Estimation of Runoff Using SCS-CN and GIS method in ungauged watershed: A case study of Kharadya mill watershed, India

H.J.Ningaraju[1], Ganesh Kumar S B[2] , Surendra H J[3]

[1]Associate Professor, Department of Civil Engineering, PESCE Mandya, Karnataka, India
[2]Assistant Professor, Department of Civil Engineering, SDMIT UJIRE, Karnataka, India
[3]Assistant Professor, School of Civil Engineering REVA University, Bengaluru, Karnataka, India

Abstract—*Water is the precious gift of nature becoming scarce needs to be conserved. Estimation of runoff in a watershed is very important in order to manage the scarce water resources efficiently. In India the availability of accurate runoff information is rare where most of the watersheds are ungauged, which poses a serious challenge for hydrologists. In this paper Soil Conservation Services Curve Number (SCS-CN) method and the Geographical Information System (GIS) was used for runoff estimation of ungauged Kharadya milli watershed in Mandya district, Karnataka, with an area of 23.95 sq.km. The average annual rainfall is 749 mm from 2003 to 2013. The runoff was varied between 35.47 mm to 240.16mm. The land use details of study area were obtained by integration of GIS and remote sensing. 58.63% of watershed consists of gravelly clay soil and 39.49% area is cultivable crop land. The study reveals that the integration of GIS with the SCS-CN method is a powerful tool for estimating runoff from the ungauged watersheds for better watershed management and conservation purposes.*

Keywords— Watershed, Runoff, SCS-CN, GIS.

I. INTRODUCTION

Water is the precious gift of nature to the mankind becoming a scarce commodity needs to be conserved through watershed management. Watershed is a geographically dynamic unit that contributes runoff a common point. The hydrological behavior of a watershed play an important role in water resources planning and management (Gajbhiye et al. 2013) such as: flood control and its management, irrigation scheduling, design of irrigation and drainage network, hydro power generation etc. (Mishra et al. 2013). Runoff is one of the important hydrologic variables used in the watershed management. Runoff is the flowing of precipitated water in the catchment area through a channel after satisfying all surface and sub surface losses (Dubayah,R. et al, 1997). Rainfall- runoff in a watershed is very complex, influenced by various storm and drainage characteristics (Seth et al 97-98). Accurate estimation of runoff is critical for planning and management of water resources and a challenge for the hydrological engineers and planners. Most of the watersheds in India are ungauged due to economic and social constraints (Sarangi et al 2005, Zade et al 2005) has led to the development of techniques for estimation of runoff from ungauged watersheds (Chattopadhyay and Chowdhury 2006).

There are several approaches to estimate the ungauged basin runoff. The Curve Number method (SCS-CN) is one of the most widely used approach because of its flexibility and simplicity. Many researchers have utilized Geographical Information System (GIS) and curve number has proved to be rapid, accurate estimator of runoff. In this method land use/ land cover classes are integrated with the hydrologic soil group in GIS to estimate weighted Curve Number (CN). The estimated weighted CN for the entire area can be used to compute runoff.

Various studies carried out from various regions of India by Sarangi et al (2005), Chattopadhyay and Chowdhury (2006),Singh et al. (2007), J P Patil et al (2008), Somashekar et al.,(2011), N.Nagarajan and Poongothai (2011), Geena G.B.et al, (2011), Manoharan A, Muragappan A (2012), Sindhu D et al (2013),.Thakuriah Gitika et al(2014), Abhijit M et al(2014) Ishtiyaq Ahmad et al(2015) Sarita Gajbhiye (2015) have revealed that SCS-CN method integrated with GIS is an efficient tool aid in better watershed management. Works done previously on the study of runoff estimation in the ungauged watersheds of Karnataka are very minimal. Hence, an attempt has been made in this study to estimate the runoff using SCS-CN method integrated with GIS for the ungauged Kharadya mill watershed.

II. STUDY AREA

The study area, Kharadya milli watershed is situated in Mandya district of Karnataka state, India and geographically lies between 76^0 37' 30" and 76^0 45' E longitude and $12^0$45'and 12^0 37' 30" N latitude covering an area of 23.95 km^2. Fig.1 shows the location map of study area. Maximum length and width of watershed are 7.34 km and 5.04 km respectively. The study area attains maximum elevation of 1065.000 m and a minimum of 848.000 m. It has a typical subtropical climate with hot dry summers and cool dry winters. Temperature extremes vary between the minimum of 15^0C during December or January months to the maximum of 35^0C in May or June. The rainfall in the study area is highly erratic varying between 400mm to 1200mm.

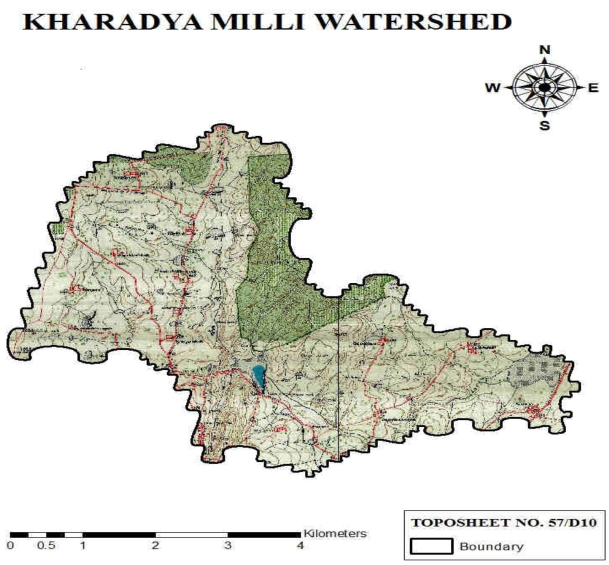

Fig.1: Location map of Kharadya milli watershed

III. METHODOLOGY

In this study, Topographic map on a scale of 1:25000 prepared by Survey of India (SOI) bearing number 57 D/10 was used for the delineation of watershed boundary. Soil map and land use/ land cover maps prepared by Karnataka State Remote Sensing and Application Centre (KSRSAC), Bangalore in accordance with National Bureau of Soil Survey was used. Fig. 2 shows the methodology followed to estimate runoff using SCS Curve Number model. Daily rainfall data for the year of 2003 to 2013 (10 years) data from Draught Monitoring Centre (DMC) Bangalore were used to calculate the runoff using SCS-CN method. Fig. 3, Fig.4, shows land use/land cover map, soil map of Kharadya milli watershed.

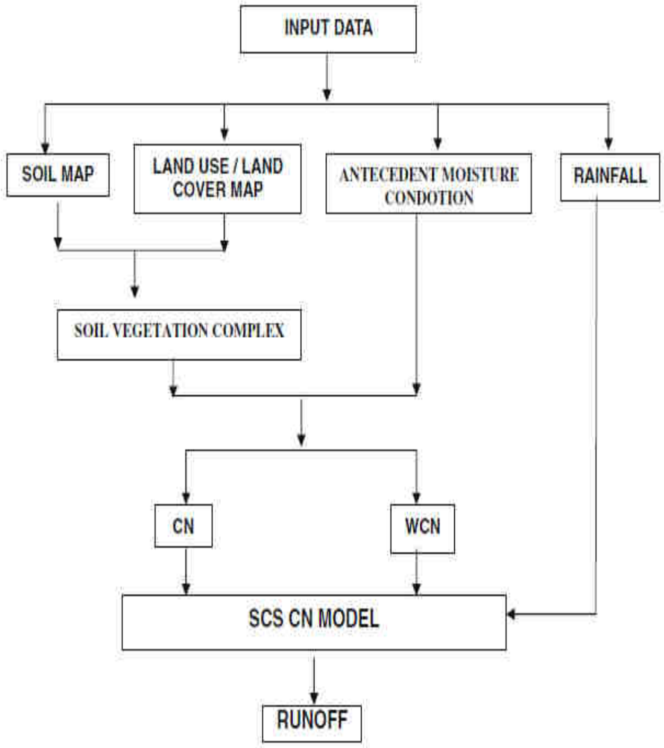

Fig.2: Methodology to estimate runoff by SCSCN model

3.1 SCS Curve Number Method

The most commonly used empirical method is the Soil Conservation Service Curve Number (SCS-CN) method to estimate the direct runoff from a watershed (USDA, 1972). The estimation of run-off using GIS based SCS method can be used for the watershed management efficiently. The SCSCN method explaining the water balance equation can be expressed as below

$P = Q + F + Ia$ ………………………. (1)

$Q/ P- Ia = F/S$……………………..(2)

$Q = (P – Ia)^2/ (P – Ia) + S$………..(3)

where, P = Total precipitation (mm), Q = Actual runoff (mm), F= cumulative infiltration (mm),

Ia= Initial abstraction (mm) which represents all losses before the runoff begins and is given by empirical equation

$I_a = 0.2\,S$…………………….. … (4)

Substituting in equation 3

$Q = (P - 0.2S)^2 / (P + 0.8S)$…….(5)

Where S= potential maximum retention (mm) after the runoff begins in the watershed and is given by empirical equation

$S = 25400/CN - 254$ ………… ….. (6)

Where CN is the curve number estimated using antecedent moisture condition (AMC) and hydrological soil group (HSG).

The CN is a relative measure of retention of water by given soil vegetation complex and taken on valves from 0 to 100. HSG is expressed in terms of four groups (A, B, C and D), according to the soil after prolonged wetting. AMC is expressed in three levels (1, 2 and 3), according to rainfall limits dormant and growing seasons.

3.2 ANTECEDENT MOISTURE CONDITION (AMC)

Antecedent Moisture Condition refers to water content present in the soil at a given time. It is determined by total rainfall in 5 day period preceding a storm. Antecedent soil moisture condition had a significant effect on runoff and an increase in valve indicates increase in runoff. Soil conservation service (SCS) had developed three antecedent soil moisture conditions such as AMC 1, AMC 2 & AMC 3 depending on soil conditions and rainfall limits for dormant and growing seasons are shown in Table 1.

Table. 1 AMC for determination of CN value

AMC	Total Rain in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

The Curve Number values for AMC-I and AMC-II were obtained from AMC-II (Chow et al. 1988) by the method of conservation. Area weighted composite curve number for various conditions of land use and hydrologic soil conditions are computed as follows:

$CN = (CN_1 \times A_1) + (CN_2 \times A_2) + (CN_3 \times A_3) +$…………… $(CNn \times A_x n) / A$ ………………. (8)

Where A1, A2, A3… An represent areas of polygon having CN values CN1, CN2, CN3,….., CNn respectively and A is the total area. The estimated weighted CN for the entire area is used to compute runoff. SCS runoff CN for hydrologic soil cover complex under AMC II condition for the study area is given in Table 2.

Table. 2:Runoff curve numbers for AMC II for hydrological cover complex

Sl.No.	Land Use	A	B	D
1	Agricultural land without conservation	72	81	91
2	Land with scrub	36	60	79
3	Land without scrub	45	-	-
4	Forest (degraded)	45	66	-
5	Forest plantation	25	55	-
6	Settlement	-	72	-
7	Tank with water	-	100	-

(Source: Chow et al, 1988)

3.3 HYDROLOGICAL SOIL GROUP (HSG) CLASSIFICATION

As per National Engineering Handbook (NEH) developed by USDA, soils are classified in four groups A, B, C and D with respect to rate of runoff potential and final infiltration rate.

Group A: Soils in this group have low runoff potential and high infiltration rate when thoroughly wet. Water is transmitted freely through the soil; *Group B*: Soils in this group have moderately low runoff potential and moderate infiltration rate when thoroughly wet. Water transmission through the soil is moderate; *Group C*: Soils in this group have moderately high runoff potential and low infiltration rate, when thoroughly wet. Water transmission is somewhat restricted through the soil; *Group D*: Soils in this group have high runoff potential and low very low infiltration rate, when thoroughly wet. Water transmission is restricted through the soil. Table 3shows the hydrological soil group classification.

Table. 3 Hydrological Soil Group classification (Mc. Cuen, 1982)

ISSN: 2349-6495

Soil Group	Minimum Infiltration rate (mm/hr)
A	7.62- 11.43
B	3.81- 7.62
C	1.27 – 3.81
D	0- 1.27

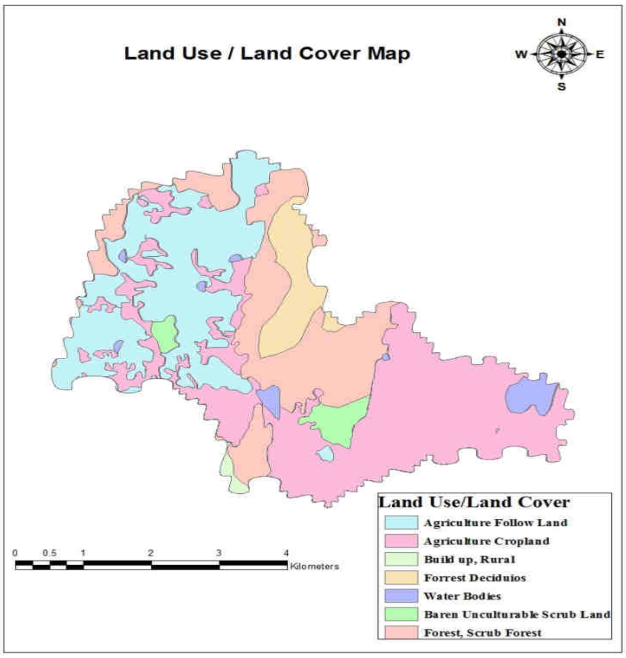

Fig. 3: shows the land use and land cover of the study area

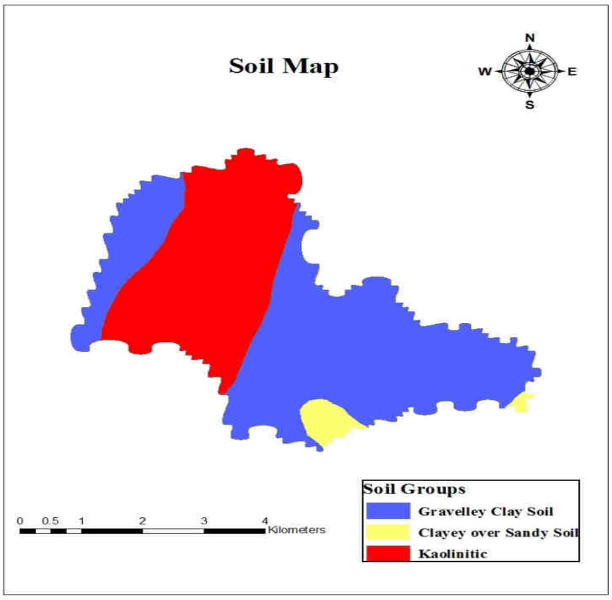

Fig.4:shows the soil map of the study area

IV. RESULT AND DISCUSSIONS

The land use and land cover categories of the study area were interpreted from satellite data. Fig. 3 shows the land use/ land cover of the study area. It majorly constitutes of culturable crop land (39.49%) followed by agricultural follow land (26.16%) and scrub forest land (22.11%). The major area of the watershed was under culturable crop land plays the major role for the direct surface runoff. The values of land use/ land cover of the study area are presented in Table 4.

Table 4. The Spatial distribution of land use and land cover classification

Sl.No	Type of land use and land cover	Area (Sq.Km)	% of Area
1	Barren unculturable scrub land	0.685	2.86
2	Water bodies	0.616	2.37
3	Forest deciduous	1.500	6.26
4	Forest, scrub forest	5.300	22.11
5	Built-up rural	0.132	0.55
6	Culturable crop land	9.464	39.49
7	Agricultural follow land	6.270	26.16
Total		23.967	100.00

The hydrological soil map was obtained from Karnataka State Remote Sensing and Application Centre (KSRSAC). Fig. 4 shows the HSG of the study area. The values of HSG of the study area are also presented in Table 5. Based on the hydrological soil group, the study area consists of ‘A’, ‘B’ and ‘D’ type of hydrologic soil group (HSG). Further, ‘A’ type of HSG predominantly covered throughout the area followed by ‘D’ and ‘B’ type consisting of 58.63%, 38.26% and 3.11% of total area respectively.

Table 5: The values of HSG of the study area

Sl.No	Hydrological soil Group(HSG)	Area (Sq.km)	% of Area
1	A	14.040	58.63
2	B	0.747	3.11
3	D	9.164	38.26
Total		23.95	100

The weighted values of curve number for the three AMC conditions of the study area are calculated as per SCS. The values of curve numbers are listed in table 6.

Table 6: Curve Number for Three Antecedent Moisture Conditions

AMC	I	II	III
CN	**45.80**	**62.56**	**77.51**

In order to estimate the runoff of the study area the daily rainfall data from 2003 to 2013 (for 11 years) obtained from Drought monitoring cell (DMC) Bangalore and calculated the weighted curve number of the watershed were used. From the daily runoff results, the monthly and the annual runoff vales are obtained.

Table 7 shows the annual rainfall and runoff for Kharadya milli watershed for the period 2003 to 2013. According to Drought monitoring cell (DMC) Bangalore, the mean annual rainfall of the study area for the period between 2003 and 2013 is 749 mm with a maximum rainfall of 1202.60mm in 2005 and a minimum of 400.50mm in 2012. From SCS Curve number, the maximum runoff for the watershed was estimated to be 240.16 mm in the year 2005 and minimum runoff of 35.47mm in the year 2012. Fig. 6 shows the rainfall runoff relationship for Karadya watershed. The figure indicates that rainfall and runoff are strongly correlated with correlation coefficient (r) value being 0.9.

Table 7: Annual Rainfall and Runoff Values (2003-2013)

Year	Rainfall (mm)	Runoff (mm)
2003	495.6	42.70
2004	973.00	122.23
2005	1202.60	240.16
2006	482.00	40.86
2007	820.90	106.75
2008	875.40	120.01
2009	728.90	117.53
2010	955.50	134.60
2011	669.80	65.24
2012	400.50	35.47
2013	634.80	60.04

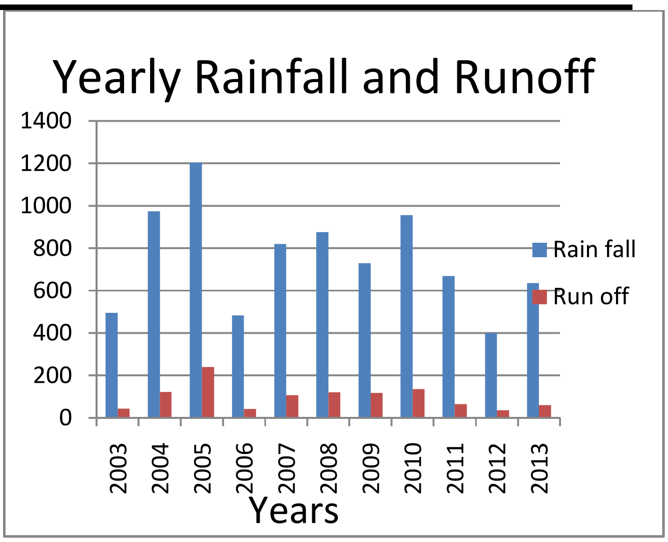

Fig.5: shows the annual rainfall and runoff for Kharadya milli watershed for the period 2003 to 2013

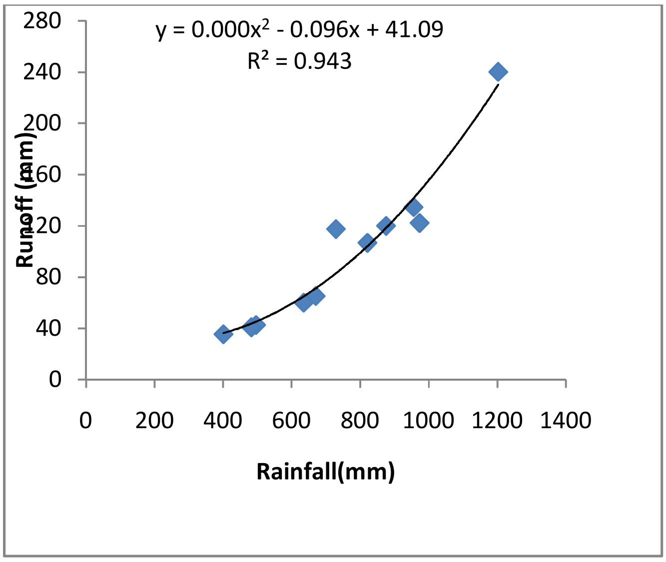

Fig.6:Runoff rainfall relationship for Kharadya milli watershed

V. CONCLUSIONS

In this study GIS based SCS curve number method was used to estimate runoff from the ungauged watershed. Based on the results of soil classification and land use, the study area was classified into three hydrologic soil groups. The composite curve number for normal condition is 62.56, where for the dry and wet conditions are 45.80 and 77.51 respectively. Results obtained clearly shows the variation in runoff potential with different land use/land cover and

ISSN: 2349-6495

with different soil conditions. Further it may conclude that the land use planning and watershed management can be done effectively and efficiently using SCS-CN number method with GIS. The study demonstrate that SCS –Curve Number with GIS is a powerful tool for estimating runoff of ungauged watersheds for better watershed management and conservation purposes.

REFERENCES

[1] *Abhijit M. Zende1, Nagarajan R1, Atal K.R."Analysis of surface runoff from Yerala River Basin using SCS-CN and GIS" International Journal of Geomatics and Geosciences Volume 4, No 3, 2014*

[2] *2. Chattopadhyay G S; Choudhury S. Application of GIS and remote sensing for watershed development project - A case study. 2006. Available from: http://www.gisdevelopment.netS*

[3] *Chow, V. T., Maidment, D. R., and Mayse, W. (1988). "Applied Hydrology", New York:Mc Graw Hill.*

[4] *Dubayah, R and Lerrenmaier D., Combing Remote Sensing and Hydrological Modeling for Applied Water and Energy Balance Studies, NASA EOS Interdisciplinary Working Group Meeting, San Diego, CA.* ***(1997)***

[5] *Geena G.B. and P.N. Ballukraya (2011) Estimation of runoff for Red hills watershed using SCS method and GIS Indian Journal of Science and technology Vol. 4, No. 8, 2011: 899-904.*

[6] *Ishtiyaq Ahmad 1, Vivek Verma 2, and Mukesh Kumar Verma 3 "Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment" 2nd International Conference on Geological and Civil Engineering IPCBEE vol. 80 (2015)*

[7] *Manoharan A, Muragappan A (2012), "Estimation of Runoff in ungauged rural watershed , Tamilnadu, India "international jounal of Engineering science &Technology 2012 Vol. 4 No.02 pp 449-456*

[8] *Mc. Cuen, R. H. (1982). "A guide to hydrologic analysis using SCS methods", Englewood Cliffs: Prentice Hall Inc.*

[9] *Nagarajan, N. and Poongothai, S. (2012). "Spatial Mapping of Runoff from a Watershed Using SCS-CN Method with Remote Sensing and GIS." J. Hydrol. Eng. 17, SPECIAL ISSUE: Soil Conservation Service Curve Number (SCS-CN) Methodology, 1268–1277*

[10] *Patil, J. P., Sarangi, A., Singh, O. P., Singh, A. K. and Ahmad, T., 2008. "Development of a GIS Interface for Estimation of Runoff from Watersheds, Water Resources Management,Vol. 22, No. 9, pp 1221-1239.*

[11] *Poongothai, S. and Thayumanavan, S. (2002a). "Estimation of Runoff from a Watershed Using GIS Based SCS Method". Proceedings of National Seminar on Water Resources Systems Planning and Management, 7-8, March 2002, Department of Civil Engineering. Annamalai University, Annamalai Nagar, pp –A27 –A37.*

[12] *Sarangi A and : Bhattachary AK,et al (2005),comparision of Artificial Neural Network & regression models for sedimenyt loss prediction from Banha watershed in India , Agriculture water management 78, 195 -208*

[13] *Sarita Gajbhiye " Estimation of Surface Runoff Using Remote Sensing and Geographical Information System " International Journal of u- and e- Service, Science and Technology Vol.8, No.4 (2015), pp.113-122*

[14] *Gajbhiye, S. K. Mishra and A. Pandey, "Effects of Seasonal/Monthly Variation on Runoff Curve Number for Selected Watersheds of Narmada Basin", International Journal of Environmental Sciences, vol. 3, no. 6, (2013a), pp. 2035-2046.*

[15] *Gajbhiye, S. K. Mishra and A. Pandey, "A procedure for determination of design runoff curve number for Bamhani watershed", IEEE-International Conference on Advances in Engineering and technology (ICAET - 2013), (2013b) 23-25 January, pp 1-9.*

[16] *Seth SM, Kumar Bhism, Thomas T, Jaiswal RK (1997-98) Rainfall-Runoff Modelling for Water Availability Study in Ken River Basin Using SCS-CN Model and Remote Sensing Approach. Technical Reports, NationalInstitute of Hydrology, Roorkee, No. CS/AR-12/97-98*

[17] *Sindhu D1, B L Shivakumar2, A. S Ravikumar "ESTIMATION OF SURFACE RUNOFF IN NALLUR AMANIKERE WATERSHED USING SCS-CN METHOD" IJRET: International Journal of Research in Engineering and Technology Nov-2013, pp 404 – 409*

[18] *S. K. Mishra, S. Gajbhiye and A. Pandey, "Estimations of design runoff curve numbers for Narmada watershed (India)", Journal of Applied*

Water Engineering and Research, vol. 1, no. 1, (2013), pp. 67-79.

[19] *Somashekar R. K., Ravikumar P., Sowmya S. V.,Mubhashir Aziz Dar, Ravikumar A. S., (2011) "Runoff estimation and morphometric analysis for Hesaraghatta watershed using IRS-ID LISS III FCC satellite data Journal of Indian Satellite and Remote sensing vol39 pp95-106*

[20] *Thakuriah Gitika and Saikia Ranjan Estimation of Surface Runoff using NRCS Curve number procedure in Buriganga Watershed, Assam, India - A Geospatial Approach International Research Journal of Earth Sciences Vol. 2(5), 1-7, June (2014)*

[21] *Zade M:RaySS : Dutta S : PaanigraphS (2005) " Analysis of runoff pattern for all major basins of India derived using remote sensing data . Current Science 88(8) 1301-1305.*