International Journal of u- and e- Service, Science and Technology
Vol.8, No.4 (2015), pp.113-122
http://dx.doi.org/10.14257/ijunesst.2015.8.4.12

Estimation of Surface Runoff Using Remote Sensing and Geographical Information System

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Abstract

Accurate estimation of runoff and sediment yield amount is not only an important task in physiographic but also important for proper watershed management (Gajbhiye et al. 2014a; Gajbhiye 2015). Watershed is an ideal unit for planning and management of land and water resources (Gajbhiye et al. 2013; Gajbhiye et al. 2014d). Direct runoff in a catchment depends on soil type, land cover and rainfall. Of the many methods available for estimating runoff from rainfall, the curve number method (SCS-CN) is the most popular. The curve number depends upon soil and land use characteristics. This study was carried out in Kanhaiya nala watershed located in Satna district of Madhya Pradesh using remote sensing and GIS. The total area of watershed 19.53 km^2. Soil map, Land Use and slope map were generated in GIS Environment. Since the curve number method is used here as a distributed model, it is necessary to get information concerning a large number of sub-catchments in the basin. Hence remote sensing and GIS techniques have been used. Landsat (ETM) satellite image was used to obtain land cover information by ERDAS 9.1 software. The thematic layers like soil map, elevation map, rainfall map and land cover map were created in Arc GIS 9.3. Curve numbers are assigned for different land cover and soil types. In present study the runoff varies from 1196.93 mm to 1551.17 mm of the study area.

Keywords: *Remote Sensing, GIS, Watershed, Runoff and Curve Number*

1. Introduction

India supports 16 percent of world population on 2.42 percent of global land area. An estimated 175 Million Hectares (M ha) of land constituting about 66 percent of total geographical area suffers from deleterious effect of soil erosion and land degradation. Active erosion caused by water and wind alone accounts for 150 M ha of land, which accounts to a soil loss of about 5300 million tonnes of top soil. In addition 25 M ha have degraded due to ravine and gullies, shifting cultivation, salinity / alkalinity, water logging etc.

Watershed, a geographically dynamic unit area that contributes runoff to a common point has been accepted as a basic unit for planning and implementation of the protective, curative and amelioration programmes. An accurate understanding of the hydrological behaviour of a watershed is important for effective management. The watershed management planning highlights the management techniques to control erosion in the catchment/watershed area (Gajbhiye *et al.* 2014b; Sharma *et al.* 2014b). Surface runoff and sediment losses are the two important hydrologic responses from the rainfall events occurring over the watershed systems (Gajbhiye *et al.* 2014c). Rainfall generated runoff is very important in various activity of water resources development and management such as a: flood control and its management, Irrigation scheduling, Design of irrigation and drainage network, hydro power generation etc. (Mishra *et al.* 2013). RS and GIS technique can be used effectively to generate the land use/land cover and change detection map for evaluating the changes in an area. Land cover / Land use is perhaps the category in which remote sensing has made its largest impact and comes closest to maximizing the capabilities of remote sensing.

GIS, which has been designed to restore, manipulate, retrieve and display spatial and non-spatial data, is an important tool in analysis of parameters such as land use/ land cover, soils, topographical and hydrological conditions. To carry out resource monitoring and assessment of area of interest, information derived through remote sensing data has to be merged or integrated with database in GIS. Thus the remote sensing along with GIS application aid to collect, analyze and interpret the data rapidly on large scale intermittently and is very much helpful for watershed planning (Sharma *et al.* 2014c; Gajbhiye 2014). Conventional methods of runoff estimation using SCS model are time consuming and error prone. Thus, Remote Sensing and Geographical Information (GIS) techniques are being increasingly used, as all the factors of SCS model are geographic in character. Due to geographic nature of these factors of SCS runoff model can easily be modelled into GIS. Some of the research worker in India has attempted to calculate runoff curve number using satellite data. Ragon and Jackson (1980) have estimated runoff curve of a basin using Landsat data. Hill *et al.* (1987) have generated SCS runoff curve numbers for a 1542 km^2 basin at Louisiana and Mississipi using Raster GIS. Tiwari *et al.* (1991) have modified SCS runoff curve numbers for the Kaliaghti River basin of West Bengal, India from a digitized land use/land cover map derived from the IRS-1A (LISS-II) data. Gajbhiye and Sharma (2012) Land Use and Land Cover change detection of Indra river watershed through Remote Sensing using Multi-Temporal satellite data. Gajbhiye and Mishra (2012) Application of NRSC-SCS Curve Number Model in Runoff Estimation Using RS & GIS. Gajbhiye *et al.* (2013a,b) examined seasonal and monthly effects on the runoff Curve Number and design curve number for four watersheds of Narmada basin. Sharma et al. (2013a) Use of Geographical Information System In Hypsometric Analysis of Kanhiya Nala Watershed. Sharma et al. (2013b, 2014a) studied geomorphic parameters grouping for hydrological modelling using principal component analysis. Looking to all these facts a study was undertaken with the objective to estimate the surface runoff using RS and GIS.

2. Material and Methods

2.1 Study Area

The study area Kanhaiya nala watershed which lies within the Tons River catchment is situated between 80^0 31' 51.01" and 80^0 35' 17.05 E longitude and 24^0 06' 29.23" and 24^0 11' 05.03" latitude with elevation range 480 to 620 m above Mean Sea Level (MSL). Kanhaiya nala watershed situated in Satna District (M.P.) is shown in Fig 1. The total area of the watershed is 19.53 km^2. It has a typical subtropical climate with hot dry summers and cool dry winters. Temperature extremes vary between the minimum of 4°C during December or January months to the maximum of 45°C in May or June. Average annual precipitation is 1100 mm, which is concentrated mostly between mid-June to mid-September with scattered winter rains during late December and January months.

2.2 Data Source

Topographic map at the scale of 1:50000 prepared by Survey of India (SOI) were used for dineation of watershed. SOI toposheet no. 63 D/12 was used for the delineation of watershed boundary. The Landsat ETM with 30 m resolution procured from GLCF. The Landsat ETM satellite with date of pass 11 Oct. 2006 were used to prepare the LULC map of watershed. Soil map prepared by National Bureau of Soil Survey on 1:250000 and printed on 1:500000 was used.

2.3 Software Used

Arc GIS 9.3 software was used for creating, managing and generation of different layer and maps. ERDAS 9.1 was used for generation of LULC map. The Microsoft excel was used for mathematical calculation.

2.4 Methodology

Preparation of Various Thematic Maps: Various thematic maps prepared by ERDAS Imagine 9.1 and Arc GIS 9.3 are contour map, drainage map, DEM, Slope map and land use/ land cover map. Initially base map was prepared from the SOI (Survey of India) toposheets on 1:50000 scale.

2.4.1 LULC Map: The LULC map was generated with the help of satellite data using unsupervised classification. In Kanhaiya nala watershed five land use/land cover classes were identified i.e. river, pond, open land, agriculture and forest. (Figure 2 and Table 2).

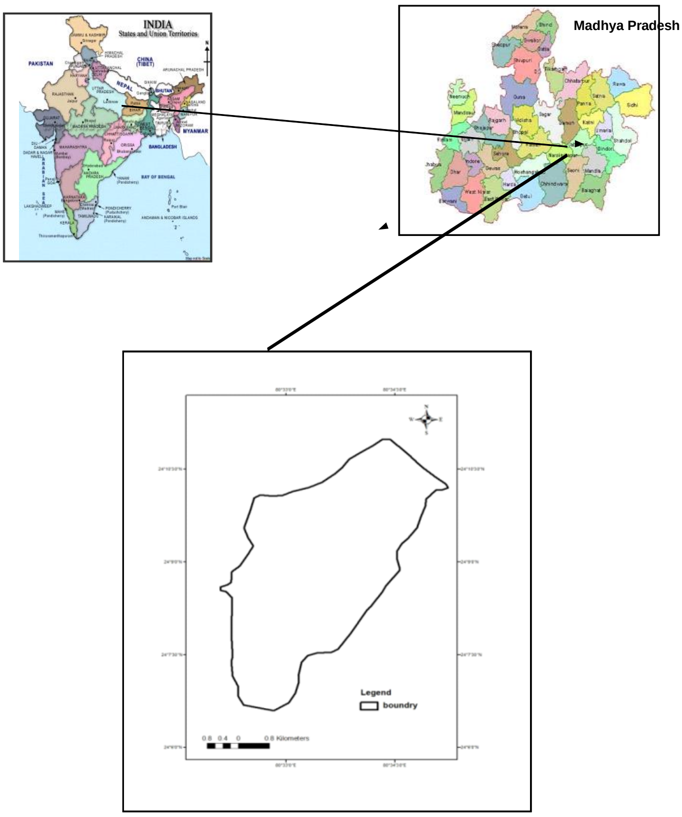

Figure 1. Location Map of the Study Area

2.4.2 Soil Map

The soil map of watershed was rectified in ERDAS Imagine 9.1. Boundary of the different soil texture was digitized in Arc GIS. In our study only one type of soil (loamy) was present (Figure 3) which comes under the hydrologic soil group B.

2.4.3 Elevation Map

The contour map was prepared from the toposheet of the scale 1:50000 with the contour interval of 20 m. Contour lines were digitized a little bit further outside the boundary of the study area to prevent the boundary of the study area giving wrong result.

The contour map could be used to generate a Digital Elevation Model (DEM). The Digital Elevation Model (DEM) consists of an optimal array of round elevations at regularly spaced intervals. DEM data plays the same role as that of conventional paper contours and relief shading with one additional benefit of it providing a powerful analytical perspective. Slope is an important factor for understanding the nature of terrain. The runoff characteristics and soil erosion of the command area are controlled by the degree of slope. Figure 4 presents the elevation map of the study area.

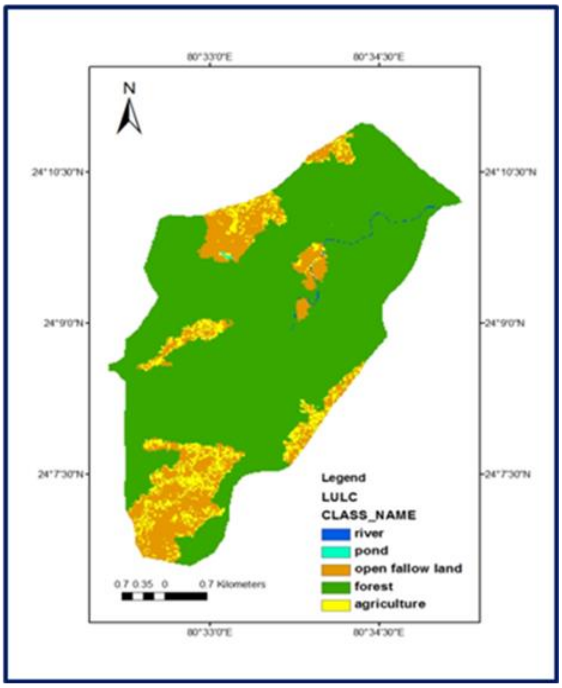

Figure 2. LULC Map of the Watershed

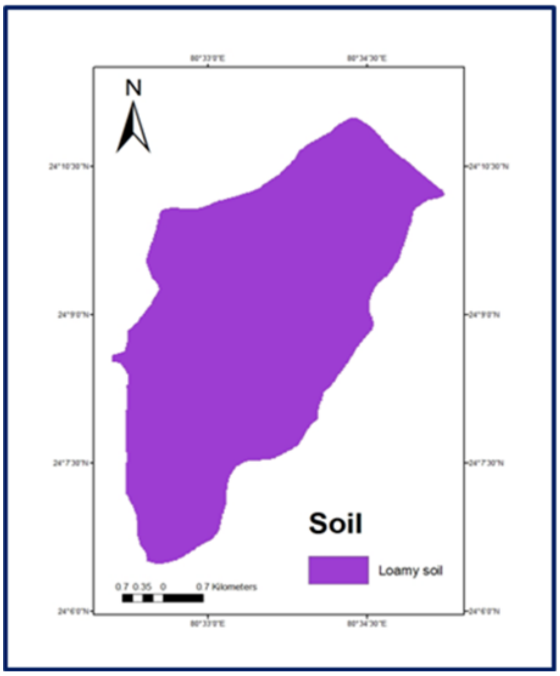

Figure 3. Soil Map of the Watershed

2.4.4 Generating CN Map: To create the CN map, the soil map and land use map were uploaded to the Arc GIS. The soil map and land use map were selected for intersection, after intersection a maps with new polygon representing the merged soil-land map. The appropriate CN value for each polygon of the soil-land map was assigned.

$$CN = (\sum (CNi \times A_{i)})/A$$

Where,
CN = weighted curve number.
CN_i = curve number from 1 to any no. N.
A_i = area with curve number CN_i
A = the total area of the watershed.

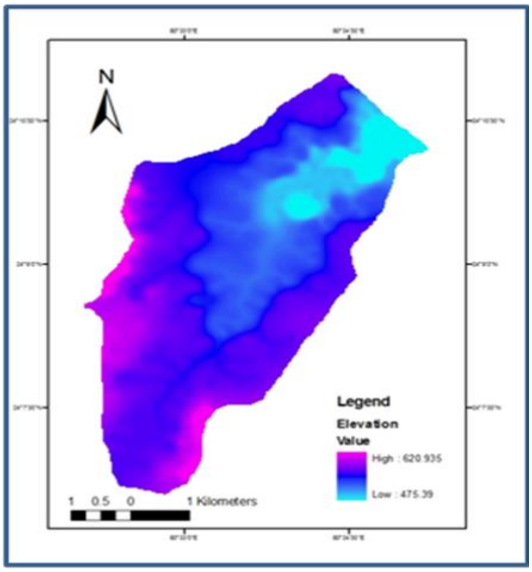

Figure 4. Elevation Map of the Watershed

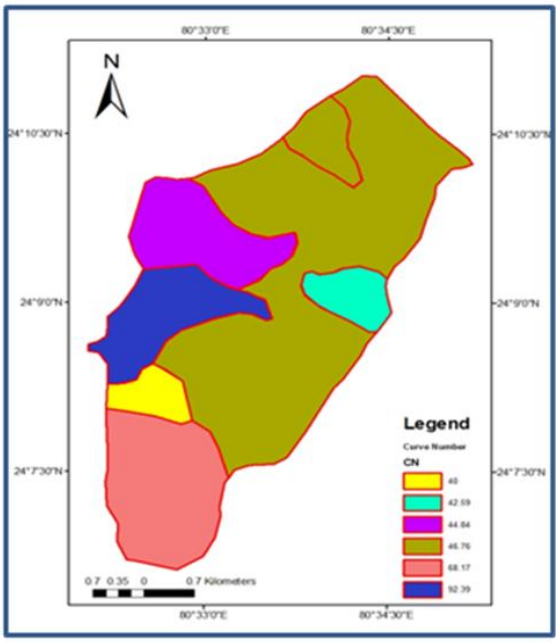

Figure 5. CN Map of the Watershed

2.4.5 Generate Rainfall Map: In the present study the relationship between elevation and rainfall, developed by Shreshta (1997), has been used for the preparation of a rainfall map. This relationship is as follows:

$$R = 1384.2 + 0.339Z$$

Where,
R is the rainfall in mm
Z is the elevation is meters.

2.4.6. Estimation of Runoff Depth Using SCS Model: The Soil Conservation Service Model also known as the Hydrologic Soil Cover Complex Model, is a versatile and widely used procedure for runoff estimation. The model uses runoff producing capability expressed by a numerical value (Curve Number) varying between 0-100. The equation used for estimation of runoff depth is –

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

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

Where,
Q = Runoff depth (mm).
S = Maximum recharge capacity.
CN = Curve Number.
P = Rainfall depth (mm).

Initial abstraction (S) which is function of curve number has been calculated in GIS environment in Spatial Analysis tool.

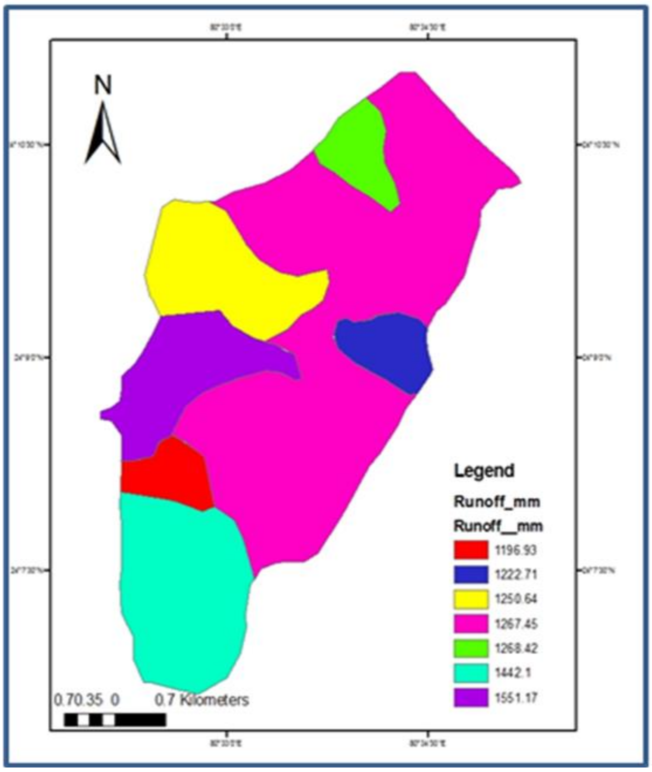

Figure 6. Runoff Depth Map of the Watershed

3. Result and Discussion

The soil of the Kanhaiya nala watershed is loamy, which comes under the hydrologic soil group 'B' (Figure 3).The study watershed was delineated into seven subwatersheds. The land use/land cover classification of the watershed is presented in Table 2. On the basis of unsupervised classification the classes namely River (0.20 %), Pond (0.03 %), Open/fallow land (14.28 %), Agriculture land (5.68 %) and Forest (79.67 %) were identified. Further land use / land cover digital data was used for generation of CN.

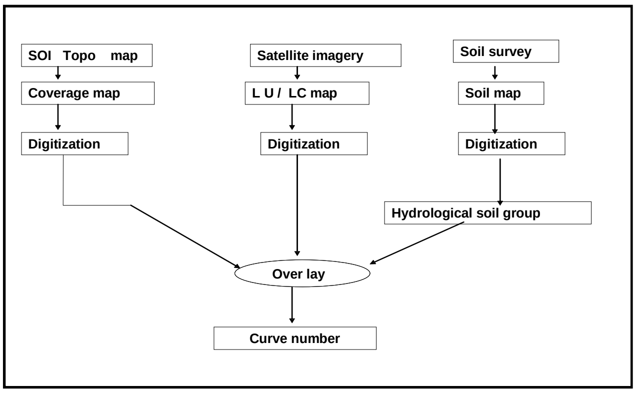

Figure 7. Flow Diagram for Determination of Curve Number

Table 1. Runoff Curve Numbers for (AMC II) for the Indian Conditions

Sl No.	Landuse	Trestment/practice	Hudrologic condition	Hydrologic soil group			
				A	B	C	D
1	Cultivated	Straight row	…..	76	86	90	93
		Contoured	Poor	70	79	84	88
			Good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			Good	62	71	77	81
				67	75	81	83
		Bunded	Poor	59	69	769	79
			Good	95	95	5	95
		Paddy (rice)	…..				
2	Orchards	With under stony cover	…..	39	53	67	71
		Without under stony cover	……	41	55	69	73
3	Forest	Dense	….	26	40	58	61
		Open		28	44	60	64
		Shrubs		33	47	64	67
4	Pasture	…….	Poor	68	79	86	89
			Fair	49	69	79	84
			Good	39	61	74	80
5	Wasted Land	……..	….	71	80	85	88
6	Hard Surface	…….	….	77	86	91	93

Curve Number: The USDA curve number Table No 1 (Tripathi, 1999) modified for Indian conditions was used for the determination of the curve number for individual sub watersheds based on the hydrological soil groups and land use classes of respective areas. The weighted CN (AMCII) values are given in Table 3.

Table 2. Land Use /Land Cover Classification of the Kanhaiya Nala Watershed

S.No.	Classes	Area (Km^2)	Percentage
1	Open land	2.79	14.28
2	Agriculture	1.11	5.68
3	Forest	15.56	79.67
4	River	0.04	0.20
5	Pond	0.03	0.15
Total		19.53	100

Runoff Mapping: Runoff potential has been estimated using Soil Conservation Service (SCS) Model. Maps for various parameters have been generated and finally a map showing variation in annual runoff potential has been prepared.

Table 3. Curve Number for Kanhaiya Nala Watershed

S.No	Sub-Watershed	CN (AMCII)	S	Q (mm)
1	KN_1	68.17	118.59	1442.10
2	KN_2	40.00	381.00	1196.93
3	KN_3	92.39	20.92	1551.17
4	KN_4	44.84	312.45	1250.64
5	KN_5	46.76	289.19	1268.42
6	KN_6	42.59	342.38	1222.71
7	KN_7	46.76	289.19	1267.45

The weighted CN value of sub watershed 1, 2, 3, 4, 5, 6, and 7 comes to be 68.17, 40.00, 92.39, 44.84, 46.76, 42.59 and 46.76 respectively. The runoff value for sub watershed 1, 2, 3, 4, 5, 6, and 7 to be 1442.10, 1196.93, 1551.10, 1250.64, 1268.24, 1222.71 and 1267.45 respectively. It can be inferred from Table 3 that the CN unadjusted value are higher in comparison to CN adjusted with slope. There is no provision for runoff monitoring in Kanhaiya nala watershed, therefore this method could be used to find out the runoff. Thus the generated curve numbers may be used for prediction of runoff from an ungauged watershed.

4. Conclusion

Remote sensing and GIS technique is a very reliable alternative or a dependable support system to our conventional way of surveying, investigation, planning, monitoring, modelling, data storing and decision making process. The synoptic concept of satellite image is fairly easy for identification of the broad physical features such as stream network, land use/land cover, soils surface, water bodies etc. The land use/land cover is an important parameter input of SCS model which could be determined very accurately with help of this technique. With the help of RS, GIS and SCS model it is possible to make management plans for usage and development of watershed. Although Curve number method is empirical approach to determine the runoff depth from the watershed. But it can be useful for estimating the runoff for places which do not have runoff record.

References

[1] A. Xu, "A new Curve number calculation approach using GIS technology", ESRI 26th International user conference **(2006)**.
[2] R. Amutha and P. Porchelvan, "Estimation of surface runoff in malattar sub watershed using SCS-CN method", J. Indian Soc. Remote Sens, vol. 37, **(2009),** pp. 291-304.
[3] M. Ebrahimian, Lai food see, M. H. Ismail and I. A. Malik, "Application of NRCS curve number method for runoff estimation with GIS in the Kardeh watershed, Iran. European Journal of Scientific Research, vol. 34, no. 4, **(2009),** pp. 575-590.
[4] L. O. Fresco, "Using land evaluation and farming system methods for planning sustainable land use an example from Costa Rica", land use planning application proceeding FAO Expert consultation Rome, 10-14 Dec 1190. World soil rescores reports no. 68, 1991, **(1990),** pp. 153-157.
[5] S. Gajbhiye, "Estimation of Rainfall generated runoff using RS and GIS" LAMBERT Academic Publishing, Germany, ISBN 978-3-659-61084-4, (**2014**).
[6] S. Gajbhiye and S. K. Sharma, "Land Use and Land Cover change detection of Indra river watershed through Remote Sensing using Multi-Temporal satellite data", International Journal of Geomatics And Geosciences, vol. 3, no. 1, (**2012**), pp. 89-96.
[7] S. Gajbhiye and S. K. Mishra, "Application of NRSC-SCS Curve Number Model in Runoff Estimation Using RS & GIS", IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012), (**2012**) March 30-31.
[8] S. 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.
[9] S. 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.
[10] S. Gajbhiye, S. K. Mishra and A. Pandey, "Prioritizing erosion prone area through morphometric analysis: an RS and GIS perspective", Applied Water Science, DOI: 10.1007/s13201-013-0129-7 (**2013**).
[11] S. Gajbhiye, S. K. Mishra and A. Pandey, "Relationship between SCS-CN and Sediment Yield", Applied Water Science, vol. 4, (**2014a**), pp. 363–370.
[12] S. Gajbhiye, S. K. Mishra and A. Pandey, "Simplified sediment yield index model incorporating parameter curve number", Arabian Journal of Geosciences, DOI 10.1007/s12517-014-1319-9, (**2014b**).
[13] S. Gajbhiye, S. K. Mishra and A. Pandey, "Hypsometric Analysis of Shakkar River Catchment through Geographical Information System", Journal Geological Society of India, vol. 84, (**2014c**), pp.192-196.
[14] S. Gajbhiye, S. K. Sharma and C. Meshram, "Prioritization of Watershed through Sediment Yield Index Using RS and GIS Approach", International Journal of u- and e- Service, Science and Technology, vol. 7, no. 6, (**2014d**), pp. 47-60.
[15] S. Gajbhiye, "Morphometric analysis of a Shakkar River Catchment Using RS and GIS. International Journal of u- and e- Service", Science and Technology, vol. 8, no. 2, (**2015**), pp. 11-24.
[16] M. L. Gandini and E. J. Usuoff, "SCS-CN estimation using RS NDVI in a GIS environment", Journal of environmental hydrology, vol. 12, **(2004).**
[17] A. A. Kulkarni, S. P. Aggarwal and K. K. Das, "Estimation of Surface runoff using rainfall-runoff modelling of warasgaon dam catchment", Map India 2004, New Delhi, **(2004)**.
[18] H. A. J. Lanen Van, D. Van, G. J. Reinds and G. H. J. Koning, "Physical land valuation methods and GIS to explore the growth potential and its effects within the European communities", Agricultural system, vol. 38, no.3, **(1992),** pp. 307-328.
[19] 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.
[20] T. R. Nayak and R. K. Jaiswal, "Rainfall-runoff modelling using satellite data and GIS for Bebas River in M.P", IE (I) journal 84, **(2003),** pp. 47-50.
[21] NBSS, Soil series of Madhya Pradesh, **(1998)**.
[22] NNRMS, NNRMS standards, Indian space research organization NNRMS secretariat, NNSMS standards doc ver3.0;7/18/2005, **(2005)**.
[23] A. Pandey and A. K. Sahu, "Generation of curve number using Remote Sensing and Geographic Information System", **(2000),** pp. 1-4.
[24] A. Pandey and A. K. Sahu, "Generation of CN using RS and GIS", http//www.gisdevelopment.net, **(2002)**.
[25] M. S. Reddy, "Theme paper on "Water vision 2050" Indian water resource society Roorke", **(1999),** pp. 51-53.
[26] G. D. Rossiter, "A theoretical frame work for land evaluation", Goederma, vol. 72, pp. 165-190, **(1996)**.
[27] E. R. C. Sharma, S. Undriyal, Y. K. Bhatt, L. K. Sharma and Y. K. Rai, "Integrated watershed management: a case study in Sikkim Himalaya", Gyanodaya Prakashan, Nainital, Berkeley, CA **(1992)**.
[28] S. K. Sharma, S. Tignath, S. Gajbhiye and R. Patil, "Use of Geographical Information System In Hypsometric Analysis of Kanhiya Nala Watershed", International Journal of Remote Sensing & Geoscience, vol. 2, no. 3, **(2013a),** pp. 30-35.

[29] S. K. Sharma, S. Tignath, S. Gajbhiye and R. Patil, "Application of Principal Component Analysis in Grouping Geomorphic Parameters of Uttela Watershed For Hydrological Modeling", International Journal of Remote Sensing & Geoscience, vol. 2, no. 6, (**2013b**), pp. 63-70.
[30] S. K. Sharma, S. Gajbhiye and S. Tignath, "Application of principal component analysis in grouping geomorphic parameters of a watershed for hydrological modelling", Applied Water Science, DOI 10.1007/s13201-014-0170-1 (**2014a**).
[31] S. K. Sharma, S. Gajbhiye, R. K. Nema and S. Tignath, "Assessing Vulnerability to Soil Erosion of a Watershed of Tons River Basin in Madhya Pradesh using RS and GIS", International Journal of Environmental Research and Development, vol. 4, no. 2, (**2014b**), pp. 153-164.
[32] S. K. Sharma, A. Yadav and S. Gajbhiye, "Remote Sensing and GIS Approach for Prioritization of Watershed". LAMBERT Academic Publishing, Germany, ISBN 978-3-659-53529-1, (**2014c**)
[33] R. Suresh, "Soil and Water Conservation Engineering", Standard Publisher Distributers, Delhi, **(1997),** pp. 97-98.
[34] X. Zhan and M. L. Huang, "Arc CN runoff: An ArcGIS tool for generating CN and runoff maps", Environmental modelling & software, vol. 19, **(2004),** pp. 875-879.

