International Symposium on
Integrated Water Resource Management (IWRM-2014)
February 19-21. 2014, CWRDM, Kozhikode, Kerala, India

Integrating GIS and Hydrological Model for Flood Forecasting

Nayak T R [1] and Narulkar S M [2]

[1] NIH Regional Centre, WALMI Campus, Bhopal (M.P.) – 462 016

[2] S.G.S. Inst. of Technology & Science, Indore (M.P.) – 452 001

Email [1] tejramn@yahoo.com, [2] snarulkar@gmail.com

ABSTRACT. Floods cause significant loss to life and property by way of civilian casualties, more people are killed annually than by any other natural disaster, annual economic losses consist of property worth crores of Rupees damaged or lost. Natural disasters caused by floods challenge scientists to forecast the magnitude and timing of peak flood discharges more accurately. Hydrological models combined with GIS have become important tools for flood forecasting. In the present study, SCS-CN model has been used to estimate daily direct runoff and Huff's disintegration model has been applied to distribute the daily direct runoff into hourly rainfall excess, which has been convoluted with the synthetic unit hydrograph derived by SCS method to generate hourly discharge at specified location. The model comprises of three components, first development of rainfall-runoff relationship, second computation of 1-hr Synthetic Unit Hydrograph (SUH) and third, convolution of the rainfall excess with SUH. The Uri river watershed of lower Narmada river basin has been selected for the study. The average daily rainfall and curve number has been used to estimate daily direct runoff volumes, which are convoluted with Unit Hydrograph to get hourly discharge for some selected events during the monsoon months in the year 2005- 2007. The model results have been compared with the observed hourly flows and found very good correlation between them. In order to predict floods in the river basin for next 24 hours, prediction of 24 hr. expected rainfall is required. By continuous correction in predicted rainfall is carried out by replacing the actual rainfall to obtain predicted flood hydrograph.

Keywords: NRCS-CN model, Synthetic Unit Hydrograph, GIS, Narmada basin.

INTRODUCTION

The increasing rate of water resources development activity and utilization of water for various uses have focused attention of development and application of physically based hydrological models to deal with constantly changing hydrological environment. The change of land-use has had a considerable impact on hydrological processes. Generally, deforestation, land development & urbanization cause significant increase in peak discharge and runoff volume. The rainfall runoff relationship can be developed on the basis of some kind of lumped models viz. empirical models, unit hydrographs etc., but the results are approximate and cannot be relied upon. However, if these kinds of techniques are applied on a distributed scale over the space then the results are better than the lumped model application. GIS technology provides a flexible environment for entering, analyzing, and displaying digital data from various sources, for identifying urban features, detecting change, and developing databases. Many researchers have developed an integrated approach to combine RS and GIS techniques with the Rainfall-Runoff model to elucidate the effects of floods/river stage on inundated area and estimation of damages.

REVIEW OF PREVIOUS WORK

The SCS-CN (now known as NRCS-CN) method is the most commonly used technique for estimating storm runoff volume. The model is based on direct estimation of runoff, soil characteristics and land use, vegetation, cover and Antecedent Moisture Conditions (Mockus 1964; SCS 1986; Hawkins 1993; Mishra and Singh 2003, 2004; NRCS 2004, Baltas 2007). The main difficulty is the large variability observed in the CN values evaluated for the same watershed for various rainfall depths. This variability was attributed to variations in the antecedent moisture conditions to the temporal and spatial variability of rainfall, to scale effects, and many other reasons. Therefore, many studies aimed at improving the method and finding a better way to incorporate the Antecedent Moisture Conditions (Simanton et al. 1996; Mishra et al. 2005, 2008; Jain et al. 2006; Brocca et al. 2008; Kannan et al. 2008). Pandey and Sahu (2002) pointed out that the land use/land cover is an important parameter input of the SCS-CN model. Nayak and Jaiswal (2003) found that there was a good correlation between the measured and estimated runoff depth using GIS and CN. They concluded that GIS is an efficient tool for the preparation of most of the input data required by the SCS curve number model. Zhan and Huang (2004) described the development and application of the ArcCN Runoff tool, an extension of ESRI ArcGIS software which can be applied to determine curve numbers and calculate runoff or infiltration for a storm event within a watershed. They also suggested that the implementation of a precipitation time series and the consideration of factors such as dry and wet antecedent moisture conditions (for CN parameters) would improve the predictions of the ArcCN Runoff tool. Ebrahimian et al. (2012) evaluated the applicability of Natural Resources Conservation Service-Curve Number (NRCS-CN) method together with GIS in estimating runoff depth in a mountainous watershed.. Nayak and Narulkar (2011) and Nayak et.al. (2012) has applied spatially distributed model to assess the impact of landuse changes on runoff in the Goi river sub-basin in lower Narmada basin. They found that the application of RS and GIS provides useful spatial data which can directly be used as input parameters in the SCS-CN model.

OBJECTIVE OF THE STUDY

The objective of the present study is aimed at generating flood hydrograph for a sub-catchment of Narmada River Basin by combining rainfall-runoff model with synthetic unit hydrograph. The well established Soil Conservation Service Curve Number (SCS-CN) model is proposed for computation of direct runoff and in order to convolute the lumped runoff volume into an hourly discharge, the Synthetic Instantaneous Unit Hydrograph (SIUH) as suggested by SCS is developed for Uri river sub-catchment in Narmada River Basin. One of the major limitations is the rainfall data availability, which is mostly measured on daily basis, is overcome by disintegrating the runoff using Huff's distribution model. The observed hydrograph of river flow is also compared with the model runoff hydrograph computed for all the four quartiles suggested by Huff and Angel, 1992. The best fit model is suggested for prediction of flood hydrograph in the study area.

MATERIALS AND METHODS

Study Area

Narmada is the longest west flowing river of India. It rises from a spring at a height of 1057m above MSL on the summit of Amarkantak Hill in Madhya Pradesh and flows westwards over a length of 1,312 km and drains an area of 98796 sq.km before falling into the Arabian Sea. Uri river is an important north side tributary of River Narmada. It originates from Vindhyan Ranges near village Bhilkheri in Sardarpur district Madhya Pradesh and meets the River Narmada near Nisarpur town at about 13 km downstream of Barwani city.

The Uri river catchment upto Dhulsar gauging site has been considered for this study. It has an elliptical shaped catchment and having 787 sq.km geographical area lies between East longitudes 74°47' to 75°03' and North latitudes 22°11' to 22°37'. The gauging at Dhulsar was started by the Central Water Commission in February, 1999. The drainage density in Uri watershed is high due to hilly terrain and undulating lands. The time of concentration of runoff is about 8 hours at Dhulsar gauging site, therefore the sub-basin experience occasional floods for very short duration during monsoon months. Index map showing location and drainage map of Uri watershed is given in Fig.1.

The NRCS-CN Model

Most widely used modified NRCS (earlier known as SCS) Curve Number model has been selected for estimation of direct runoff resulted from the observed daily rainfall. The method is based on an assumption of proportionality between retention and runoff in the following form:

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \quad \ldots \quad (2)$$

Where, P is total storm rainfall or potential runoff (mm); Q is actual direct runoff (mm) and S is potential maximum retention by soil (mm), I_a is initial abstraction. Solving Eq.2 for Q,

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad \ldots \quad (3)$$

Eq.3 is physically subjected to the restriction that P ≥ Ia (i.e. the potential runoff minus the initial abstraction cannot be negative). To simplify the Eq.3, initial abstraction is related to potential maximum retention. The general relationship is given as:

$$I_a = \lambda . S \quad \ldots \quad (4)$$

The initial abstraction consists mainly of interception, infiltration and surface storage, all of which occur before runoff begins. Generally for all practical applications, λ is taken as 0.2. The potential maximum retention by the soil is related with the curve number (CN).

$$S = \frac{25400}{CN} - 254 \quad \ldots \quad (5)$$

CN values range from 0 to 100. The watersheds with higher CN value yield higher runoff volume for a given rainfall. The underlying difference between S and CN is that the former is a dimensional quantity (L) whereas the latter is a non-dimensional quantity.

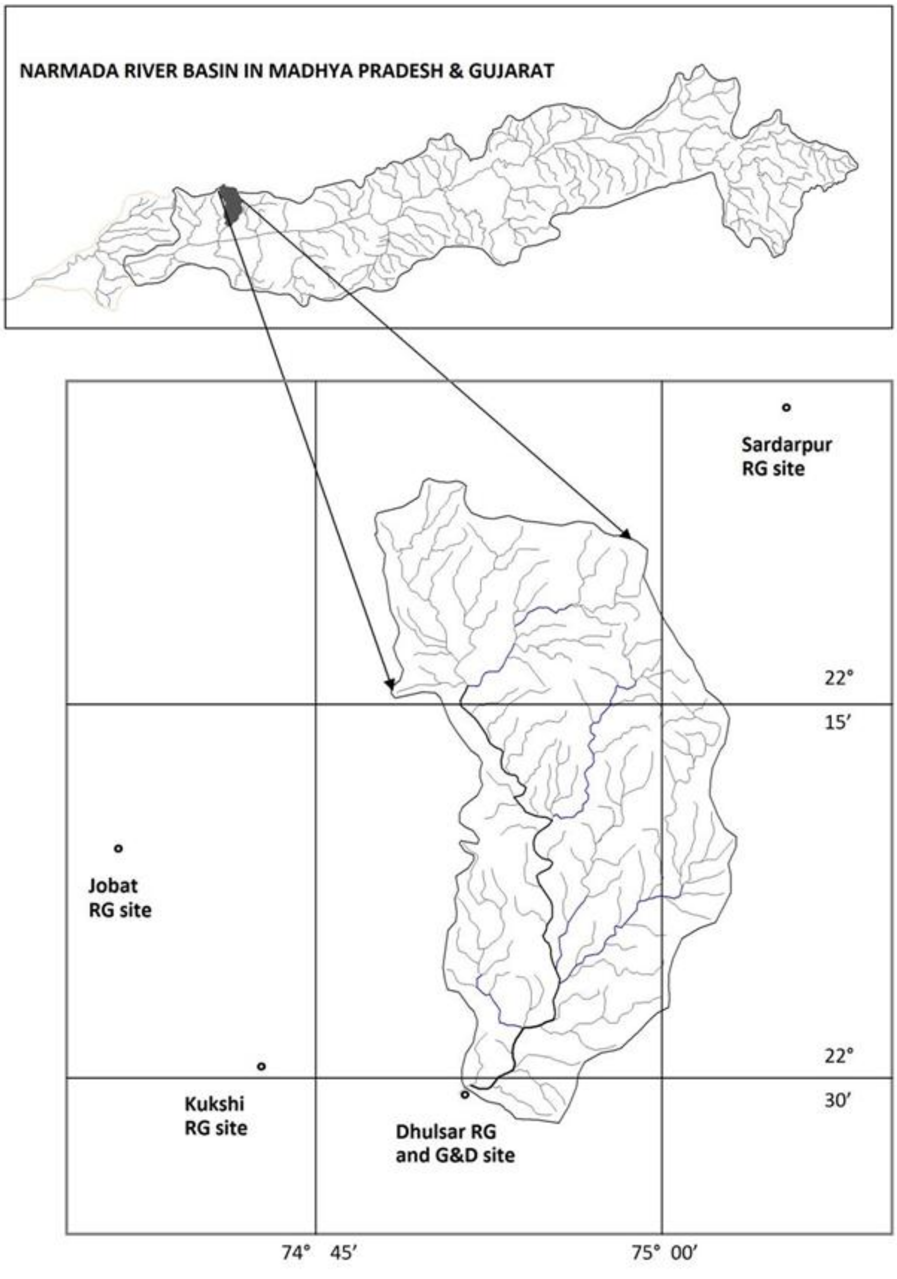

Figure 1: Index map showing Uri river catchment and rain-gauge stations

One of the major limitations of the NRCS method of computation of direct runoff is that it does not incorporate the time distribution of the direct runoff or rainfall excess. In most of the Indian River basins, the rainfall is measured on daily basis, i.e. once in a day at 0800 AM, which gives the quantity of cumulative rainfall during the last 24 hours. Thus, the runoff computed by the NRCS-CN model gives the cumulative volume of direct runoff or rainfall excess resulted by the rainfall during the previous 24 hours.

Synthetic Unit Hydrograph (SUH)

In order to disintegrate the rainfall excess over the time, the unit hydrograph is generally developed for the watershed under consideration. In this study, the procedure suggested by Soil Conservation Services has been adopted to develop the Synthetic Unit Hydrograph (SUH). The SUH has basically two components, time to peak and peak discharge and has a triangular shape which produces a unit depth of direct runoff or rainfall excess. However, the SCS method of development of a Unit Hydrograph provides more realistic curvilinear shape. The SUH developed for Uri river watershed has been given in Table 1.

Table 1: Synthetic Unit Hydrograph (in cumec) for Uri watershed

Time	0	1.5	3	4.5	6	7.5	9	10.5	12	13.5	15
Disch.	0	39.9	133	232.75	266	239.4	179.55	113.05	73.15	47.88	33.25

Time	16.5	18	19.5	21	22.5	24	25.5	27	28.5	30
Disch.	21.28	15.295	9.975	6.65	5.32	3.724	2.66	1.33	0.532	0

RESULTS AND DISCUSSION

The Integrated Land and Water Information System (ILWIS) package has been used as the basic GIS tool. This has been used for preparation of thematic maps on landuse and

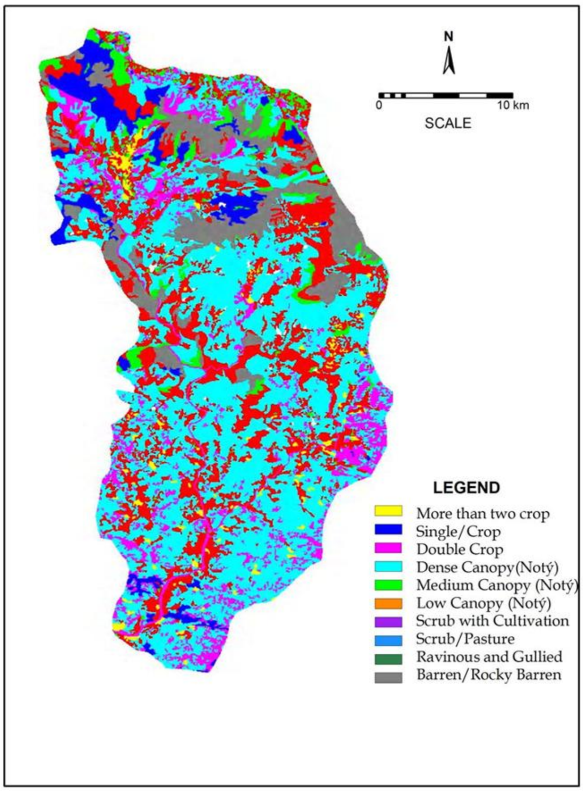

Figure 2: Landuse map of Uri watershed in year 2007

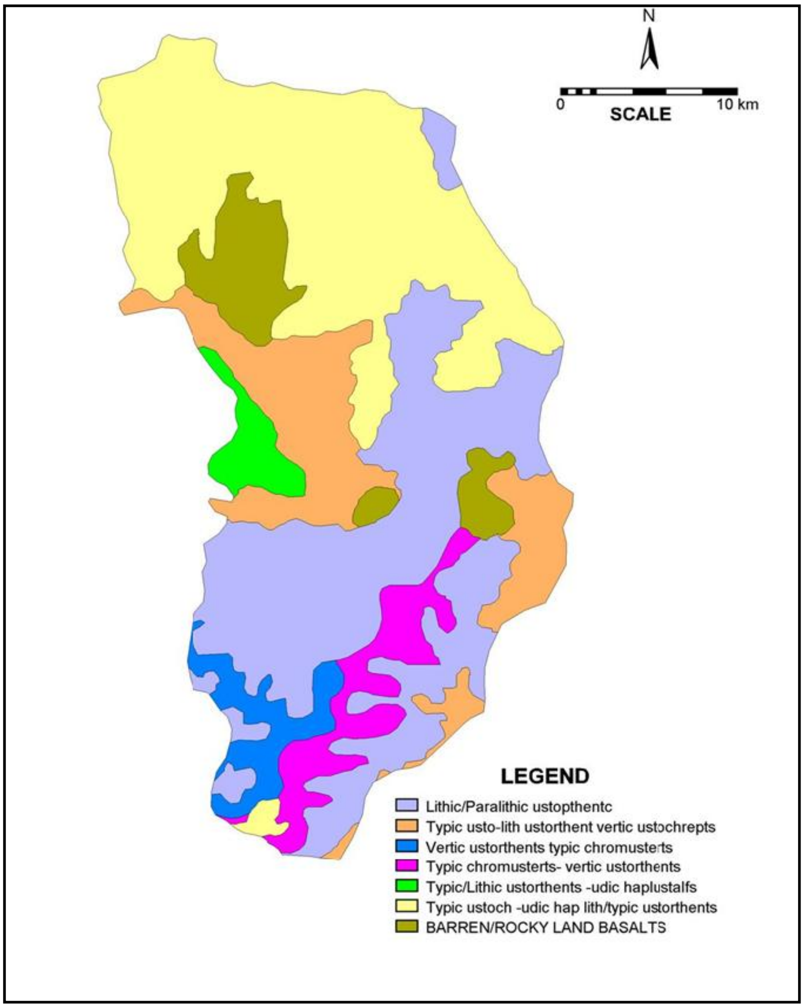

Figure 3: Soil map of Uri watershed

soils which are given in Fig.2 and Fig.3, super-imposition of landuse and soil maps, delineation of polygons of identical landuse classes and hydrological soil group, attribution of the map to assign appropriate CN values. The weighted average Curve Number computed for Uri river sub-basin are found to be 67.74, 82.26 and 92.70 for AMC-I, AMC-II and AMC-III respectively. Daily average rainfall in the watershed have been computed by Thiessen polygon method from the rainfall observed at four rain gauge stations, i.e. Dhulsar, Kukshi, Jobat and Sardarpur.

Finally, the daily direct runoff volume has been computed using NRCS model by knowing the values of Curve Number, the average precipitation and AMC condition (Table 2). In the present study, daily rainfall has been taken for computation of direct runoff through modified NRCS-CN model. It means, observation of hourly rainfall is required or the daily rainfall occurred in the catchment has to be disintegrated over the period of 24 hours and the hourly rainfall can be taken as input to the runoff model.

Table 2: Direct runoff computed by SCS model

Date	P(mm)	Q(mm)
Year 2005		
27-Jul-05	8.35	0.00
28-Jul-05	112.68	37.39
29-Jul-05	23.46	9.60
30-Jul-05	11.9	2.24
30-Jul-05	0	0.00
01-Aug-05	12.72	2.65
02-Aug-05	4.47	0.01
Year 2006		
05-Aug-06	28.48	4.25
06-Aug-06	95.35	74.94
07-Aug-06	61.4	42.57
08-Aug-06	47.97	30.22
09-Aug-06	13.5	3.06
10-Aug-06	23.26	9.45
11-Aug-06	58.01	39.41
12-Aug-06	19.05	6.46
13-Aug-06	14.68	3.71

Date	P(mm)	Q(mm)
Year 2007		
03-Aug-07	9.00	0.00
04-Aug-07	20.32	1.08
05-Aug-07	28.48	10.60
06-Aug-07	9.08	0.81
07-Aug-07	79.71	47.13
08-Aug-07	107.59	68.33
09-Aug-07	29.09	10.99
10-Aug-07	6.86	0.28
11-Aug-07	0.45	0.00
12-Aug-07	1.85	0.00
13-Aug-07	4.11	0.00

Computation of Flood Hydrograph (Hourly Discharge)

The direct runoff computed by NRCS-CN model has been disintegrated using factors of the 3rd Quartile of Huff's disintegration model and ordinates of unit hydrographs were adjusted for 1-hr UH. Then, the direct runoff or rainfall excess have been used for convolution with 1-hr UH to compute the ordinates of the resulting flood hydrograph at Dhulsar G&D site. The observed hourly discharge has been compared with the model discharge for selected events in 2005, 2006 and 2007, which are presented through graphs given in Fig.4.

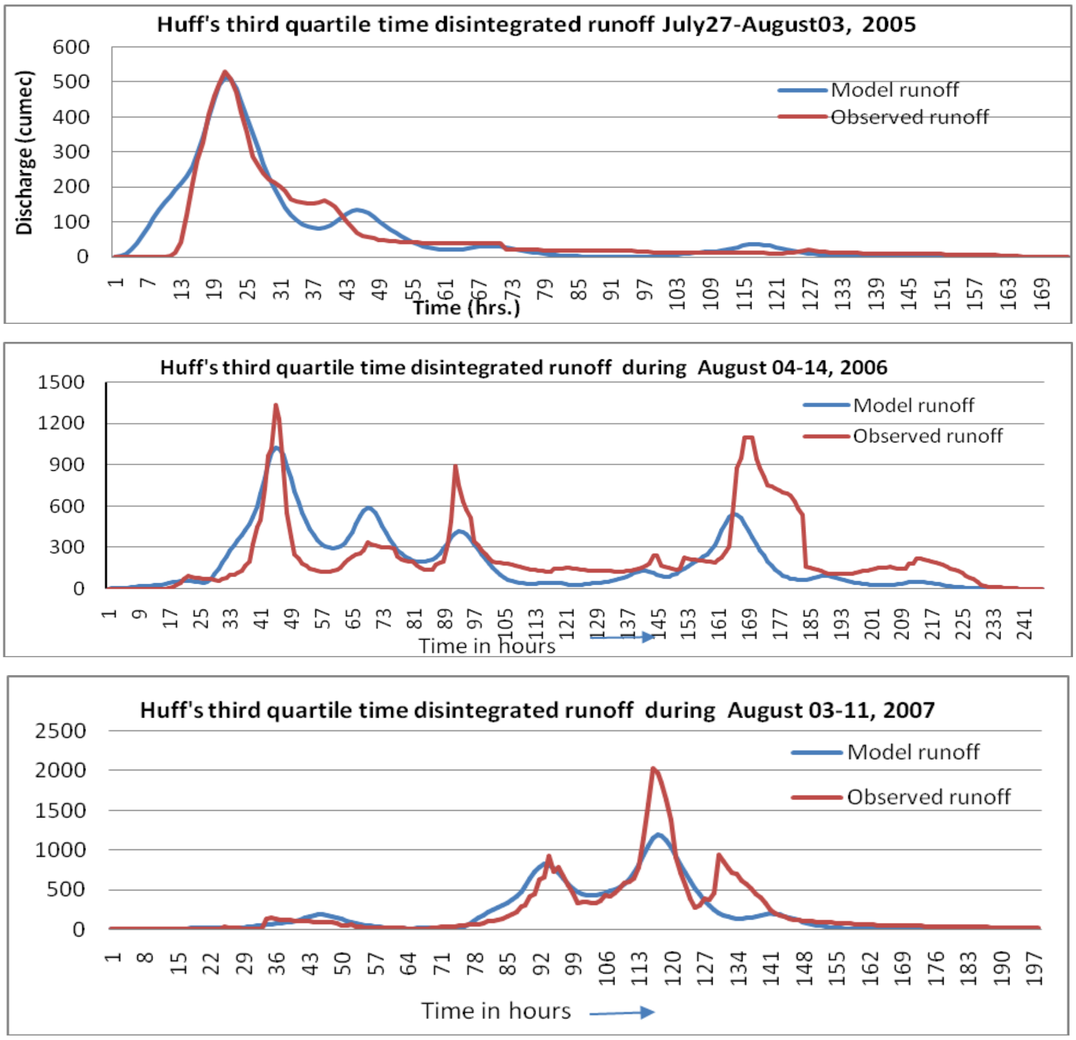

Figure 4: Comparison of Model runoff and observed runoff

Model Efficiency

The Nash-Sutcliffe model efficiency has been checked by using observed and computed flood hydrograph at Dhulsar G&D site in Uri river sub-basin for the monsoon period during the year 2005, 2006 and 2007. The observed and computed hydrographs have been evaluated by comparing the hourly discharges by determining (1) Correlation coefficient and (2) Root Mean Square Error. Both the evaluation criteria show that the Third Quartile distribution model suggested by Huff and Angel (1992) fits best for computation of flood hydrograph.. Higher value of the correlation coefficient indicates more efficient model, whereas the lowest value of RMSE means better model.

CONCLUSION

The NRCS Curve Number method has been applied for computation of direct runoff volume in Uri catchment of Narmada river basin. Synthetic Unit Hydrograph were generated for the watershed by adopting the SCS procedure to generate flood hydrograph from the known lumped value of rainfall excess (direct runoff). The following conclusions may be drawn from the results obtained in the study:

1. The SCS-CN method in GIS platform coupled with remote sensing data is found to be effective, since the spatial variation of soils and land use of the watershed are addressed.
2. The SCS curve number method may be applied on the Narmada River Basin and its Sub Catchments with an ease if the raingauge network is sufficient to compute fairly accurate average precipitation over the catchment area.
3. The 3rd Quartile fractions of Huff's distribution model is best fit in lower Narmada basin.
4. Runoff may be predicted for the next 24 hours by knowing the rainfall forecast of next day, which can be continuously corrected on the basis of actual rainfall.

REFERENCES

Baltas EA, Dervos NA, and Mimikou MA (2007) Technical Note: Determination of the SCS initial abstraction ratio in an experimental watershed in Greece; Hydrol. Earth Syst. Sci. 11: 1825–1829.

Brocca L, Melone F, and Moramarco T (2008) On the estimation of antecedent wetness conditions in rainfall-runoff modeling; Hydrol. Process. 22(5): 629–642.

Ebrahimian M, Ainuddin NA, Mohd Soom MAB, and Sood AM (2012) Application of NRCS-curve number method for runoff estimation in a mountainous watershed; Caspian J. Env. Sci. 10 (1): 103-114.

Hawkins RH (1993) Asymptotic determination of runoff curve numbers from data; J. Irrig. Drain. E.-ASCE 119(2): 334-345.

Jain MK, Mishra SK, Suresh Babu P, Venugopal K, and Singh VP (2006) Enhanced runoff curve number model incorporating storm duration and a nonlinear Ia-S relation; J. Hydrol. Eng.-ASCE 11(6): 631–635.

Kannan N, Santhi C, Williams JR, and Arnold JG (2008) Development of a continuous soil moisture accounting procedure for curve number methodology and its behaviour with different evapotranspiration methods; Hydrol. Process. 22(13): 2114-2121.

Mishra SK and Singh VP (2003) Soil Conservation Service Curve Number (SCS-CN) Methodology; Kluwer Academic Publishers, Dordrecht.

Mishra SK and Singh VP (2004) Long-term hydrological simulation based on the Soil Conservation Service curve number; J. Hydrol. Process. 18: 1291-1313.

Mishra SK, Jain MK, Pandey RP, and Singh VP (2005) Catchment area-based evaluation of the AMC-dependent SCS-CN-based rainfall-runoff models; Hydrol. Process. 19(14): 2701-2718.

Mishra SK, Pandey RP, Jain MK, and Singh VP (2008) A rain duration and modified AMC-dependent SCS-CN procedure for long duration rainfall-runoff events; Water Resour. Manag. 22(7): 861–876.

Mockus V (1964) Personnel communication; Letter to Orrin Ferris dated March 5 1964.

Nayak TR and Jaiswal RK (2003) Rainfall-runoff modelling using satellite data and GIS for Bebas river in Madhya Pradesh; IE (I) Journal 84: 47-50.

Nayak TR and Narulkar SM (2011) Effects of land use and land cover changes on water yield in Goi watershed of Narmada basin; J of Indian Water Resour. Soc. 31(1-2):34-43.

Nayak Tejram, Verma MK, and Hema Bindu S (2012) SCS curve number method in Narmada basin; International Journal of Geomatics and Geosciences 3(1): 219-228.

NRCS (2004) Estimation of Direct Runoff from Storm Rainfall Part 630: Hydrology National Engineering Handbook Chapter 10.

Pandey A and Sahu AK (2002) Generation of curve number using remote sensing and Geographic Information System http://www.GISdevelopment.net (accessed on Sept. 2007).

Simanton JR, Hawkins RH, Mohseni-Saravi M, and Renard KG (1996) Runoff curve number variation with drainage area walnut gulch Arizona; T. ASAE 39(4): 1391–1394.

Soil Conservation Service (1985) National Engineering Handbook, Section 4: Hydrology. U.S. Department of Agriculture, Washington, DC.

Zhan X and Huang M (2004) ArcCN-runoff: an ArcGIS tool for generating curve number and runoff maps; Environ. Modell. Software 19(10): 875-879.