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Hydrological impact assessment of SWC measures in Ralegaon Siddhi model watershed

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ABSTRACT

Ralegaon Siddhi watershed is one of the well-known models of watershed management in India. The watershed development programmes (WDPs) via soil and water conservation (SWC) activities have not only enhanced the socio-economic status, but also improved the hydrological regimes of the watershed. Therefore, the present study has been carried out to assess the impact of these SWC activities on hydrological parameters, such as land use, surface runoff and soil loss. The integrated Remote Sensing (RS) and Geographical Information System (GIS) based SCS-CN/GIS and USLE/GIS methodologies were employed for change detection during pre-treatment and post-treatment periods of watershed in land use/land cover (LULC), and further estimation of surface runoff and soil loss. The alteration in land use pattern due to land management activities under Comprehensive Watershed Development Program (COWEDP) has improved the hydrological soil cover complexes of the watershed and resulted into reductions in surface runoff from 45 to 17% and the average rate of soil loss from 8.97 to 2.00 t $ha^{-1}yr^{-1}$. The study depicted the importance of SWC activities in WDP and elucidated the integrated approach of RS and GIS as an impact assessment tool.

1. INTRODUCTION

Prior to watershed development programme (WDP) in India, the efforts for increasing the agricultural production were concentrated on irrigation and improved inputs, such as seeds and chemical fertilizers. Major investments were made in large and medium-scale irrigation projects, which ultimately resulted into water logging and land degradation. According to the estimate given by the National Bureau of Soil Survey and Land Use Planning (NBSSLUP), 96.40% of the land area is affected by various kinds of degradation, out of which 40.60% is severely degraded. The quantity of soil erosion per year in Maharashtra is 773.5 m tons, and 94% of that erosion is water induced. The detrimental effects of soil erosion are reflected in the land's declining productivity. To overcome the negative effects of these large valley projects, it was often being made out that watershed management is the answer to water management and food security problem. Therefore, in the recent trend, watershed management has been recognized as a key strategy for improving the productivity of land in the dry land region of India.

The various soil and water conservation (SWC) measures implemented under the Comprehensive Watershed Development Program (COWEDP) of Govt. of Maharashtra, India at Ralegaon Siddhi watershed have improved not only the socio-economic status, but also the hydrological regimes of the watershed. Now a day, this is a well-known model of watershed development and management throughout the India. To assess the impact of these SWC activities on hydrological parameters like land use/land cover (LULC), surface runoff and soil loss, the present study has been carried out by using the integrated approach of remote sensing (RS) and geographical information system (GIS) techniques. The RS technique provides reliable and accurate information on natural resources, while GIS is a powerful tool for storing, analyzing, and manipulating huge amounts of geographic information for undertaking the integrated resource analysis.

Numerous researchers (Singh *et al.*, 1993; Samant and Subramananyan, 1998; Bisht and Kothyari, 2001; Jayakumar and Arockiasamy, 2003) in the past have utilized RS technique to prepare LULC map and change detection based on digital interpretation of satellite image. Changing land use pattern in a watershed affects to the surface runoff and rate of soil erosion. For estimating the surface runoff, there are numerous models existed in literature; among these, the United State Department of Agriculture (USDA) Soil Conservation Service (SCS) method is now the most commonly used runoff estimation method in India. Even though, the method is primarily developed for agricultural watersheds of United States, it is modified by Central Unit for Soil Conservation, Soil Conservation Division, Ministry of Agriculture, Govt. of India (Anonymous, 1982) to suit Indian conditions. In the past, Ragan and Jackson (1980) attempted to generate SCS curve number (CN) using a raster GIS. Similar efforts have been made by many researchers (Durbude *et al.*, 2001; Tripathi *et al.*, 2002; Nayak *et al.*, 2003, Pandey and Dabral, 2004; Crooks and Naden, 2007; Bhadra *et al.*, 2009; Pradhan *et al.*, 2010, *etc.)* to validate and applied the SCS-CN/GIS methodology for LULC map preparation.

For soil loss estimation, Universal Soil Loss Equation/GIS (USLE/GIS) methodology permits calculation of potential soil loss from sheet and rill erosion. The procedure utilizes the capabilities of map analysis and processing system to overlay data themes containing spatially distributed values for different USLE factors. The resultant soil erosion potential map can be used in various ways for further erosion modeling by recreating it again with some of the factors changed to simulate different conditions, such as seasonal change, change in precipitation, vegetation cover, terrain, and management practices. The USLE/GIS methodology was also validated by most of the researchers in India (Jain and Kothiyari, 2000; Chandramohan and Durbude, 2002; Chakraborty *et al.*, 2004; Ismail and Ravichandran, 2006; Pandey *et al.*, 2007; Dabral *et al.*, 2008; Kalgapurkar *et al.*, 2012) and recommended its use for effective and accurate estimation of soil loss.

Therefore, in the present study, an effort has been made to employ SCS-CN/GIS and USLE/GIS methodologies for estimation of surface runoff and soil loss from Ralegaon Siddhi watershed and impact of SWC activities under WDP on various hydrological parameters.

2. MATERIALS AND METHODS

Study Area

The study watershed (Ralegaon Siddhi) is a part of Dudh nadi watershed in Parner taluka of Ahmednagar district of Maharashtra state, India and lying between $18^0$54' N to $18^0$57' N and longitudes of $74^0$23' E to $74^0$27' E (Fig. 1). The total geographical area of the watershed is 1070.52 ha. Physiographically, the area is surrounded by small hillocks with fractured rocks. The meteorological data pertaining to rainfall and temperature were collected from the observatory established at Parner taluka headquarter. The rainfall is scanty and irregular and frequently results into drought. The average annual rainfall of the region is 601 mm, while the temperature ranges between 12 to 44^0C. The agriculture is predominant along with Jowar, Groundnut and Maize as major growing crops in the area. Three types of soil textures namely; gravelly sand, sandy loam and sandy clay loam are identified in the area with sandy clay loam as a dominant soil texture. Depth of the soil ranges from 10 to 45 cm. The hilly portion (high relief) of the watershed is containing a shallow depth of kankars, while the valleys have soil depth of nearly 45 cm. As per the land capability criteria, the land of watershed can be categorized under three types of land capability classes. Almost, 44% of the land is under land capability class VI, while land capability class III covers 24% and class IV covers 32% of watershed area.

Generation of Spatial Database

The clouds free Indian Remote Sensing Linear Imaging Self Scanning (IRS LISS) satellite images of Ralegaon

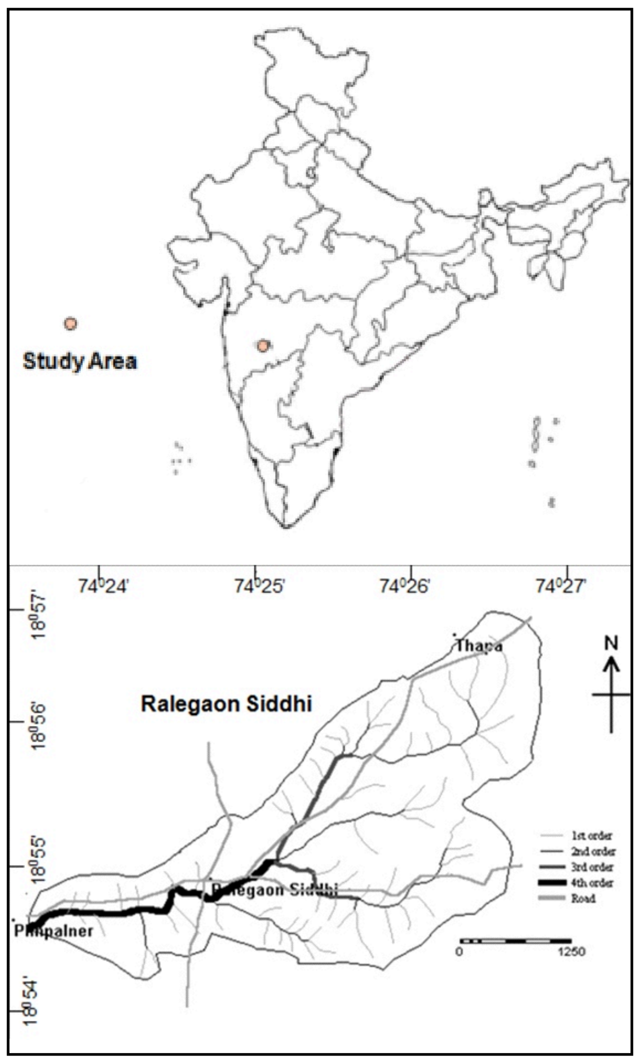

Fig. 1. Location of the study area

Siddhi watershed, Maharashtra pertaining to various acquisition dates as given in Table 1 in four spectral bands procured from National Remote Sensing Centre (NRSC, Hyderabad) were used for the preparation of temporal land use/cover maps during pre-treatment and post-treatment periods of watershed development activities. These images were first rectified with Survey of India (SoI) topographical map (47 J/5) of the study area after matching some of the identifiable features like crossing of roads, railways, canals, bridges *etc.,* on both the base maps as well as on the satellite images using GIS software namely, Integrated Land and Water Information System (ILWIS) raster data GIS. A second order polynomial model was generated and care was taken to keep the RMS error less than a half pixel. By using the topographical information derived from toposheet, Digital Elevation Model (DEM) was generated, which was used for creating L factor and S factor (LS factor) GIS layers of USLE/GIS soil loss equation method. For the classification of RS data, Maximum Likelihood Classifier (MLC) which is a parametric decision rule and well developed method from statistical decision theory has been applied to classify RS image for the preparation of LULC map. The LULC map thus generated for pre-treatment and post-treatment periods were helped for computation of CN in SCS-CN/GIS runoff estimation model and C factor and P factor GIS layers used in USLE/GIS soil loss estimation model. All these maps were encoded as GIS layers and standardized for integrated analysis under GIS environment. All encoded digital data and coverage in the GIS were spatially organized with the same resolution and co-ordinate system.

The extensive field survey has been conducted to collect soil samples from various locations throughout the entire watershed area and analyzed in the laboratory for textural classification. The infiltration tests were carried out at several sites in various LULC and soil type combinations using Guelph and Disc permeameter. The soil textural information and the infiltration rate data were used for the hydrological soil grouping (HSG) as shown in Fig. 2, which was used for the estimation of soil erodibility K factor used in USLE/GIS erosion model.

Surface Runoff and Soil Loss Estimation

The USDA SCS-CN runoff estimation and USLE soil loss estimation models can be coupled to link rainfall-runoff-erosion model. As stated above, the integrated remote sensing and GIS based SCS-CN/GIS and USLE/GIS methodologies were employed for estimation of surface runoff and soil loss during pre-treatment and post-treatment periods. The SCS-CN method, which is now known as Natural Resources Conservation Service (NRCS) method (USDA, 1990) is an empirical method derived from studies on the subject of rainfall-runoff relationships from the small watersheds in the United States. It was designed to predict direct (surface) runoff, as infiltration-excess overland flow.

The expression used for this method is as follows:

$$Q = \frac{(P\text{-}0.3S)^2}{(P+0.7S)} \qquad ...(1)$$

Where, Q is the runoff volume uniformly distributed over the drainage basin; P is the mean precipitation over the drainage basin; and S is potential maximum retention or watershed storage index.

The watershed storage index S, is conveniently expressed in terms of a dimensionless index, runoff curve number as:

$$CN = \frac{25400}{(254+S)} \qquad ...(2)$$

Evidently, this is a one-parameter model with S or CN as the parameter. This parameter depends upon characteristics of the soil-vegetation-land use (SVL) complex and antecedent soil moisture condition on a watershed. Curve numbers are dimensionless, and can vary from 0 (no runoff) to 100 (all rainfall becomes runoff). The details of SCS-CN runoff estimation method can be found in literature (SCS, 2004).

The USLE erosion model, which is designed to predict the long-term average field soil losses under specified conditions, was used for estimating the soil loss. The USLE

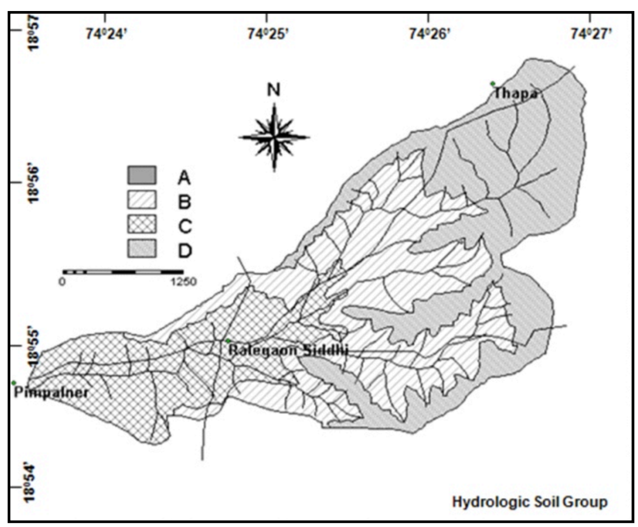

Fig. 2. Hydrological soil group

Table: 1
Specification details of the IRS satellite data

Sl. No.	Date of Satellite Pass	Path/Row	Satellites/Sensors	Bands	Remarks
1.	19 January 1989	29/55	IRS 1B/LISS II- A1	1,2,3,4	Pre-treatment
2.	8 February 2001	95/59	IRS 1D/LISS III	2,3,4,5	Post-treatment

as described by Wischmeier and Smith (1978) is given by;

$$A = RKLSCP \quad ...(3)$$

Where, A is the computed soil loss per unit area, usually in t $ha^{-1}yr^{-1}$; R is the rainfall erosivity factor, the number of rainfall erosion index (EI) units, plus a factor for runoff from snowmelt or applied water, where such runoff is significant; K is the soil erodibility factor, the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 22 m length of uniform 9% slope in continuously clean-tilled fallow; L is the slope length factor, the ratio of soil loss from the field slope length to that from a 22 m length under identical conditions; S is the slope steepness factor, the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions; C is the cover and management factor, the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow; and P is the support practice factor, the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight row farming up and down the slope. The details of USLE are described by Wischmeier and Smith (1978).

3. RESULTS AND DISCUSSION

Various thematic layers *viz.,* contour map, slope map, soil texture and LULC map were integrated under GIS environment using a set of logical conditions for computing surface runoff and soil loss from the study area. The satellite images along with ancillary data were digitally analysed under GIS environment to assess the impact of SWC activities implemented under WDP in Ralegaon Siddhi watershed on the various hydrological parameters as described below:

Land Use/Land Cover (LULC)

As stated in the methods, using MLC decision rule the LULC maps were prepared during pre-treatment and post-treatment periods as shown in Fig. 3. The spatio-temporal changes in five major LULC classes identified in the study watershed have been computed as presented in Table 2. Agricultural land is identified as a major land use in the watershed inferred the study area as agriculture watershed. The developmental activities through employment guarantee scheme (EGS) and COWDEP launched by Government of Maharashtra, India stopped the flood of people migration to urban areas, which ultimately results into expansion of rural settlement by 0.20%. Before WDP, the cultivation was mainly confined in depressions, along gentle slopes and streamlines as well as wherever the water resources and edaphic conditions are favourable. But, SWC activities under WDP especially, terracing, contour trenching and nala bunding encourage farmers to cultivate on the moderate slopes also. Hence, the agricultural land was increased from 692.20 to 788.25 ha (8.97%). The pasture land activities under this programme gets converted the barren/waste land into the grassland. The availability of water by creating check dams and tanks within watershed area promoted the farmers to cultivate even the small hillocks by cutting and leveling them into terrace farming.

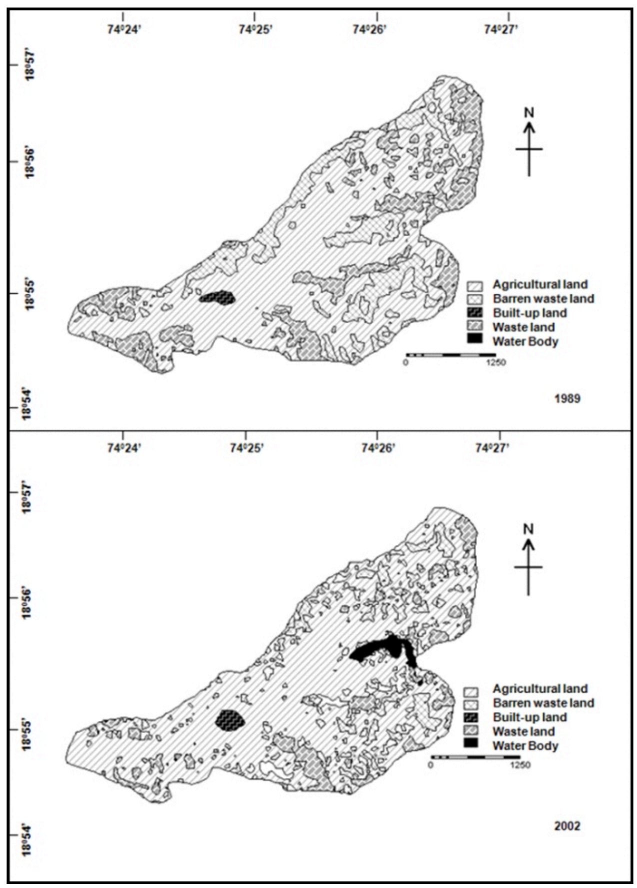

Fig. 3. Land use/land cover (LULC) map

Table: 2
Changes in major LULC classes in the study area

Sl. No.	LULC classes	Spatial and temporal distribution				Change in LULC classes	
		Pre-treatment		Post-treatment		(ha)	(%)
		(ha)	(%)	(ha)	(%)		
1.	Agricultural land	692.20	64.66	788.25	73.63	96.05	8.97
2.	Built-up land	6.16	0.58	8.29	0.77	2.13	0.20
3.	Waste land	196.60	18.36	165.04	15.42	-31.56	-2.95
4.	Barren land	175.56	16.40	91.28	8.53	-84.28	-7.87
5.	Water body	0.00	0.00	17.66	1.65	17.66	1.65

Surface Runoff

The daily rainfall distribution and the average annual rainfall during the pre-treatment and post-treatment were used for the estimation of surface runoff by using USDA SCS-CN/GIS model. The various GIS layers such as LULC, HSG and AMC were generated by processing the RS image under GIS environment. The values of CN were computed for various combinations of soil texture and LULC related attributes termed as hydrological soil cover complexes during pre-treatment and post-treatment periods as presented in Table 3. The composite CN for the entire watershed were also computed and presented in Table 4. It can be inferred from the table that the CN increased from hydrologic soil group B to D for all AMC groups. However, due to lower wetness condition of AMC I, lower CN values as compared to AMC II and AMC III were obtained. The result depicted that there is substantial reduction in CN from 82 to 77 for the AMC II, which ultimately affects the reduction in surface runoff from 54% to 16% (Table 5). The improvement in management activities *viz.,* Alteration in LULC, adaptation of improved agronomic practices, affects the overall CN of the watershed and further surface runoff.

Soil Loss

As stated earlier, USLE/GIS methodology has been employed for estimating soil loss due to erosion process in the watershed. The various GIS layers of R, K, L, S and CP factors of USLE/GIS soil loss model generated by using attributes of rainfall, soil texture, digital elevation model (DEM), LULC were computed for pre-treatment and post-treatment periods. The minimum, maximum and weighted average values of these parameters are given in Table 6. All the GIS layers related to USLE then combined together and

Table: 3
Curve numbers for various hydrologic soil cover complexes (AMC II)

Sl. No.	LULC classes	Hydrologic Cover Condition	Area (ha)	HSG	CN	Wt. CN
Pre-treatment						
A.	Agricultural land					81
1.	Small grains straight row	Good	196.72	B	75	
2.	Fallow straight row		280.72	B	86	
3.	Small grains terraced	Poor	218.76	C	79	
B.	Built-up land (dirt)		6.16	C	87	87
C.	Waste land					87
1.	Farmsteads		45.92	C	82	
2.	Pasture or range	Poor	28.52	C	86	
3.	Pasture or range	Poor	122.12	D	89	
D.	Barren land					80
1.	Farmsteads		13.84	C	82	
2.	Woodlands	Poor	87.40	C	77	
3.	Woodlands	Poor	70.84	D	83	
Post- treatment						
A.	Agricultural land					76
1.	Row crops straight row	Good	224.68	B	78	
2.	Close seeded legumes	Poor	322.36	B	72	
3.	Straight row	Poor	239.56	C	79	
4.	Small grain terraced		8.44	C	90	
B.	Built-up land (hard surface)					90
C.	Waste land					80
1.	Meadow (Permanent)	Good	22.16	C	71	
2.	Meadow	Poor	6.24	C	77	
3.	Meadow	Poor	71.12	D	83	
D.	Barren land					76
1.	Farmsteads		4.36	C	82	
2.	Woodlands (farm woodlots)	Fair	34.48	C	73	
3.	Woodlands	Good	55.20	D	77	
E.	Grass land					82
1.	Pasture or range	Good	3.80	D	80	
2.	Pasture or range	Good	29.88	D	80	
3.	Pasture or range	Fair	31.04	D	84	

Table: 4
Composite curve number (CN) for various AMC conditions

Sl. No.	Year	Composite CN		
		AMC I	AMC II	AMC III
1.	Pre- treatment	66	82	92
2.	Post-treatment	59	77	89

Table: 5
Estimated surface runoff during pre-treatment and post-treatment periods

Sl. No.	Particulars	Annual rainfall (mm)	Annual surface runoff (mm)	Runoff coefficient
1.	Pre- treatment	587.80	316.36	0.54
2.	Post-treatment	330.00	54.17	0.16

computed rate of soil loss and total soil loss from the study watershed. As such, the rain erosivity (R factor), soil erodibility (K factor), and the slope factor (LS factor) of USLE can be considered as naturally occurring factors determining the potential soil loss due to sheet and rill erosion processes (without considering management factors). There is no much influence of WDP activity on these factors, while the management factor (CP factor) plays a major role in the actual soil loss. The actual rate of soil loss and total soil loss were estimated as given Table 7. In ILWIS GIS terms, the multiplication of the maps of R-factor, K-factor, LS-factor, and CP factors together used to generate a map of RKLSCP represents the rate of soil loss and total soil loss, while the changes in rate of soil loss and total soil loss during the pre-treatment and post-treatment period represent the impact of SWC activities on soil erosion process in the watershed.

The storage created by constructing the storage structures within the watershed area and conversion of waste land into agriculture land under WDP slow down the soil detachment process and further reduces soil transportation from watershed area and minimize the soil loss. The erosion potential of the watershed (KLSCP) is reduced by three times from 0.03 to 0.01, while the rate of soil loss and total soil loss are also reduced from 8.97 to 2 t $ha^{-1}yr^{-1}$ and 9605 to 2139 t yr^{-1}, respectively. The spatial distribution of rate of soil loss within watershed area during pre-treatment and post-treatment periods is also mapped as shown in Fig. 4. By comparing both the maps, the cause of the reduction in rate of erosion due to management strategy could be clearly understood. For clear understanding, the effect of management activities on soil erosion process, the average rate of soil loss from each category of LULC is also computed and presented in Table 8. It is found that the rate of soil loss from the barren and waste land was tremendously affected as compared to other land uses/land covers.

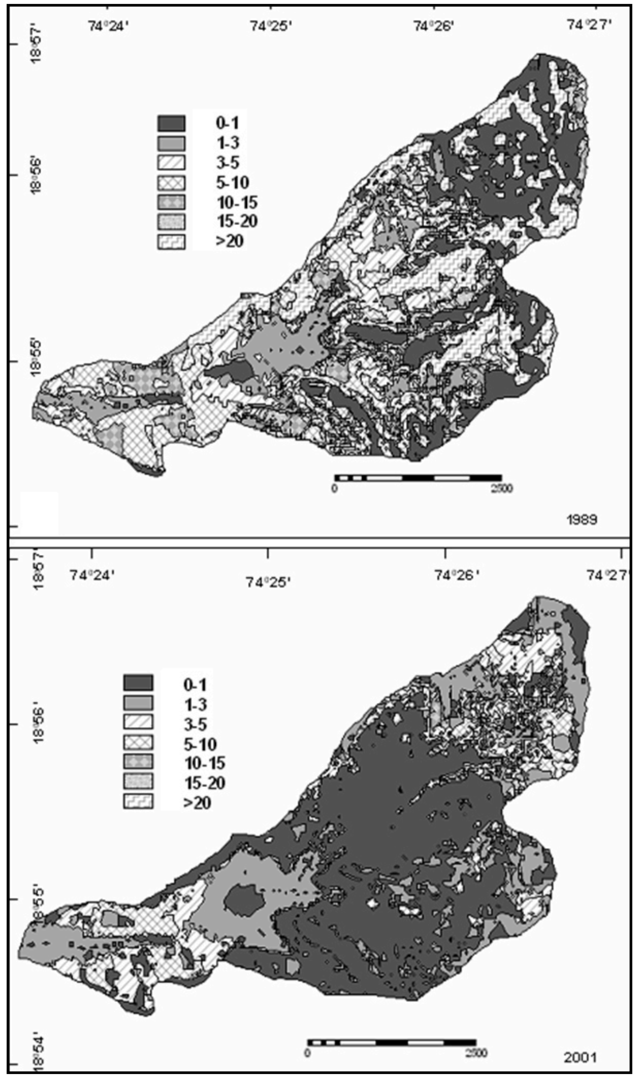

Fig. 4. Spatio-temporal distribution of rate of soil loss

Table: 6
Estimated average value of the USLE parameters

Sl.No.	USLE Parameters	Estimated Values of USLE Parameters					
		Pre-treatment			Post-treatment		
		Min.	Max.	Wt. Avg.	Min.	Max.	Wt. Avg.
1.	R factor	263.20	295.40	283.20	165.55	203.70	189.20
2.	K factor	0.02	0.19	0.08	0.02	0.19	0.08
3.	LS factor	0.04	3.85	2.20	0.04	9.62	2.20
4.	C factor	0.10	0.45	0.30	0.035	1.00	0.30
5.	P factor	0.10	1.00	0.60	0.10	1.00	0.20

Table: 7
Estimated soil loss during pre- and post-treatment periods

Sl.No.	Soil loss estimates	Years	
		Pre-treatment	Post-treatment
1.	Potential Erosion (RKLS) in t $ha^{-1}yr^{-1}$	49.84	33.30
2.	Rate of Soil Loss (RKLSCP) in t $ha^{-1}yr^{-1}$	8.97	2.00
3.	Total Soil Loss in t yr^{-1}	9605	2139

Table: 8
Estimated rate of soil loss from various LULC classes

Sl.No.	LULC class	Rate of soil loss (t $ha^{-1}yr^{-1}$)	
		Pre-treatment	Post-treatment
1.	Built-up land	0.003	0.001
2.	Agricultural land	3.597	2.200
3.	Barren waste land	11.214	3.927
4.	Waste land	5.843	0.881

4. CONCLUSIONS

The present study elucidated the integrated approach of RS and GIS to assess the impact on hydrological parameters due to SWC activities implemented in Ralegaon Siddhi watershed. The SCS-CN/GIS and USLE/GIS methodologies were employed on the procured IRS LISS satellite image to assess the temporal and spatial changes in the hydrological parameters, *i.e.,* surface runoff and soil loss from the watershed. Five major LULC classes were identified namely, agricultural land, built-up land, waste land with or without scrub, barren stony waste land and water body. The land management activities by adopting various SWC measures under watershed development programme greatly affect in reducing the surface runoff from 45 to 17%, the rate of soil loss from 8.97 to 2 t $ha^{-1}yr^{-1}$ and total soil loss from 9605 to 2139 t yr^{-1}. Thus, it can be inferred from this study that land management activities under WDP would help to minimize the runoff and soil loss which ultimately help to recharge the groundwater regime of the area and subsequently improve socio-economic condition.

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