoff have not been incorporated and hence, it ignores the impact of seasonal and monthly variation. Although the *CN* method is well documented and widely used, as [13] pointed out, a need to use the method as a guideline and interpret inputs on a more local and regional level combined with seasonal variation is essential. Runoff simulation with annually consistent parameters has limited application because watershed response varies remarkably from season to season. The seasonal tank model developed by [14] showed better performance compared to the non-seasonal tank model because it can successfully simulate runoff with little error. *CN* on monthly basis and *CN* based on five day antecedent rainfall-runoff (ARR) data set, therefore, may also result in more accurate runoff estimation and improve the performance of SCS-CN model. The investigation reported in this paper is motivated by the need toevaluate the impact of monthly *CN*and *CN* based on five day ARR data set on runoff estimation for Ozatwatershed. The standard asymptotic fit [15] procedure is employed to calculate standard *CN*, monthly *CN* and *CN* based on ARR data set.

The objectives of this study were: (1) to compare standard *CN* determined by gauged daily rainfall-runoff data set with monthly *CN* and *CN* based on ARR data set; and (2) to evaluate the impact of monthly *CN* and *CN* based on ARR data set on performance of SCS-CN method for Ozatwatershed.

II. MATERIALS AND METHODOLOGY

2.1. Study Area and Data collection

Ozat is a river flowing in western India in Gujarat state whose origin is near Visavadar and meets in Arebian Sea. Ozat is third largest river of Saurashtra region after Bhadar and Shetrunji rivers. Ozatwatershed considered in this study geographically locates within the latitudes $21^0 19'$ N to $21^0 33'$ N and the longitudes $70^0 39'$ E to $70^0 56'$ E respectively as can be seen from toposheet no 41K (10-11-14 and 15) of scale 1:50000. The gauge discharge site is located near Khambhaliya village at bridge of Junagadh to Visavadar Road 33 km away from Junagadh. Information about soil and land use have been gathered from maps of National Bureau of Soil Survey and Land use Planning (ICAR) (1994). Study area (sub-watershed) has been delineated from Survey of India (SOI) topographic sheet using AutoCAD (2010) Software (***Figure1***). The major portion of the precipitation occurs during the four months of June to September by south-west monsoon. The data set for the monsoon season has been collected and analysed in the study area. The area is situated in semi-arid region with average annual rainfall of the area is 786 mm (1980-2010), mean maximum temperature 33.34^0C and mean minimum temperature 24.30^0C. The area has the high annual variability of rainfall from 211 to 2216 mm. It is characterized by erratic rainfall pattern. The total geographical area 358.8357 Sq. Km. comprises of about 20.08% (72.0542 Sq. Km.) grass and open scrub land and remaining 79.92% area under arable land irrigated (286.7815 Sq. Km.). The major crops grown in the watershed are Ground nut, wheat and Cotton.

The hydrological data daily rainfall (mm) and runoff (m^3/s) (1980 to 2010) and meteorological data dailymaximum and minimum temperatures of Ozatwatershed were collected from the State Water Data Centre, Gandhinagar. The information related to watershed characteristics, namely, physiography, number of streams of different orders, their length, slope and area contributing runoff to these streams were obtained from the topographic maps of the watershed.

Periodic insufficient rainfall pattern, limited water storage capacity of aquifer and natural water conservation are vital issues for this region. Water availability is a critical factor in this area and therefore accurate estimation of runoff is needed for water resources management, crop water use, farm irrigation scheduling, and environmental assessment.

2.2. SCS-CN Method

The SCS-CN method is based on the principle of the water balance and two fundamental hypotheses. The first hypothesis states that the ratio of direct runoff to potential maximum runoff is equal to the ratio of infiltration to potential maximum retention. The second hypothesis states that the initial abstraction is proportional to the potential maximum retention. The water balance equation and the two hypotheses are expressed mathematically respectively, as:

$$P = I_a + F + Q \qquad 01$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \qquad 02$$

$$I_a = \lambda S \qquad 03$$

Where P is the total precipitation (mm), I_a is the initial abstraction before runoff (mm), F is the cumulative infiltration after runoff begins (mm), Q is direct runoff (mm), S is the potential maximum retention (mm), and λ is the initial abstraction (ratio) coefficient.

In larger sized watersheds, some rainfall will fall directly on riparian areas with an immediate response in the mainstream hydrograph. Small amount of rainfall events result in even smaller changes in runoff that can sometimes be difficult to discern in the discharge time series. To minimize uncertainty in the determination of the storm event discharge, storms events with $P \geq 5$ mm have been considered to determine CN values in calibration period for this study. In validation period all events have been considered to measure performance of SCS-CN method.

The λ was assumed to be equal to 0.2 in original SCS-CN model. In order to simplify the equation and eliminate one variable (λ = 0.2), I_a is fixed at I_a= 0.2S [16]. However, the assumption of λ = 0.2 has frequently been questioned for its validity and applicability, invoking a critical examination of the I_a–S relationship for practical applications [17]. A study using rainfall and runoff data from 307 US watersheds or plots found that a value of λ = 0.05 would fit the data much better [18]. [19] found that the prediction accuracy for λ = 0.05 was greater than that for λ = 0.2 using SCS-CN method to simulate plot runoff of 757 rainfall events in Zizhou and Xifeng cities located in the Loess Plateau of China. Similar results have been obtained from plots or watersheds in USA [20], semi-arid tropical highlands of Northern Ethiopia [21] and the Three Gorges area of China [22]. The assumption λ = 0.20 has been recently considered unusually high and recent studies [23-25] suggested the use of λ = 0.05. In the present study performances of SCS-CN method on application of different CN values in validation period were compared and tested with λ = 0.05

The general runoff equation combination of Eq. (01) and Eq. (02) introduced by the [26] is shown in Eq. (04):

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \text{for } P > I_a \quad 04$$

$$= 0 \text{ otherwise}$$

The potential maximum retention S (mm) can vary in the range of $0 \le S \le \infty$, and it directly linked to a dimensionless coefficient called "Curve Number" (CN). Parameter S is mapped to the CN using Eq. (04) as:

$$S = \frac{25400}{\mathrm{CN}} - 254 \quad 05$$

The CN depends on land use, hydrologic soil group, hydrologic condition, antecedent moisture condition (AMC) and it can vary from 0 to 100. Three AMCs were defined as dry (lower limit of moisture or upper limit of S), moderate (normal or average soil moisture condition), and wet (upper limit of moisture or lower limit of S), and denoted as AMC I, AMC II, and AMC III, respectively [27]. Higher amount of antecedent moisture and CN value would indicate the more runoff generation and vice versa, therefore, median CN determined from array of CN values was commonly adopted for the watershed [28-30].

Normally variations in storm characteristics and surface conditions can responsible for variation in CN between events. Possible sources of CN variability may be the effect of the temporal and spatial variability of storm and watershed properties, the quality of the measured data, and the effect of antecedent rainfall and associated soil moisture. [31]and[32] also noted that the variation of CN value, according to AMC category alone, cannot justify the observed CN values variability in every case. Much of the variability in CN has been attributed to antecedent runoff content (ARC) such that soils that are wetter have a higher curve number, creating more runoff for a given amount of precipitation, than soils that are drier ([33, 34]. Many researchers have demonstrated from rainfall and runoff data that its key parameter CN has variable components and is not a constant for a watershed [35, 36], and varies with rainfall. Based on this previous work, we evaluated the performance of theSCS-CN method using standard CN, monthly CN and CN determined by ARR data set. These CNvalues were estimated by standard asymptotic fit procedures using daily rainfall-runoff data.

2.3. Curve Number Estimation (Standard *CN*)

The CN values corresponding to the watershed soil types, land cover and land management conditions can be selectedfrom the NEH-4 tables.The CN value of AMC II (CNII) was provided by the SCS-CN manual and the CN value of AMC I (CNI) and CN value of AMC III (CNIII) can be calculated using the equations of [37].CNI, CNII and CNIII values for Ozatwatershed were computed 64.46, 81.20 and 90.85 respectively based on land used, soil characteristicsand previous 5-days rainfall of the watershed.

When rainfall-runoff dataare available for a watershed, P and Q pairs are used directlyto determine the potential retention S characterizing the watershed [38] as:.

$$S = \frac{P}{\lambda} + \frac{(1-\lambda)Q - \sqrt{(1-\lambda)^2 Q^2 + 4\lambda PQ}}{2\lambda^2} \quad 06$$

CN value can be directlycalculated from rainfall-runoff data by substituting value of S inEq. (05) and rearranging it as:

$$\mathrm{CN} = \frac{25400}{\frac{P}{\lambda} + \frac{(1-\lambda)Q - \sqrt{(1-\lambda)^2 Q^2 + 4\lambda PQ}}{2\lambda^2}} + 254 \quad 07$$

In standard asymptotic fit method (AFM), P and Qdataare re-aligned on a rank-order basis, creating a new set of P: Qpairs (ordered P: Q data). This is done by rank ordering the rainfalls and runoff separately, and reassembling them as rank-ordered pairs. These P: Q pairs have equal return period and not necessarily associated with the original rainfall P. Out of three types (standard, violent, and complacent)ofwatershed responses. The Standard response was observed in Ozat watershed and to be described by the following:

$$CN(P) = CN_\infty + (100 - CN_\infty)e^{(-kP)} \quad 09$$

Eq. (09) has the algebraic structure of the Horton infiltration equation. In the standard response, the curve number as a function of rainfall P (CN [P]) decreases to an asymptotic constant CN_∞ with k(the fitting coefficient or rate constant in the units of $1/P$) that describes the curve number approach to the asymptotic constant CN_∞. Optimized values of $CN_\infty$and $k$are obtained by fitting Eq. (09) using least-squares procedure. The recent report to NRCS [39] recommends this procedure as the preferred technique for CN parameterization. Standard CN values determined by AFM and optimized values of parameter CN_∞ and k of AFM for $\lambda = 0.05$ are presented in ***Table 1***.

2.3. Monthly Curve Number Estimation

Month wise optimized values of parameters CN_{∞} and *k*of AFM were computed using ordered *P-Q* data. *CN* values were then determined by incorporating mean monthly rainfall amount of calibration period (1980-1994), CN_{∞} and *k* in Equation (9). ***Table 1*** presents estimated monthly *CN* values by AFM for Ozatwatershed.

2.4. Curve Number Estimation Based on Five Days ARR Data Set

The parameters $CN_{\infty}$and*k*of AFM are computed using five day ARR*P-Q* data. CN values are then determined by incorporating mean annual rainfall amount in mm, $CN_{\infty}$and*k* in Eq. (09). ***Table 1*** presents CN values estimated by AFM along with values of parameter $CN_{\infty}$and*k* for $\lambda = 0.05$.

In stream flow separation, the most frequently used methods are filtering separation method and statistical method (Frequency-Duration analysis). In filtering separation method, base flow separates from the stream flow time series data by processing or filtering procedure. Although these methods don't have any physical basis it aims at generating an objective, repeatable and easily automated index that can be related to the base flow response of the watershed [40]. In this study the [41] filtering method is used to separate base flow from stream flow.

$$Q_{d(i)} = \alpha Q_{d(i-1)} + \beta(1+\alpha)(Q_{T(i)} - Q_{T(i-1)}) \quad 10$$

Where,

Q_d = Direct flow part of the stream flow which is subjected to $Q_d \geq 0$ for the time *i* in days

Q_T = Total flow (i.e base flow + direct flow)

α = a coefficient with value 0.925

β = a coefficient with value 0.5

III. STATISTICAL CRITERIA

In this study, the performances of SCS-CN method with *CN*values determined by different approaches using AFM are evaluated using two popular statistical criterion refined Willmott's index (d_r) [42] (Dimensionless statistic) and mean absolute error (MAE) (error index statistic). Dimensionless techniques provide a relative model evaluation assessment, and error indices quantify the deviation in the units of the data of interest [43]. These statistical criterions are used to measure the agreement between predicted and observed values of event runoff. To check precision and correctness of the methods, (d_r) is applied. The MAE does not tell about degree of error but it is used for the quantitative analysis of residuals.

The d_r is applied to quantify the degree to which values of observed runoff are captured by the models. The range of d_r is from -1.0 to 1.0. A d_r of 1.0 indicates perfect agreement between model and observation, and a d_r of -1.0 indicates either lack of agreement between the model and observation or insufficient variation in observations to adequately test the model.

The root mean square error (RMSE) and MAE are both error measures used to represent the average differences between models predicted and observed values. It is important to include absolute error measures (such as MAE and RMSE) in a model evaluation because they provide an estimate of model error in the units of the variable. The MAE provides a more robust measure of average model error than the RMSE, since it is not influenced by extreme outliers. A higher MAE value indicates poor model performance and vice versa. MAE = 0 indicates a perfect fit. MAE is the most natural and unambiguous measure of average error magnitude.

These statistical criteria are used to measure the agreement between predicted and observed values of event runoff in calibration (1980-1994) and validation period (1995-2010). The resulting values of d_r, and MAE are presented in ***Table 2***.

IV. RESULTS AND DISCUSSION

The SCS-CN method was applied to the data set of Ozat watershed with standard *CN*, monthly *CN* and *CN* estimated by five day ARR data set using AFM. The data set of 15 years (1980-1994) was used to determine different *CN*s and for calibration of the SCS-CN model, while the data set of 16 years (1995-2010) was used for validation of the model. ***Table 1*** showed that estimated *CN*s by different approach with λ= 0.05 for Ozat watershed. ***Table 2*** displayed the results of performance of SCS-CN method in calibration and in validation periods with different *CN*s for $\lambda = 0.05$.

For Ozat watershed *CN*I, *CN*II and *CN*III values for $\lambda = 0.20$ from NEH-tables were computed 64.46, 81.20 and 90.85 respectively. These higher values of *CN*in the original SCS-CN method tend to overestimate the runoff in the study area. In the present study, *CN* values were estimated by three different approaches using AFM method. The *CN*values were found in range from 42.20 to 97.81 (***Table 1***). The standard *CN* based on the daily rainfall-runoff data set was estimated *CN* value 58.78. The lowest value of *CN* (42.20) was found when five day ARR data set used in place of daily rainfall-runoff data set. This indicates that when five day ARR data set was used, the SCS-CN model estimates lower runoff volume. Monthly *CN* values were computed in range from 51.45 to 97.81. Gradual increment in the monthly *CN* values was found from the month of June to October. This may be due to increase in amount of antecedent moisture content from the month of June to October in the monsoon season. Hence, runoff generating capacity of the SCS-CN gradually increased from the month of June to the month of October.The optimized parameter CN_∞ values were found in range from11.59 to 58.45. Parameter *k* values were found in range from 0.02 to 0.21.

Estimated values of the statistical criteriond_r and MAE in calibration and validation periods for evaluation of performance of the SCS-CN model were presented in ***Table 2***. $d_r$and MAE values estimated 0.47 and 1.16 mm respectively in validation period for monthly *CN* approach and are almost similar to the corresponding *CN* values estimated by standard *CN* approach (d_r = 0.47 and MAE = 1.18 mm). In five day ARR approach, d_r and MAE were computed d_r = 0.58 and MAE = 0.93 mm respectively in validation period and are significantly differ from the corresponding *CN* values estimated by standard *CN* approach (d_r = 0.47 and MAE = 1.18 mm). The estimated values of d_r were found in range from 0.46 to 0.58 while the estimated values of MAE were found in range from ranging from 0.75 mm to 1.18 mm for λ = 0.05.

IV. SUMMARY AND CONCLUSIONS

In thepresent study, impact of*CN*s values determined by three different approaches on performances of SCS-CN method using AFM is examined for Ozatwatershed of India.When compared the tabulated (NEH-4) *CN* values (64.46 to 90.85) with computed *CN* values (42.20 to 97.81), it is evident that the computed *CN* values by three different approaches are substantially in a broad range and had extreme lower and upper bound *CN* values. The performance of SCS-CN method with *CN* values determined by three different approaches viz. standard *CN*, *CN* determined by five day ARR data set and monthly *CN*using AFM forλ= 0.05 is evaluated by applying two statistical criterion $d_r$and MAE.*CN* values estimated by different approaches are presented in ***Table 1***and resulting values of performance measure criterion $d_r$and MAE are displayed in ***Table 2***. The following conclusions can be drawn from this study:

1. Standard *CN*approach computed *CN*value = 58.78 which indicates that AFM method is more appropriate than the *CN* value estimated using NEH-4 standard tables (64.46 to 90.85).
2. *CN* determined by five day ARR data set approach estimated the lowest *CN* value 42.20. Hence, it is significantly reduced overestimation of runoff as compare to other approaches.
3. Monthly *CN*approach estimates *CN* values in range from 51.45 to 97.81. From ***table 2*** it is obvious that *CN* values changes from month to month and gradually increased from the month of Jun to the month of October. The highest value of*CN* = 97.81 is attained for the month of October.
4. In the month of October the lowest values of parameters CN_∞ and *k* are found 11.59 and 0.02 respectively. It may be due to very little mean monthly rainfall 16 mm in the month of October.
5. *CN* determined by five day ARR data set approach is judged to be more consistent with d_r= 0.58 and MAE = 0.93 mm in validation period for Ozat watershed.
6. Resulting values of statistical criterion d_r= 0.47 and MAE = 1.16 mmin validation period for monthly *CN* approach shown that no significant improvement is found in performance of SCS-CN method on application monthly *CN*.

Considering above all the results, we conclude that the relatively best performance was observed in SCS-CN method when it is used with *CN*s determined by five day ARR data set using AFM method. It is evident from the above evaluations that improvement in the predictive capability of SCS-CN method is possible by the use of five day ARR data set for the Ozatwatershed.

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REFERENCES

[1] S. K. Mishra, and V. P. Singh, “SCS-CN-based hydrologic simulation package, in: Mathematical Models in Small Watershed Hydrology and Applications”, edited by: Singh, V. P. and Frevert, D. K., Water Resources Publications, Littleton, CO, 391–464, 2002.
[2] S. K. Mishra, and V. P. Singh,“Soil Conservation Service Curve Number (SCS-CN) Methodology”, Kluwer Academic Publishers: Dordrecht, ISBN 1-4020-1132-6, 2003a.
[3] V. M. Ponce, and R. H. Hawkins, “Runoff curve number: Has it reached maturity?” J. Hydrol. Engrg., ASCE 1(1). 11–19, 1996.
[4] C. Michel, V. Andréassian and C. Perrin, “Soil conservation service curve number method: How to mend a wrong soil moisture accounting procedure?” Water Resour. Res., 41(2), W02011: pp 1-6, 2005. doi:10.1029/2004WR003191
[5] R. H. Hawkins, “Asymptotic determination of runoff curve numbers from data”, J. Irrig. Drain. Eng., 119, 334–345, doi: 10.1061/(ASCE) 0733-9437(1993)119:2(334), 1993.
[6] K. W. King, J. G. Arnold, and R. L. Bingner, “Comparison of Green-Ampt and curve number methods on Goodwin Creek watershed using SWAT”. Trans., ASAE. 42(4), 919–925, 1999.

[7] J. M. Jacobs, D. A. Myers, and B. M. Whitfield, "Improved rainfall/runoff estimates using remotely sensed soil moisture", J. Am. Water Resour. Assoc. 39(2), 313–324, 2003.

[8] D. C. Garen, and D. S. Moore, "Curve number hydrology in water quality modeling: Uses, abuses, and future directions", J. Am. Water Resour. Assoc., 41(2), 377–388, 2005.

[9] S. C. McCutcheon, "Rainfall-runoff relationships for selected eastern U.S. forested mountain watersheds: Testing of the curve number method for flood analysis", Technical Rep., West Virginia Division of Forestry, Charleston, WV, 2006.

[10] A. N. Sharpley, J. R. Williams, "EPIC Erosion/Productivity Impact Calculator: 1. Model Documentation". US Department of Agriculture Technical Bulletin No. 1768. US Government Printing Office: Washington, DC., 1990.

[11] K. X. Soulis, and J. D. Valiantzas, "SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds – the two-CN system approach", Hydrol. Earth Syst. Sc. 16:1001–1015, 2012. doi: 10.5194/hess-16-1001-2012.

[12] F. L. Fan, Y. B. Deng, X. F. Hu,and Q. H. Weng, "Estimating Composite Curve Number Using an Improved SCS-CN Method with Remotely Sensed Variables in Guangzhou, China", Remote Sens. 2013, 5, 1425–1438. doi:10.3390/rs5031425, 2013.

[13] J. M. Jacobs, D. A. Myers, and B. M. Whitfield, "Improved rainfall/runoff estimates using remotely sensed soil moisture", J. Am. Water Resour. Assoc. 39(2), 313–324, 2003.

[14] K. Paik, J. H. Kim, H. S. Kim, D. R. Lee, "A conceptual rainfall-runoff model considering seasonal Variation", Hydrological Processes, 19:pp 3837–3850, 2005. doi:10.1002/hyp.5984

[15] J. A. Sneller, "Computation of runoff curve numbers for rangelands from Landsat data". Technical Report HL85-2, U.S. Dept. of Agriculture, Agricultural Research Service, Hydrology Laboratory, Beltsville, MD., 1985.

[16] D. F. Young, and J. N. Carleton, "Implementation of a probabilistic curve number method in the PRZM runoff model: Environ", Modell. Softw, 21, 1172–1179, 2006.

[17] E. A. Baltas, N. A. Dervos, M.A. Mimikou, "Technical Note: Determination of the SCS initial abstraction ratio in an experimental watershed in Greece", Hydrol. Earth Syst. Sci., 11, 1825–1829, 2007. doi: 10.5194/hess-11-1825-2007.

[18] D. E. Woodward, R. H. Hawkins, R. Jiang, A. T. Hjelmfelt, J. A. Van Mullem, and Q. D. Quan, "Runoff curve number method: Examination of the initial abstraction ratio". In Proc. World Water and Environ. Resources Congress 2003 and Related Symposia. P. Bizier and P. DeBarry, eds. Reston, Va.: ASCE/EWRI, 2003.

[19] S. Fu, G. Zhang, N. Wang, and L. Luo, "Initial abstraction ratio in the SCS-CN method in the Loess Plateau of China", Trans. ASABE, 54, 163–169, 2011.

[20] R. H. Hawkins, R. Jiang, D. E. Woodward, A. T. Hjelmfelt, J. A. Van Mullem, and Q. D. Quan, "Runoff curve number method: examination of the initial abstraction ratio", in: Proceedings of the Second Federal Interagency Hydrologic Modeling Conference, Las Vegas, US Geological Survey, Lakewood, Colorado, USA, 2002.

[21] K. Descheemaeker, J. Posen, L. Borselli, J. Nyssen D. Raes, M. Haile, B. Muys, and J. Deckers, "Runoff curve numbers for steep hillslopes with natural vegetation in semi-arid tropical highland, Northern Ethiopia", Hydrol. Process. 22, 4097–4105, 2008.

[22] Z. H. Shi, L. D. Chen, N. F. Fang, D. F. Qin and C.F. Cai, "Research on SCS-CN initial abstraction using rainfall-runoff event analysis in the Three Gorges area, China". Catena, 77 (1):p.1-7, April, 2009.

[23] R. H. Hawkins, T. J. Ward, D. E. Woodward, and J. A. Van Mullem, "Curve Number Hydrology: State of the Practice", American Society of Civil Engineers, Reston, Virginia. 106pp. ISBN 978-0-7844-1044-2, 2009.

[24] F. D'Asaro, and G. Grillone,"Runoff Curve Number method in Sicily: CN determination and analysis of the Initial abstraction ratio", Proceedings of the 4th Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada (USA), 06/27/2010-07/01/2010.

[25] F. D'Asaro, and G. Grillone,"Empirical investigation of Curve Number method parameters in the Mediterranean area", Journal of Hydrologic Engineering the 04/01/2012.

[26] SCS, "Hydrology, National Engineering Handbook", Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, D.C., 1956, 1964, 1971, 1972, 1985, 1993 and 2004.

[27] S. K. Mishra, and V. P. Singh,"Soil Conservation Service Curve Number (SCS-CN) Methodology", Kluwer Academic Publishers, Dordrecht, The Netherlands, 2003.

[28] R. H. Hawkins, A. T. Jr. Hjelmfelt, and A. T. Zevenbergen, "Runoff probability, relative storm depth, and runoff curve numbers", J. Irrig. And Drain. Engrg., ASCE, 111(4), 330-340, 1985.

[29] A.T.Jr.Hjelmfelt, "Investigation of curve number procedure", J. Hydraulics Eng. 117(6), 725-737, 1991.

[30] L. E. Schneider, and R. H. McCuen, "Statistical guidelines for curve number generation", Journal of Irrigation and Drainage Engineering, 131 (3), 282-290, 2005.

[31] K. X. Soulis,J. D. Valiantzas,N. Dercas, and P. A. Londra, "Analysis of the runoff generation mechanism for the investigation of the SCS-CN method applicability to a partial area experimental watershed", Hydrol. Earth Syst. Sc. 13, 605–615, 2009, doi: 10.5194/hess-13-605-2009.

[32] T. S. Steenhuis, M. Winchell, J. Rossing, J. A. Zollweg, and M. F. Walter, "SCS runoff equation revisited for variable-source runoff areas", J. Irrig. Drain. Eng. ASCE, 121, 234–238, 1995. doi:10.1061/(ASCE)0733-9437(1995)121:3(234)

[33] M. B. Huang, J. Gallichand, C. Y. Dong, Z. L. Wang and M. A. Shao, "Use of moisture data and curve number method for estimating runoff in the Loess Plateau of China", Hydrol. Process., 21, 1471–1481, 2007.doi:10.1002/hyp.6312

[34] S. B. Shaw and M. T. Walter, "Estimating storm runoff risk using bivariate frequency analyses of rainfall and antecedent watershed wetness", Water Resources Research.45:W03404, 2009. doi:10.1029/2008WR006900.

[35] A. T. Hjelmfelt Jr., L. A. Kramer and R. E. Burwell, "Curve numbers as random variables. Proc. Int. Symposium on Rainfall-Runoff Modeling", Water Resources Publishers, Littleton, Colo., 1982: pp 365–373.

[36] R. H. McCuen, "Approach to Confidence Interval Estimation for Curve Numbers", Journal of Hydrologic Engineering, 7(1), pp 43-48, 2002.

[37] USDA-"Soil Conservation Service (USDA SCS)", National Engineering Handbook. Section 4. Hydrology. USDA-SCS, Washington, D.C., 1985.

[38] C. L. Chen, "An evaluation of the mathematics and physical significance of the Soil Conservation Service curve number procedure for estimating runoff volume", Proc., Int. Symp. on Rainfall-Runoff Modeling, Water Resources Publ., Littleton, Colo., 387–418, 1982.

[39] D. E. Woodward, J. A. Van Mullem, R. H. Hawkins, and A. Plummer, "Curve Number Completion Study", Consultant's report to USDA, NRCS, Beltsville MD, 38pp, 2010.

[40] J. G. Arnold, R. S. Muttiah, R. Srinivasan and P. M. Allen, "Regional estimation of base flow and ground water recharge in the upper Mississippi river basin". Journal of Hydrology, 227:21-40, 2000.

[41] R. J. Nathan, T. A. McMohan, "Evaluation of automated techniques for base flow and recession analyses", Water Resources Research. 26(7): 1465-1473, 1990.

[42] C. J. Willmott, S. M. Robeson, and K. Matsuura, "A refined index of model performance", Int. J. Climatol., 32: 2088–2094, 2012. doi.org/10.1002/joc.2419

[43] D. R. Legates, and G. J. McCabe, "Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation", Water Resources Res., 35(1): 233-241, 1999.

Table 1. Comparision of CN determined by different procedures using standard asymptotic fit method

	Month	Mean Monthly Rainfall in mm	*CN*	CN_∞	K in mm^{-1}
	λ= 0.05				
Standard *CN* based on daily rainfall-runoff data set			58.78	58.45	0.10
CN based on ARR data set			42.20	40.64	0.07
Monthly *CN*	June	198	51.45	46.80	0.18
	July	295	66.42	65.88	0.21
	August	150	76.38	51.71	0.07
	eptember	86	85.87	64.09	0.09
	October	16	97.81	11.59	0.02

Table 2. Impact of different CNs on performance of SCS-CN method
In Calibration Period (1980-1994)

	With standard *CN* Values		With Monthly *CN* Values		With *CN* based on five day ARR data set	
λ	d_r	MAE in mm	d_r	M E in mm	d_r	E in m
0.05	0.46	0.94	0.46	0.92	0.57	0.75

In Validation (1995-2010)

	With standard *CN* Values		With Monthly *CN* Values		With *CN* based on ARR data	
λ	d_r	MAE in mm	d_r	MAE in mm	d_r	MAE in mm
0.05	0.47	1.18	0.47	1.16	0.58	0.9

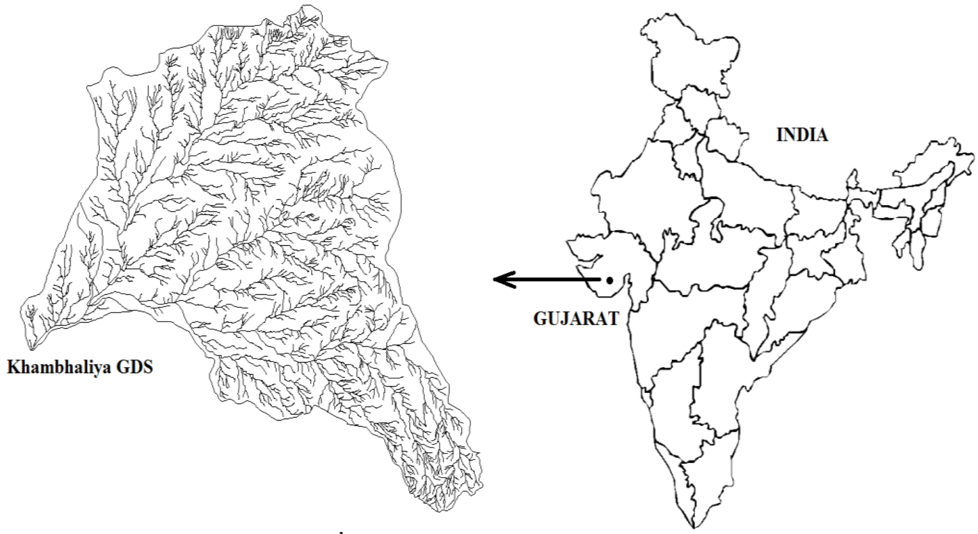

Figure 1. Digitized 6th order Drainage network map of OzatWatershed

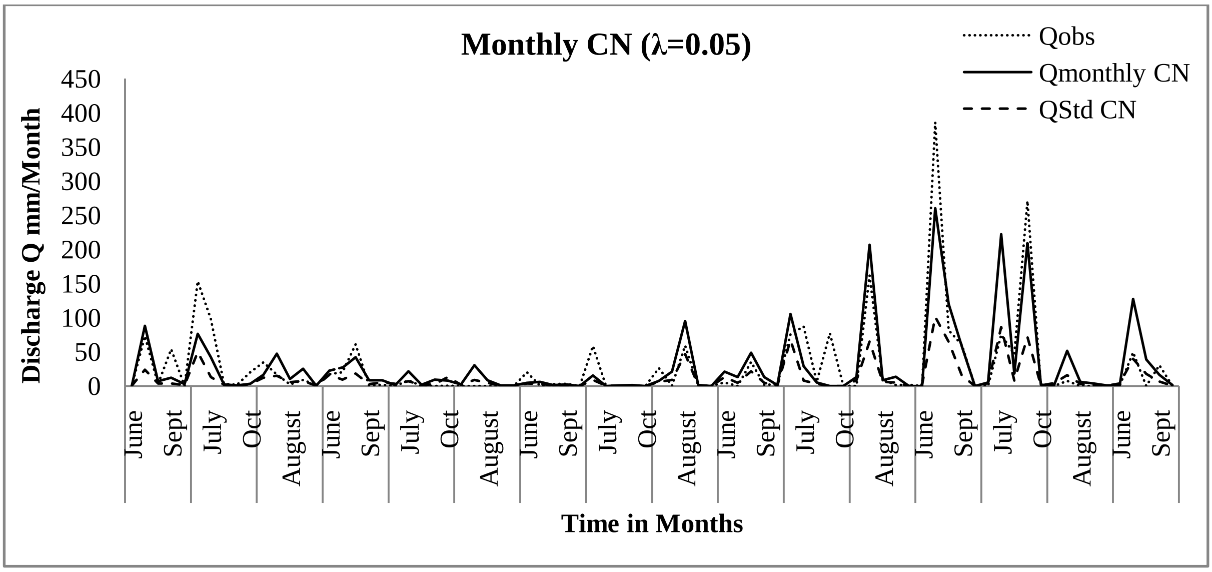

Figure 2. Performance of Median CN and Median Monthly CN on Monthly Time Scale in Validation

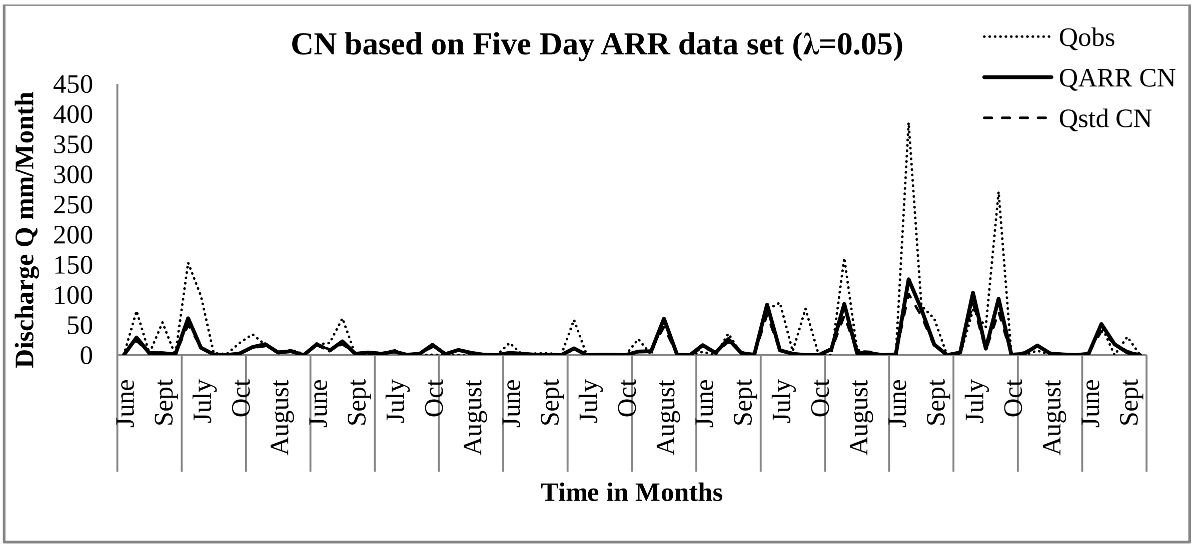

Figure 3. Simulated Performance of SCS-CN Method with CN by Standard Asymptotic Fit Procedure and Five Days ARC on Monthly Time Scale

