IMPACT OF LANDUSE CHANGES ON SURFACE RUNOFF IN BEDA CATCHMENT, NARMADA BASIN IN CENTRAL INDIA

Tejram Nayak[1] trnnca@gmail.com

Abhijit Soni[2] abhijit_soni28@rediffmail.com

M.K. Verma[2] mkseem670@gmail.com

1. NIH Regional Centre, Manorama Colony, Sagar (M.P.) – 470001 (India)

2. Deptt. of CE, National Institute of Tech., Raipur (C.G.) – 492001 (India)

ABSTRACT

Urbanization and development of lands have increased significantly in last few years to fulfil the requirements of increasing population and economic and infrastructure development in India. The hydrological response of watershed is usually altered due to revolution in the watershed development. Thus it is necessary to quantify the likely changes in the surface runoff in a watershed as an impact of the planned or unplanned changes made in the land use. The landuse changes in the Beda river watershed and its effect on surface runoff has been examined by comparing the estimated surface runoff produced by the similar rainfall during the year 1989 and 2007. The land use/cover maps for the two periods were prepared from the satellite imageries and their spatial distributions have been compared using ILWIS GIS software. The weighted average Curve Numbers (CN) of Beda catchment for both the years have been calculated based on land use/cover type and hydrologic soil group as mentioned in the reports of USDA Soil Conservation Service. The direct surface runoff computed through the SCS Curve Number method have been compared with the calculated runoff from the observed hydrograph the for selected rainfall events during both the years. The surface runoff produced due to the similar rainfall during the past and recent year have also been compared. It was noticed that the runoff volume has been increased in recent years (i.e. 2007) in comparison to those in the past years (i.e. 1989) for the similar rainfall events.

Key Words: SCS-Curve Number, Landuse changes, Rainfall-runoff, Narmada

INTRODUCTION

The water resources available in most of the river basins in India are under heavy stress due to increased demand and inadequate flow demanding proper water management to ensure squeezed gap between the demand and supply. One has to create special structures for storage, diversion and conveyance of water and operate them to meet the goals of water management. The systems of such structures need appropriate planning and optimum operation to ensure fulfillment of the goals of water management. Generally the flows occurring in the rivers vary over the period of years according to changes in the hydro-meteorological conditions. The flows are sometimes very low and sometimes quite high. The high flows are termed as floods, occur for a shorter duration but may cause damage to the existing structures as well as in the surroundings. Hence, it becomes imperative to safeguard the created structures against the floods with the provision of some arrangement within the structure to pass the high magnitude of flow. The question lies in the fact that these floods are broadly uncertain and variable and result from a complex combination of: (i) Magnitude and intensity of rainfall, (ii) Type of land-use land cover within the catchment, (iii) Initial moisture status of the soil and (iv) Drainage Network.

One has to predict the exact quantity of flood discharge occurring at a particular time. The catchment where the actual measurement of the flood (discharge) is carried out is known as the gauged catchment and the others are known as un-gauged catchments. For most of the gauged catchments, the flood is considered to be known as soon as it is recorded. However, the prediction of long term behavior is not possible. In either of the cases the flood pattern prediction in the form of a flood hydrograph with a lead time ranging from a few hours to many hours is required. It has been established since long that the mathematical models have been the best tools for the prediction of floods in a catchment. The process is also called as hydrological modeling or watershed modeling. Rainfall-runoff models are probably what most hydrologists spontaneously refer to when discussing hydrological models. The basic principle in hydrological modeling is that the model is used to calculate river flow based on meteorological data, which are available in a basin or in its vicinity.

The Soil Conservation Service (SCS) of United States Department of Agriculture (USDA) developed a hydrologic model that relates the amount of surface runoff from rainfall to soil-cover complexes. The theory of the SCS-CN model is that the runoff can be related to soil cover complexes and rainfall through a parameter known as a Curve Number (SCS,1972). Though each of the hydrological models have their own merits and demerits, the Soil Conservation Service Curve Number (now called Natural Resources Conservation Service Curve Number Method, NRCS-CN) method is simple, well acclaimed and produces better results (Stuebe and Johnston, 1990; Ponce and Hawkins,1996; Michel et al., 2005; Mishra et al., 2005; Schneider and McCuen, 2005). Many researchers (Pandey and Sahu, 2002; Nayak and Jaiswal, 2003; Zhan and Huang, 2004; Gandini and Usunoff, 2004) have utilized the Geographic Information System technique to estimate runoff Curve Number values throughout the world. In recent years, attempts were made to evaluate CN values and finding a better way to incorporate the Initial Abstraction Antecedent Moisture Conditions (Mishra and Singh, 2006; Mishra et al., 2006; Jain et al., 2006; Sahu et al., 2007; Brocca et al., 2008; Soulis et al., 2009). Nayak and Narulkar (2011) applied the SCS-CN method to quantify the impact of landuse changes in Goi river sub-basin.

In the present study, distributed SCS-CN model in ILWIS GIS platform has been applied to estimate variations in runoff during significant rainfall events for two different periods, i.e. year 1989 and 2007 for the Beda river catchment of Narmada river basin in Central India. The satellite imageries of the two periods were used for land use/cover mapping and to prepare soils map of the Beda catchment to calculate the average Curve Numbers for both the years. Finally, the impact of the land use/cover changes on the quantum of runoff resulting from the similar rainfall in the Beda River Catchment has been evaluated.

STUDY AREA

Narmada river 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 Shahdol district of Madhya Pradesh in the Maikal hill range and flows westwards over a length of 1,312 km and drains an area of 98796 sq.km before falling into the Arabian Sea. Thirty four major tributaries drain into the main river from North and South banks accumulating 24.5 lakh cusecs standard flood at Sardar Sarovar dam at Ch.1164 km. from the origin. Beda river is a major Southern tributary of Narmada, originates near village Dhupa at El. 876m in Satpuda Ranges and joins the River Narmada at about 2 km upstream of Mandleshwar town in Khargone district of Madhya Pradesh. It has a fan shaped 3973 sq.km catchment and lies between 21°23’30” N & 22°9’30” N latitudes and 75°21’20” E & 76°09’50” E longitudes as shown in Index map at Fig.1.

The gauging of river Beda near Kogaon was started by Central Water Commission, Bhopal in February, 1978 and recently an automatic river gauging system has been installed under the Real Time Data Acquisition System (RTDAS) by Narmada Control Authority (NCA), Indore. The drainage density in Beda watershed is very high due to hilly terrain and undulating lands. The temperature of Beda catchment is maximum in the month of May and minimum in the month of December. 50 years rainfall data at Khargone (M.P.) reveal that 90.5% of the precipitation takes place during southwest monsoon, 7.5% during post monsoon, 1.5% during pre-monsoon and only 0.5% of the total precipitation occurs in the winter period. The Annual Average Rainfall at Khargone is 832 mm.

MATERIALS AND METHODS

The basic information required for SCS-CN model is landuse and soil maps of the catchment area to calculate the average curve number of the basin.

Land use

The land use/cover maps for the year 1989 and 2007 were collected from CE&AD, SGSITS, Indore and MPCS&T, Bhopal respectively. Visual interpretation technique was applied for preparing the land use map from the False Colour Composite (FCC) of satellite imageries (IRS 1A LISS-II) for the year 1989. Digital FCC imageries of the year 2007 (IRS 1D LISS-III) were on screen delineated for level-1 classification of the major land use classes at MPCOST, Bhopal. The land use map for the year 1989 and 2007 are shown in Fig.2 and Fig.3 respectively. The land use of Beda watershed in 2007 shows that the cultivable lands dominate with 67.9% coverage, followed by forest cover with 20.6% stretch, 8.9% area under scrub/pasture and barren/rocky and remaining 1.5% of the total area comes in wetland and 1.1% constitutes paved surfaces and settlements.

Soils

The soils map was procured from CE&AD, SGSITS, Indore which were prepared using IRS-1A LISS-I satellite imageries under a State Govt. sponsored project (Fig.4). The soils map has been further classified for the hydrologic soil group map. The soils of

58% of the catchment area come in hydrologic group ‘D’, 28% in group ‘B’ and soils of the rest 14% of the area fall in hydrologic group ‘C’.

Hydrological Data

The daily rainfall at Khandwa and Khargone district HQ is recorded by the Indian Meteorological Department (IMD) on regular basis since last many decades. The Central Water Commission has established Gauge & Discharge and rain gauge site near Kogaon village on river Beda in the year 1978 to record hourly observations during monsoon months and daily observations during non-monsoon months. In all there are three rain gauge stations in the catchment area. Thiessen polygon method was applied to estimate the average rainfall in the catchment and the Thiessen weights assigned to each station are given in Table-1.

Table 1: Weights for Average Rainfall Computations

Raingauge Station	Kogaon	Khandwa	Khargoan
Thiessen polygon weight	0.16	0.13	0.71

Significant isolated rainfall occurred during the year 1989-91and 2007-09 over the Beda catchment have been selected for computation of direct runoff through SCS curve number method. The discharges observed in Beda river at Kogaon site during the same period have been selected for the study.

SCS-CN Model

The SCS Curve Number method is based on an assumption that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. The generalised SCS model (SCS,1972) relates direct runoff depth, Q (mm) with the rainfall, P (mm) in the basin by the expression:

$$Q = \frac{(P-\mathrm{I_a})^2}{(P-\mathrm{I_a}+\mathrm{S})} \qquad \ldots \qquad (1)$$

Where, S is potential maximum retention by soil (mm) and I_a is initial abstraction. The initial abstraction consists mainly of interception, infiltration and surface storage occurring before runoff begins and also depends upon Antecedent Moisture Condition (AMC) of soils. Eq. 1 is physically subjected to the restriction that P ≥ I_a (i.e. the potential runoff minus the initial abstraction cannot be negative) and Q = 0 otherwise. To simplify the Eq. 1, initial abstraction is related to potential maximum retention by the relationship as given below:

$$I_a = \lambda . S \qquad \ldots \qquad (2)$$

Generally for all practical applications, λ is taken as 0.2. However, in Indian context pertaining to the black soil region the value of λ is taken as 0.3 for black soil region for AMC-I and for all other soil regions; and the value of λ is taken as 0.1 for black soil region for AMC-II&III (NIH, 1998). The variable S in mm is related with the curve number (CN) by the expression:

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

The antecedent moisture condition (AMC) is the index of the soil condition with respect to runoff potential before the storm. The antecedent moisture condition is divided in three categories by USDA, TR-55 based on the crop season and 5-days antecedent precipitation (SCS, 1986) as follows:

AMC I: Dormant season antecedent soil moisture less than 12 mm, Growing season antecedent soil moisture less than 36 mm.

AMC II: Dormant season antecedent soil moisture between 12 and 28 mm, growing season antecedent soil moisture between 36 and 53 mm.

AMC III: Dormant season antecedent soil moisture greater than 28 mm, growing season antecedent soil moisture greater than 53 mm.

Thus, the direct runoff depth, Q is function of two factors, the precipitation and the curve number chosen for the specific catchment.

RESULTS AND DISCUSSIONS

The surface runoff in a watershed depends on many physical parameters such as shape, size, slope, drainage density, landuse/land cover and soil characteristics. The SCS Curve Number method considers landuse-soil complex only of a watershed. The data requirements are less and spatial information generated through GIS can be directly used in the model. Water resources potential of the Narmada river basin is being exploited to its maximum potential though multiple irrigation and multipurpose schemes. One such major irrigation, “Upper Beda Project” on Beda river is under construction. The present analysis on impact of landuse change on surface runoff shall be helpful for estimation of peak floods during heavy rains in Beda catchment.

Changes in Landuse

Comparison of the land use map of Beda catchment for the years 1989 and 2007 reveal that the agricultural area has been increased from 1690 sq.km. (43%) to 2660 sq.km. (68%), whereas the forest cover reduced from 1611 sq.km. (41%) to 807 sq.km. (20.6%). Low canopy/forests-scrub area have suffered maximum as it shrunk from 795 sq.km. to merely 173 sq.km. followed by the dense forest reduced from 430 sq.km. to 254 sq.km, however, the medium canopy cover (open forest) remaining almost same. The results also show that much of the areas under dense forest have been degraded to medium/open forests and forest-scrubs. Also, the open forest and forest-scrubs have been converted into cultivable lands by the local farmers. The land use change in Beda catchment can be broadly concluded as the dense forest cover is degraded to open forest and range lands have been converted into agricultural fields. The classification results for the year 1989 and 2007 and changes in land use are given in Table-2.

Computation of Average Curve Number

In the estimation of runoff using SCS Curve Number Method, the most important factor is determination of proper Curve Number (CN) values. Area weighted average curve

Table.2: Landuse/Land cover in Beda river sub-basin

Landuse Class	Old Landuse (1989)			Recent Landuse (2007)			Landuse Changes	
	No.of Pixels	Area (Sq.km.)	Percent of total Area	No.of Pixels	Area (Sq.km.)	Percent of total Area	Sq.km.	Percent
Built Up- Urban/Rural	not reported	not reported	--	17510	43.78	1.12%	43.78	--
Agricultural Land-Crop Land & Current Fellow	484475	1211.19	30.91%	914424	2286.06	58.33%	1074.87	88.7
Scrub with Cultivation / Agriculture inside Forest	191719	479.30	12.23%	149635	374.09	9.55%	-105.21	-22.0
Dense Canopy / Forest-Deciduous)-Dense/Closed	171925	429.81	10.96%	101673	254.18	6.49%	-175.63	-40.9
Medium Canopy / Forest-Deciduous)-Open	154676	386.69	9.87%	152023	380.06	9.70%	-6.63	-1.7
Low Canopy / Forest-Scrub Forest	317897	794.74	20.28%	69072	172.68	4.41%	-622.06	-78.3
Scrub-Pasture / Scrub Land + Forest Blank	131792	329.48	8.41%	5989	14.97	0.38%	-314.51	-95.5
Waterbodies-River/Stream	not reported	not reported	---	23875	59.69	1.52%	--	--
Wastelands-Barren Rocky/Ravinous/Stony waste	115116	287.79	7.34%	133399	333.50	8.50%	--	--
Grand Total	**1567600**	**3919.00**	**100.0%**	**1567600**	**3919.00**	**100.0%**		

numbers for Beda watershed have been calculated for two different periods of land use conditions for the year 1989 and year 2007. Appropriate CN values correspond to AMC-II have been assigned to different polygons obtained from cross map between land use and soil maps in ILWIS GIS Software. These were taken from reputed publications related to SCS Method. Finally, sum of the products of area and CN value has been divided by the catchment area to get area weighted average CN value for the Beda watershed. The CN values correspond to other antecedent moisture conditions, i.e. for AMC-I and AMC-III have been computed by the following formulae:

$$CN_I \text{ for AMC-I} = 0.39*CN_{II}*EXP(0.009*CN_{II}) \quad \ldots \quad (4)$$

$$CN_{III} \text{ for AMC-III} = 1.95*CN_{II}*EXP(-0.00663*CN_{II}) \quad \ldots \quad (5)$$

Where, CN_{II} = runoff curve number for AMC-II.

The computation of Average Curve number values for the year 1989 and 2007 have been shown in Table-3. These CN values were used in SCS equation to get the direct runoff volume for given rainfall for different AMC conditions and growing seasons.

Table-3: Area weighted average CN for Beda catchment for the year 1989 & 2007

Anticident Moisture Condition	Year 1989			Year 2007		
	AMC-I	AMC-II	AMC-III	AMC-I	AMC-II	AMC-III
Average curve number, CN	62.28	77.98	90.06	67.58	81.82	92.23
Potential retention, S	153.84	71.74	28.03	121.85	56.44	21.40
Dormant season, $I_a = 0.1$ S	15.38	7.17	2.80	12.19	5.64	2.14
Growing season, $I_a = 0.2$ S	30.77	14.35	5.61	24.37	11.29	4.28
Full growth season, I_a=0.3S	46.15	21.52	8.41	36.56	16.93	6.42

Rainfall and Observed Direct Runoff

Daily rainfall data recorded at the three influencing rain gauge stations namely, Kogaon, Khandwa and Khargoan and daily discharge observed at Kogaon G&D site have been collected from CWC and NCA, Indore. The plot of observed discharge against time represents flood hydrograph, which includes baseflow components also, therefore, direct runoff volume has been computed after deduction of baseflow from the observed discharge at Kogaon G&D site. The weighted average rainfall in Beda Catchment and corresponding Direct Runoff for the selected events during the year 1989 and 2007-09 have been used for model calibration and validation.

Computation of Direct Runoff using SCS Method

The runoff depends on intensity and duration of rainfall and watershed characteristics. The SCS-CN method takes into account for amount of precipitation only. Also, the limitations of SCS curve number method in considering uniform precipitation, soil moisture and vegetation growth over the entire area are significant in the present study due to large geographical area of the Beda Catchment.

The SCS-CN model has been applied to estimate total runoff volume by taking historical rainfall events and corresponding hydrographs available from the records for two different periods. The computed surface runoff volumes have been compared with the observed direct runoff. The detailed comparison of computed and observed direct surface runoff volumes for the year 1989 and 2007-09 chosen for the analysis have been presented in Table-4.

Impact of Landuse Changes

The changes in landuse pattern have altered the average curve number of the watershed, which is reflected in runoff generated from a given rainfall, considering the other characteristic remain same. In order to quantify the imapact of landuse changes on surface runoff between the two periods, the rainfall input to the SCS-CN model have been assumed the same for both the years, i.e. 2001 and 2007. Increase in runoff volume is mainly due to reduction in forest cover, increase in agricultural fields and impervious surfaces in the catchment area. About 35% average increase in peak runoff volume produced during the year 2007-09 have been estimated than that produced in the year 1989, keeping the other parameters same as shown in Table-4.

CONCLUSIONS

From the above results, the applicability of the SCS method to Beda River catchment is proven. In case of land uses data of the year 1989, the variation is from 33% to about 58 %. The variation is too large since the then forest cover was extensive and quite dense. The impact of land use change is obvious from the results of 1989 land use data. In the data based on the year 2007 the variation between the observed values and the computed values is small as it is in the range of ±10%. The method application is though tedious, the method seems to be promising for the application for the ungauged river catchments of river Narmada in its lower zone.

The results of the study shown in Table-6 & 7 demonstrate that the SCS-CN model performed well in estimating the runoff volume in the Beda catchment. The effect of land use changes on runoff can be evaluated in terms of change in curve number from the year 1989 to the year 2007. The direct runoff volume resulted from the same depth of rainfall with the average curve number. From the results, it is clear that the runoff quantity has been increased in recent years (2007-2009) with the same depth of rainfall as those in 1989.

Disclaimer

Table-4: Effect of land use/cover change on direct surface runoff

Date	Anticident Moisture condition	Season	Daily rainfall in mm	Q in mm as per landuse in 1989	Total direct runoff in MCM	Q in mm as per landuse in 2007	Total direct runoff in MCM	Percent variation in total runoff
28-Jun-89	AMC-II	Dormant	46.57	13.97	148.54	17.21	183.25	23.40%
29-Jun-89	AMC-II		33.98	7.29		9.47		
30-Jun-89	AMC-III		31.45	14.48		16.94		
01-Jul-89	AMC-III		0.95	0.00		0.00		
02-Jul-89	AMC-III		2.38	0.00		0.00		
03-Jul-89	AMC-III		11.18	1.93		2.68		
04-Jul-89	AMC-III		2.23	0.00		0.00		
05-Jul-89	AMC-III		5.50	0.24		0.45		
22-Jul-89	AMC-I	Dormant	31.03	1.44	34.45	2.52	48.94	42.10%
23-Jul-89	AMC-III		11.38	2.01		2.79		
24-Jul-89	AMC-III		11.55	2.08		2.88		
25-Jul-89	AMC-III		14.12	3.26		4.30		
26-Jul-89	AMC-III		0.50	0.00		0.00		
08-Aug-89	AMC-I	Growing	36.36	0.20	31.23	1.07	47.34	51.60%
09-Aug-89	AMC-III		22.70	6.48		8.52		
10-Aug-89	AMC-III		7.89	0.17		0.52		
12-Aug-89	AMC-II		13.30	0.00		0.00		
13-Aug-89	AMC-III		11.81	1.12		1.96		
02-Jul-09	AMC-I	Dormant	17.25	0.20	28.05	0.02	18.27	53.50%
05-Jul-09	AMC-I		6.11	0.62		0.35		
08-Jul-09	AMC-I		11.18	0.00		0.00		
09-Jul-09	AMC-I		43.31	6.33		4.29		
21-Jul-09	AMC-I	Dormant	18.72	0.33	78.17	0.07	61.59	26.90%
22-Jul-09	AMC-I		23.58	0.97		0.41		
23-Jul-09	AMC-II		48.71	18.64		15.23		
4-Oct-09	AMC-III	Growing	8.41	0.67	53.84	0.25	42.07	28.00%
5-Oct-09	AMC-III		28.77	13.07		10.48		
6-Oct-09	AMC-III		0.73	0.00		0.00		
26-Aug-08	AMC-III	Full Growth	12.52	2.29	10.01	1.37	6.74	48.50%
27-Aug-08	AMC-III		8.93	0.26		0.35		
28-Aug-08	AMC-III		4.60	0.00		0.00		
7-Jul-07	AMC-II	Dormant	30.36	7.53	62.56	5.66	45.66	37.00%
8-Jul-07	AMC-II		29.01	6.84		5.10		
9-Jul-07	AMC-III		5.661	0.50		0.26		
10-Jul-07	AMC-III		7.11	0.94		0.57		
11-Jul-07	AMC-III		4.07	0.16		0.05		
26-Aug-07	AMC-II	Growing	12.99	0.85	132.17	0.44	106.29	24.30%
28-Aug-07	AMC-III		15.13	4.91		3.77		
1-Sep-07	AMC-III		26.34	12.84		10.74		
2-Sep-07	AMC-III		23.56	10.72		8.83		
7-Sep-07	AMC-III		14.30	4.41		3.35		

REFERENCES

1. 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.

2. Gandini, M.L. and Usunoff, E.J. 2004. SCS Curve Number estimation using remote sensing NDVI in a GIS environment. J. of Environmental Hydrology, 12 (16).

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

4. Michel , C., Vazken, A. and Perrin, C. 2005. Soil Conservation Service Curve Number Method: How to mend a wrong soil moisture accounting procedure. Water Resources Research, 41 (2), 1-6.

5. Mishra, S.K. and Singh, V.P. 1999. Another look at the SCS-CN method. J. of Hydrologic Engineering, ASCE 4(3), 257-264.

6. Mishra, S.K., Jain, M.K., Pandey, R.P., and Singh, V.P., 2005. Catchment area-based evaluation of the AMC-dependent SCS-CN-based rainfall-runoff models. Hydrol. Process., 19(14), 2701-2718.

7. Mishra, S.K., Sahu R.K., Eldho T.I. and Jain, M.K., 2006. An Improved Ia-S Relation Incorporating Antecedent Moisture in SCS-CN Methodology. Water Resources Management, 20, 643–660.

8. Nayak, T.R. and Jaiswal, R.K. 2003. Rainfall-runoff modelling using satellite data and GIS for Bebas river in Madhya Pradesh. IE (I) Journal, 84, 47-50.

9. Nayak, T.R. and Narulkar, S.M. (2011). Effects of land use and land cover changes on water yield in Goi watershed of Narmada basin. J. of Indian Water Resources Society, 31 (1-2): 35-44.

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

11. Ponce, V.M. and Hawkins, R.H. 1996. Runoff curve number: Has it reached maturity? J. Hydrol. Engg. – ASCE, 1(1), 11-19.

12. Sahu, R.K., Mishra, S.K., Eldho, T.I. and Jain, M.K. 2007. An advanced soil moisture accounting procedure for SCS curve number method. Hydrol. Process., 21, 2872-2881.

13. Schneider, L.E. and McCuen, R.H. 2005. Statistical guidelines for curve number generation. J. Irrigation and Drainage Engineering-ASCE, 131(3), 282-290.

14. Soil Conservation Service (1972). Hydrology. Chapter 9, Hydrologic Soil Cover Complex, Section -4, National Engineering Handbook, USDA, Washington, DC.

15. Soil Conservation Service (1986). Urban hydrology for small watersheds. Technical Release 55, U.S. Department of Agriculture, Washington, DC.

16. Soulis, K.X., Valiantzas, J.D., Dercas, N. and Londra, P.A. 2009. Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. Hydrol. Earth Syst. Sci., Vol.13, 605-615.

17. Stuebe, M.M. and Johnston, D.M. 1990. Runoff volume estimation using GIS techniques. Water Resources Bulletin, 26(4), 611-620.

18. 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.

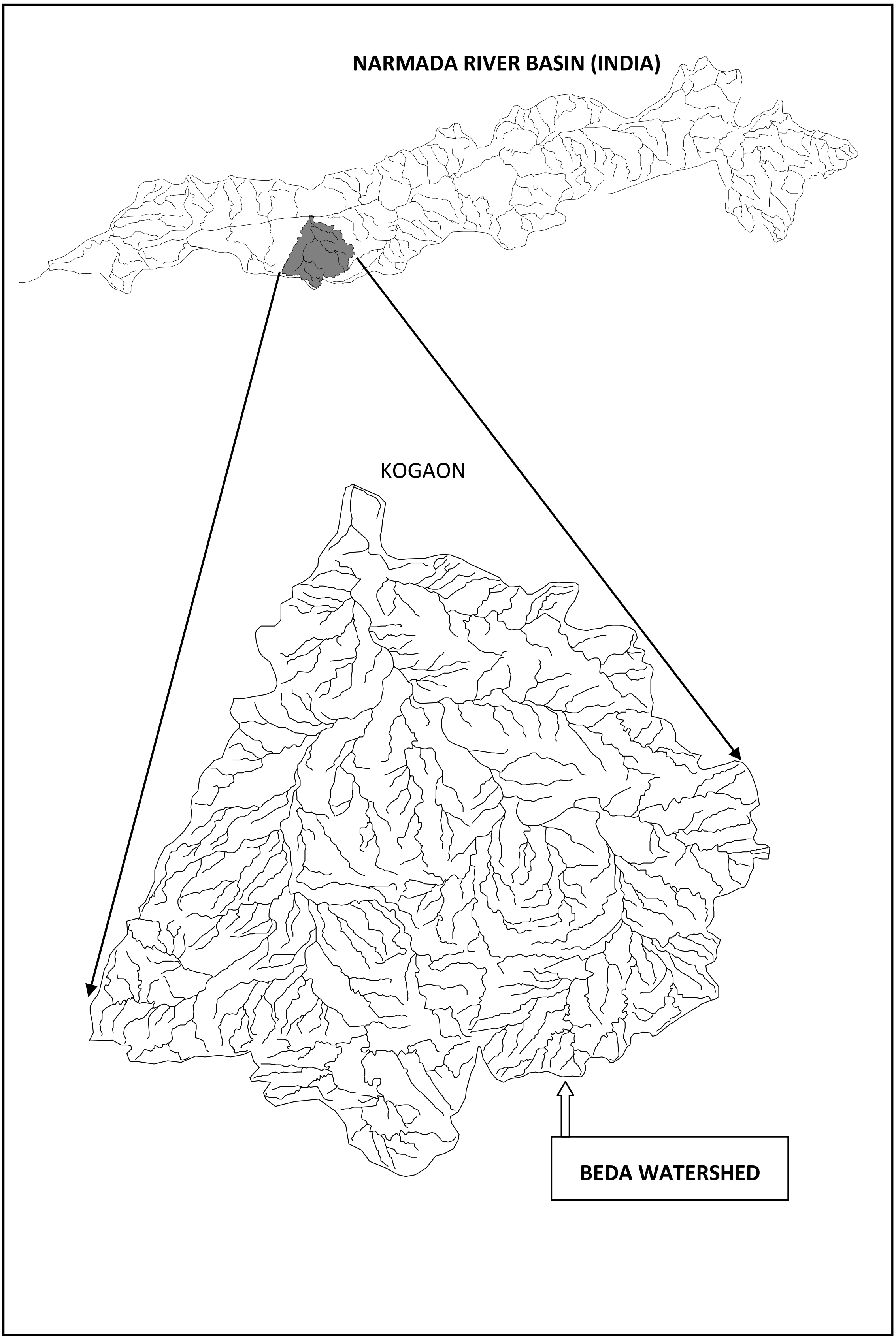

Fig.1: Index Map showing Beda river catchment in Narmada basin.

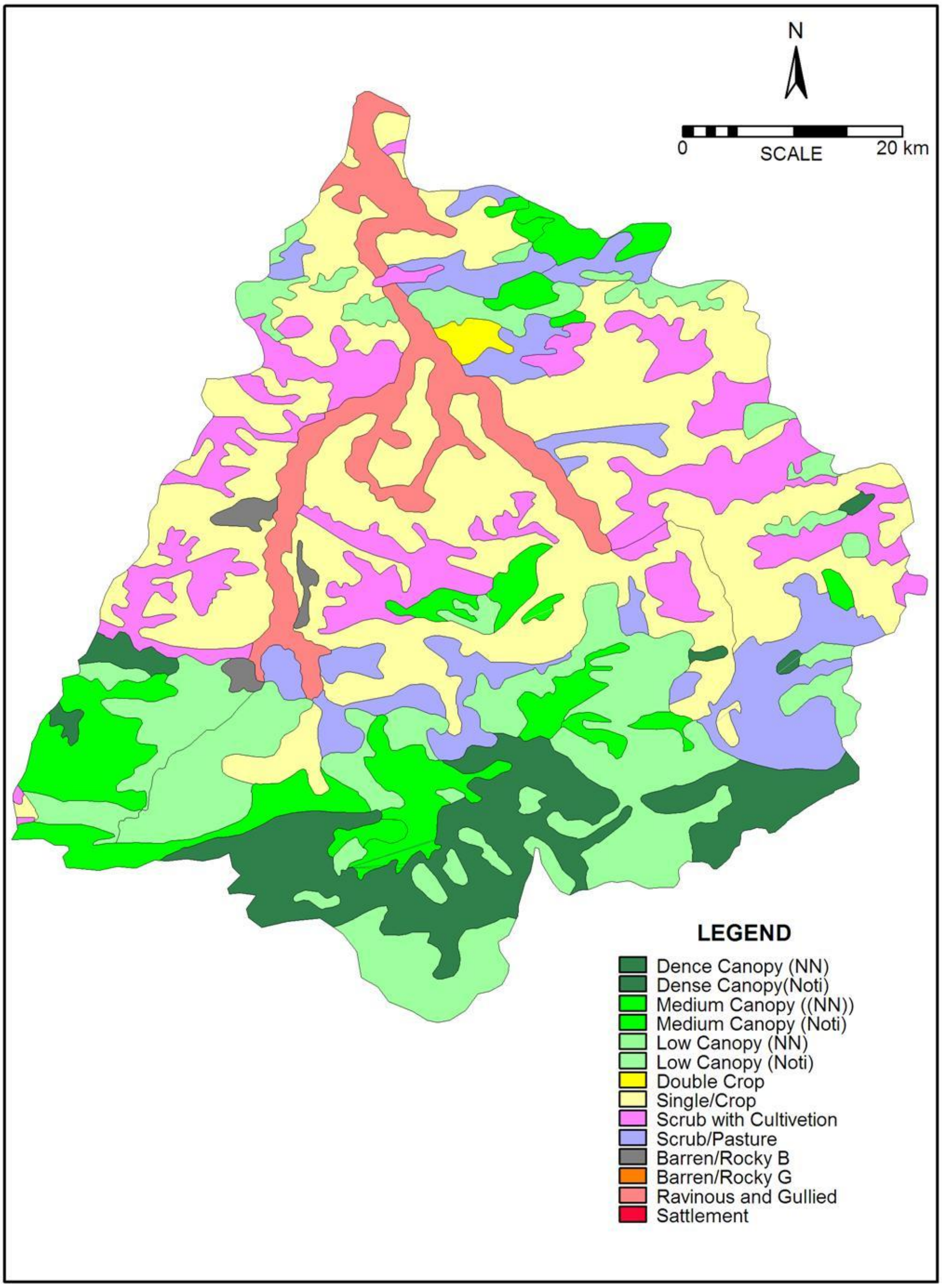

FIG. 2 : LANDUSE OF BEDA RIVER WATERSHED IN 1989

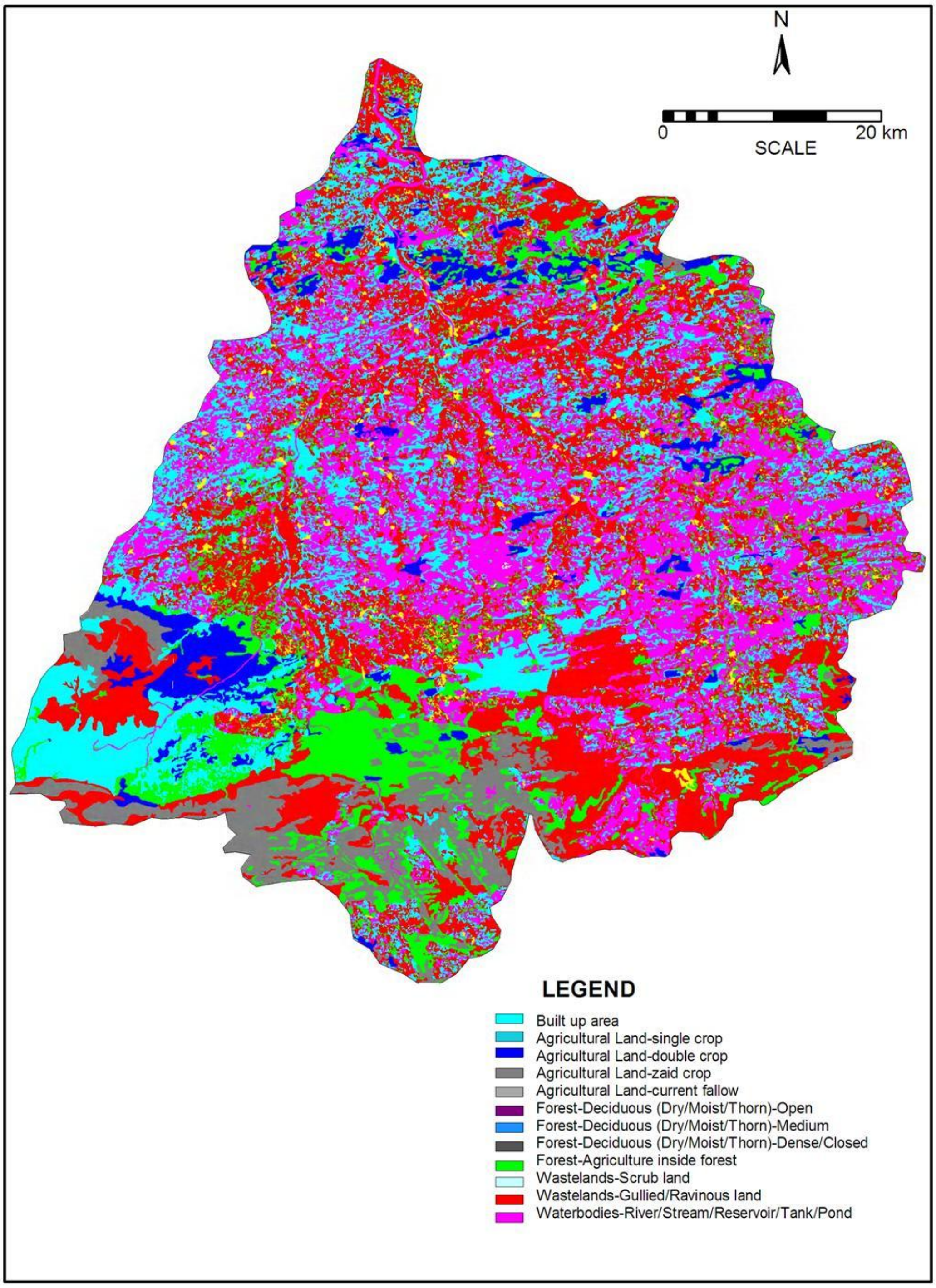

FIG. 3 : LANDUSE OF BEDA RIVER WATERSHED IN YEAR 2007

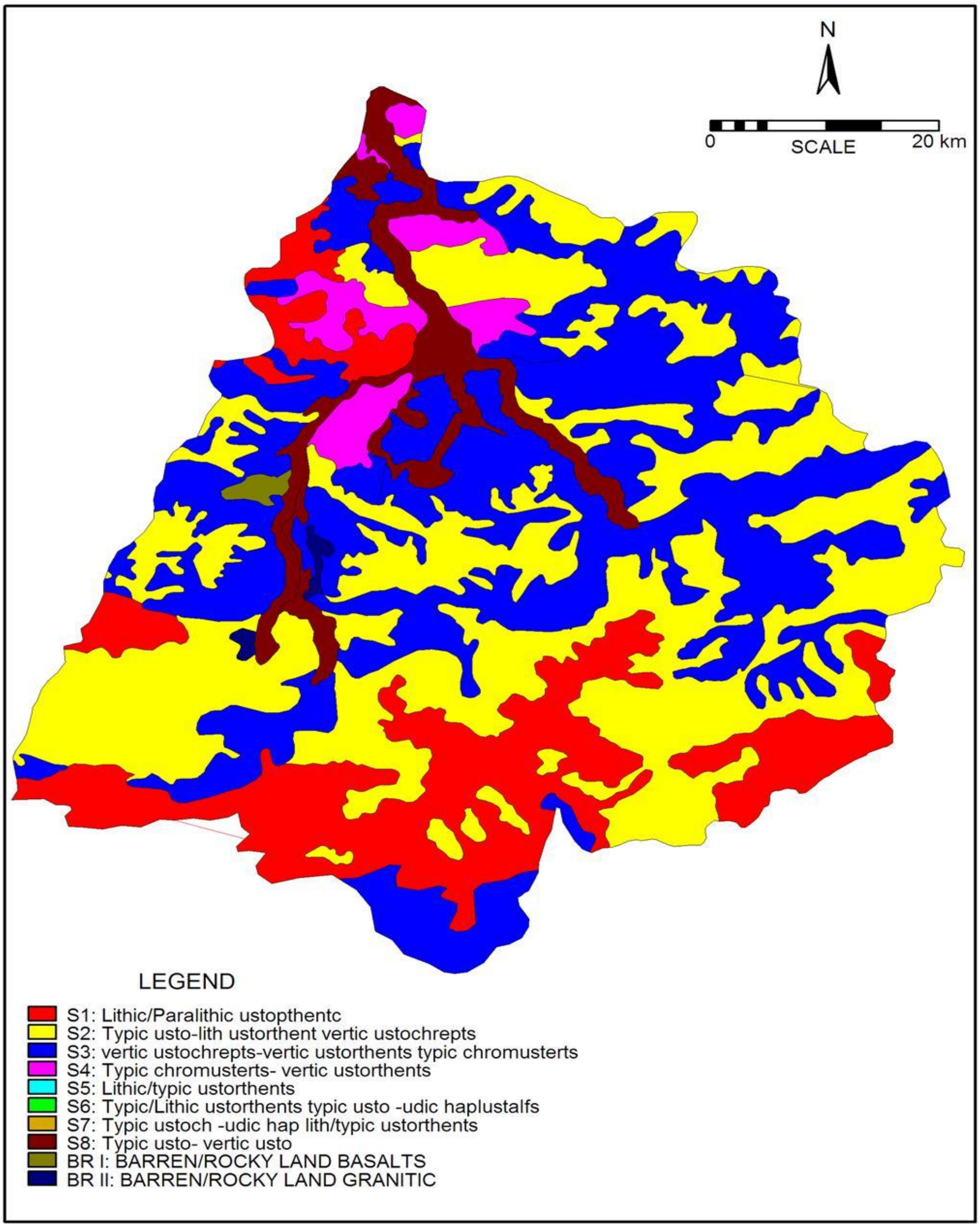

FIG. 4 : SOIL MAP OF BEDA RIVER WATERSHED