MODELING APPROACH IN SOIL EROSION RISK ASSESSMENT AND CONSERVATION PLANNING IN HILLY WATERSHED USING REMOTE SENSING AND GIS

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KEY WORDS: Remote Sensing, GIS, Watershed, Erosion modelling, Land capability, Shiwalik hills, Piedmont plain.

ABSTRACT:

The present study was employed within Geographic Information System (GIS) environment to predict erosion risk following semi-empirical Morgan, Morgan & Finney (MMF) model. The digital elevation map (DEM) derived from SRTM was used as the base for topographic- related analyses in the model. The soil, land use, and other related input parameters of the model were derived using remote sensing data. In the watershed, 36.9 percent of area is under agriculture whereas 35.7 per cent areas covered with forest. The croplands were predicted to the average soil loss of 10.5 to 21.1 t/ha/yr whereas in Shiwalik hills it ranges from 25.3 to 44.32 t/ha/yr. Area under soil erosion risk with moderate, high and very high was estimated to 33.4 %, 26.0 % and 2.92 %, respectively. The erosion risk assessment was used as input to assess the land capability in the watershed. Shiwalik hills were assessed to land capability class of VI, VII and VIII whereas most of the piedmont plains were assessed to land capability class III. Spatial distribution map suggesting appropriate conservation measures was generated to prevent the soil erosion and further degradation of land.

1. INTRODUCTION

Soil erosion by water is the most important land degradation problem world wide (Eswaran et al., 2001). Land degradation from water-induced soil erosion is a serious problem in the Shiwalik hills known as northwestern foothill of the Himalayas. Fragile rocks and good relief make it unstable and highly prone to erosion (Singh et al., 1992; Sastry and Sharma, 2001). Erosion from productive croplands decreases soil quality, diminishes on-site land value, and causes off-site environmental damage. To protect the land from further degradation and make the mitigation measures effective, it is essential to know the spatial distribution of the areas susceptible to degradation and to assess erosions hazard severity. The combined use of Remote Sensing, GIS and erosion models have been shown to be an effective approach for estimating the severity and spatial distribution of erosion. Models predict soil erosion rates under different soil resources and land use conditions for soil conservation planning.

Soil erosion modelling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Most of these models need information related with soil type, landuse, landform, climate and topography to estimate soil loss. The models are designed for specific set of conditions of particular area. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is an empirical model assessing long term averages of sheet and rill erosion. The USLE and its modified version such as MUSLE (Williams, 1975) and RUSLE (Renard et al., 1997) have been widely used to various scale and regions. Morgan, Morgan and Finney model (Morgan *et al*., 1984) a semi-empirical model having strong physical base used to assess soil loss. Recently, many process-based such as Water Erosion Prediction Project (WEPP : Nearing, 1989), Agricultural-Non-Point-Source Pollution (AGNPS : Young et al. 1989) and Areal Nonpoint Source Watershed Environment Simulation model (ANWERS : Beasley, et al., 1980) have become available for predicting soil erosion. Because of the fact that most process-based erosion prediction models, in general, are not well tested and require many input parameters, the empirical erosion prediction models continue to play an important role in soil conservation planning. The soil loss estimation employing these models indicates the severity of soil erosion under the present land use practices. In the present study, Morgan, Morgan & Finney (MMF) model, was employed within Geographic Information System (GIS) environment to predict erosion risk and used to assess land capability in the watershed for soil conservation planning.

2. MATERIAL AND METHODS

2.1 Brief model description

Morgan, Morgan and Finney (Morgan *et al*., 1984) model developed to predict annual soil loss from field sized areas on hillslopes was used in the present study. The model separates the soil erosion process into a water phase and a sediment phase.

In the water phase, rainfall energy was computed by:

$$E = R\,(11.9 + 8.7 \log_{10} I) \qquad (1)$$

Where, E is kinetic energy of rainfall (J m^{-2}), R is the annual rainfall (mm) and I is the Typical value for intensity of erosive rain (mm h^{-1}) as 25 mm h^{-1} suggested by Morgan *et al.* (1984) for tropical climate.

The overland flow was estimated by:

$$Q = R * e^{(-Rc/ Ro)} \quad (2)$$

Where, Q is the annual volume of overland flow (mm), R is the annual rain (mm), R_c is soil moisture storage capacity under land cover (mm) and R_o is mean rain per day (mm).

The soil moisture storage capacity is computed considering soil moisture content at field capacity (MS), bulk density (BD), rooting depth (RD) and the ratio of actual to potential evapotranspiration (Et/Eo), as follows:

$$R_C = 1000 * MS * BD * RD (E_t / E_0)^{0.5} \quad (3)$$

Mean rain per rainy day (R_o) is calculated by dividing the average annual rain (R) by the number of rainy days (R_n) in a year.

In the sediment phase, soil detachment by rainfall *F* (kg m^{-2}*)* is based upon empirical relationship between rainfall energy *E*, soil detachability index *K* (kg kJ^{-1}) and percentage of rainfall interception by vegetation cover *A*.

$$F = 0.001 \times K (E \times \exp^{-0.05 \times A}) \quad (4)$$

The distributed transport capacity map G was estimated by:

$$G = 0.001 \times C\, Q^2 \sin S \quad (5)$$

Where, G is the transport capacity of overland flow (kg m^{-2}), C is the crop cover management factor, Q is overland flow volume (mm) and sin S is the sine of the slope gradient. The transport capacity of overland flow (G) is compared with the soil detachment (F) and the lower of the two is taken as the annual rate of soil loss.

2.2 Study area

The present study was taken in Saharanpur district of Uttar Pradesh, India. The watershed (Nawagaon and Maskara Rao) lies between longitude of 77^o 34' to 77^o 51' E and latitude of 30^o 09' 00" N to 30^o 21' N covering an area of 205.95 Sq. Km. The watershed is elongated in shape with a perimeter and area of 79.44 Km. Geomorphologically, the watershed comprises of south of Shiwalk hills and piedmont plains. Geology of Shiwalik mainly contain conglomerates consisting of quartzite, granite and phyllite boulders and pebbles. The watershed was devided into 11 sub watershed for soil conservation planning. The study area belongs to sub-tropical semi-arid climate. The average annual rainfall is about 1170 mm and average rainy days is about 72 days. The rainfall received during the months of July to September is due to South-west monsoon. The mean temperature ranges from 15.1 ^oC in winters to 29.4 ^oC in summers.

2.3 Data preparation

Land use /land cover map was generated using digital satellite data of Resourcesat LISS IV of spatial resolution of 5.8 m acquired on 28^{th} January 2005. Land cover map (Figure 1) showed 36.9 percent of area is under cropland whereas moderate dense and moderate forest comprises of 19.3, and 16.4 percent area, respectively. Dense scrub and open scrub / barren accounts 0.8 and 3.3 percent respectively of the total area. Sugarcane, wheat, ground nut and maize are the major crops are grown in the area. The values of parameters A, E_t / E_0, RD and C for different land cover types were taken as suggested by Morgan et al. (1994) and Narain *et al*. (1994).

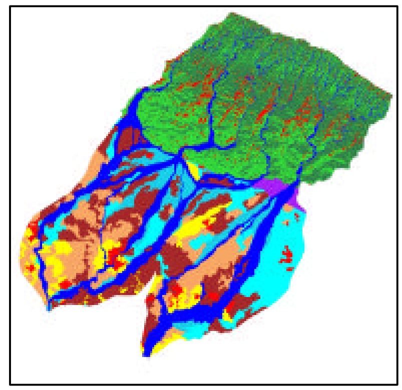

Figure 1. Land use / land cover map

Physiographic-soil map was prepared on scale of 1:50,000. Eighteen physiographic – soil units were delineated. Reconnaissance soil survey was carried out and soil samples were collected and analyzed for soil organic carbon and soil texture. Soil erodibility index (K) of surface soil was computed, using the USLE soil erodibility nomograph based equation (Wischmeier and Smith, 1978). These soils are sandy loam to loam in texture. Soil moisture at field capacity (MS) and bulk density (BD) were taken from standard table (Morgan *et al*. 1984). Physiographic soil map was digitized to prepare polygon map and then rasterized generated soil attribute maps for the model.

A digital elevation model (DEM) was generated by digitizing contour lines at 20 m intervals. The SRTM DEM was also used. DEM was used to prepare slope gradient map. It revealed that 13.3 per cent area lies in nearly level (0-2 %), 42.1 per cent under undulating (2-6 %), 10.4 per cent under rolling (6-16 %), 11.4 per cent under hilly (16-25 %), 14.4 per cent under steep (25-40 %), 6.7 per cent under very steep (40-60 %) and 1.7 per cent under extremely steep (>60 %) slope classes (Wischmeier & Smith, 1978).

Parameters R and Rn were calculated from the daily rainfall data obtained for the year 1988 – 2004 from State Soil Conservation Training Centre at Muzzafrabad in Saharanpur District, Uttar Pradesh. The rainfall energy (E) was computed using equation 1.

2.4 Running the model in GIS

Soil parameters (K, MS and BD) and land cover parameters (C, Et/E_o, RD and A) were stored in attribute tables associated with soil and land cover maps, respectively. Soil and land cover maps were reclassified with the attributes (parameters) to generate soil and land cover parameter maps. These maps were integrated in GIS environment. In water phase, R_c map was generated with integration of parameter maps (MS, BD, RD and E_t/E_0) using equation 3. Then overland flow (Q) map was generated using equation 2. In sediment phase, prediction of detachment by rainsplash (F) and the transport capacity of the runoff (G) were computed with integration of input parameter maps using equation 4 and 5, respectively. The prediction of detachment is compared with transport capacity of the runoff for each pixel and the lower of the two values is considered as limiting factor for soil erosion rate and the same value is assigned to that pixel (Fig. 1). Finally, the composite map of annual rate of soil loss is derived for the watershed. The predicted soil erosion potential map was classified into erosion hazard risk classes and sub-watersheds were prioritized based on the area falls under various erosion risk classes by computing weighted area index.

The land capability map was generated in GIS by integrating soil physical characteristics, predicted erosion hazard risk and slope map derived from digital elevation model (DEM). Thereafter, Land capability, erosion severity and land cover maps were spatially integrated following knowledge matrix to suggest soil conservation measures in the watershed.

3. RESULTS AND DISCUSSION

The predicted annual rate of soil loss was classified into five erosion risk classes (Figure 2) to assess erosion severity. It revealed that 11.07 per cent area lies in very low risk of erosion (0 – 5 t/h/yr), 5.75 per cent under low risk of erosion (5 – 10 t/h/yr), 33.41 per cent under moderate risk of erosion (10 – 25 t/h/yr) of erosion. The proportion of area with high risk of erosion (25 - 50 t/h/yr) and very high risk of erosion (>50 t/h/yr) are 26 and 2.92 percent respectively.

Among the various land use / land cover, the average soil loss was predicted higher in open scrub/ barren lands and lowest in the orchard land use. The forest cover in the Shiwalik hills was predicted to average soil loss of 25.59 t/ha/yr in the moderated to open forest and 13.20 t/ha/yr in moderately dense forest cover. The croplands cultivated for maize, groundnut and wheat (low vigour) crops were predicted to the average soil loss of 21.1 t/ha/yr whereas cropland under wheat (high vigor), sugarcane and mustard crops to average soil loss of 10.5 t/ha/yr.

The Shiwalik hills experience high rate of soil erosion in the watershed although being under forest cover due to its soil type and terrain conditions. The average soil loss in Shiwalik hills ranges from 25.3 to 44.32 t/ha/yr. The average soil loss was estimated higher in upper piedmont then the lower piedmont plain. The flood plain along the river course showed erosion rate of 21.86 t/ha/yr. It is evident by observing the extension of river course on temporal satellite data. In the alluvial plains, upper alluvial was found with moderated risk of erosion whereas lower alluvial plain with low risk of erosion.

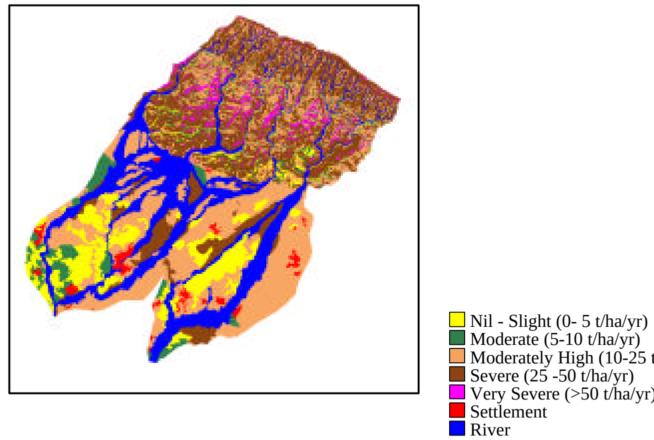

Figure 2. Soil erosion risk map

Land capability classification used to classify the land based on their capability to support various types of land use and as a tool to suggest conservation measures to prevent the soil erosion. Land capability potential assessment (Figure 3) in the watershed showed that 34.2 per cent area falls in the capability class suited for forest cover whereas 44.8 per cent is suited for cropland and of which 82.6 percent have severe to very severe limitation for cultivation.

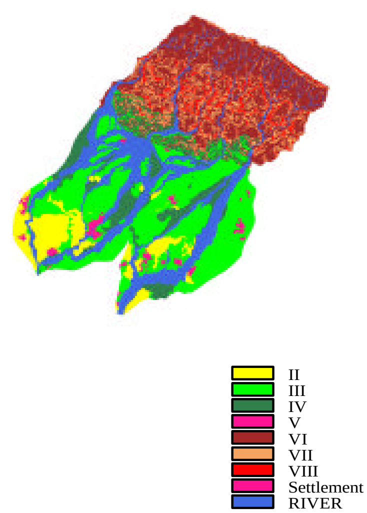

Figure 3. Land capability class map

Erosion assessment in the watershed revealed that Shiwalik hills have high to very high rates of erosion and are the major contributors to the sediment yield. 58.90 percent of the Shiwalik hills were assessed to the capability class of VI, VII, and VIII with an area of 58.9, 21.1 and 7.68 percent of the total, respectively. These lands have limitation of erosion and soil depth. Upper piedmont was assessed to land capability class of III whereas lower piedmont was spatially estimated under capability class of II, III and IV comprising of 10.33, 78.64 and 11.06 percent of the area respectively. Capability class of II, III and IV with area of 53.77 %, 42.07 % and 4.16 percent was found in the upper alluvial plain. These lands have limitation of soil erosion.

The agronomic and mechanical measures in combination were suggested by analyzing the land capability and current land use / land cover. A knowledge matrix was formulated based on literature and consulting with local farmers and forest planners.

Land use / land cover	Land capability classes					
	II	III	IV	VI	VII	VIII
Wheat (High Vig.)	CB	GB/CB/CT	GB/CB/CT			
Wheat (Low vigour)	CB/CT	GB/CB/CT	GB/CB/CT			
Orchard	CB	CB/CT	GB/CB/CT			
Current Fallow	CB/CT	GB/CB/CT	GB/CB/CT			
Dense Forest		CT	GCD/CT	GCD	GCD	GCD
Open Forest		CT/P	GCD/CT/PTG	GCD/PTG	GCD/PTG	GCD/PTG
Dense Scrub		SCT/PTG	GCD/CT/PTG	GCD/PTG	GCD/PTG	GCD/PTG
Barren/Scrub		SCT/PTG	GCD/CT/PTG	GCD/PTG	GCD/PTG	GCD/PTG

Table 1. Knowledge matrix to suggest conservation measures

There were eight types of conservation measures namely CT : Contour Trenching; CB : Contour Bunding; P : Plantation; GB : Grass Bunding; GCD : Gabbion Check Dam; GD : Grade Stabilizer; SCT : Staggered Contour Trenches and PTG : Plantation in Trenches & Grasses were identified for the watershed. Land capability was analysed in relation to current land use / land cover using knowledge matrix to suggest conservation measures in the watershed (Figure 4). The grass bunding (GB) / contour bunding (CB) / contour trenching (CT) conservation measures were suggested in 25.39 percent area belonging to cropland. 18.29 percent area were suggested under Gabion Check Dams (GCD) measures whereas 16.15 percent area under GCD/ PTG conservation measures in the watershed which were under forest cover in the Shiwalik hills.

4. CONCLUSIONS

The assessment of soil erosion is of great significance for land use planning and watershed management in hilly region. The study illustrated the ability to predict erosion by integrating of meteorological, terrain, and field survey and satellite data in GIS environment to generate spatial soil loss and erosion risk

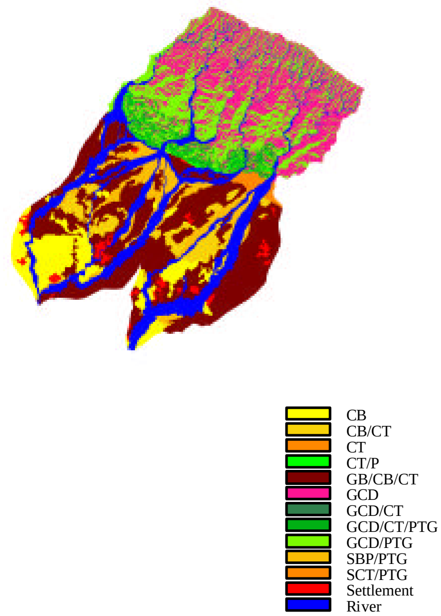

Figure 4. Suggested soil conservation measures

map for the watershed. It helped to identify the spatial patterns of soil loss present in the watershed. The average soil loss in the Shiwalik hills was predicted high to very high. Among various land cover classes, scrubland was predicted to the highest average soil loss followed by moderate forest cover and cropland, respectively. The estimated erosion risk map served as vital information layer to evaluate the land capability in association with soil based capability map. The spatial variability in capability of land was analyzed in relation to land use / land cover which helped in suggesting suitable conservation measures in the watershed.

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MONITORING SUSTAINABILITY OF RECLAMATION OF SODIC SOILS AT PLOT LEVEL USING HIGH RESOLUTION SATELLITE DATA

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ABSTRACT

Soil salinity poses a serious threat for sustainable agricultural production. Out of 6.73 million ha salt affected soils in India, nearly 3.8 million ha is occupied by sodiclands, primarily spread in the Indo-Gangetic alluvial plains in the states of Haryana, Punjab, Uttar Pradesh and parts of Bihar and Rajasthan. In order to utilize these lands, Government of Uttar Pradesh through Uttar Pradesh Bhumi Sudhar Nigam, has been executing a project for reclamation of about 0.24 million ha of sodicland in seventeen districts of the state. Remote Sensing Applications Centre, Uttar Pradesh has been assigned the responsibility of identification and mapping of sodiclands at village level for reclamation and thereafter monitoring land use changes in reclaimed sodic plots in third/fourth year of reclamation. To assess the sustainability of reclamation after three/four years, randomly selected five villages reclaimed in the year 2000, studied for land use/land cover changes using IRS-1D LISS-III and PAN merged satellite data of rabi (winter) season. The study reveals that 86% of the earlier barren sodic plots were under crop. In the case of single and double cropped sodic plots, 97% were under crop in third/fourth year after reclamation. The results thus indicate the sustainability of sodicland reclamation taken up under the project.

1. INTRODUCTION

In India, approximately 175 million ha of land is reported to be suffering from one or the other kind of degradation (Das, 1985). Majority of these degraded lands suffer from erosion (water and wind), soil salinity/sodicity, mineral toxicity/deficiency, physical and biological degradation and water logging.

Sodic soils are predominant in the Indo-Gangetic plains encompassing the states of Haryana, Punjab, Uttar Pradesh, parts of Bihar and Rajasthan. Isolated patches of these soils also occur in Madhya Pradesh, Maharashtra and southern states of Andhra Pradesh, Karnataka and Tamil Nadu. The existence of the saline/sodic soils in the country is recorded from ancient times, with the largest area of 1.2 million ha in Uttar Pradesh state.

Reclamation and scientific management of sodic lands in India is necessary for sustaining the agricultural production and food security. Through appropriate reclamation and management programmes, productivity of these soils can be improved substantially. It has reported that about 55 million tones of food grain can be produced additionally by reclaiming all the available salt affected lands. In order to utilize these sodiclands for higher productivity, a sodicland reclamation project is being executed in seventeen districts of Uttar Pradesh with the World Bank assistance since 1993 and more than 0.22 million ha sodiclands have been reclaimed so far. However, in certain areas, because of topographical and water table conditions, reversion to sodicity conditions have been reported. It is therefore imperative to study the condition of reclaimed plots after three to four years in order to assess the sustainability of reclamation.

Application of remote sensing to land degradation studies is not new. Numerous remote sensing studies have involved the mapping and monitoring of salt affected soil with variety of satellite data (Saha *et al.* 1990, Singh, 1994; Rao *et al.* 1996; Dwivedi *et al.* 2001; Metternicht and Zink, 2003; Hute, 2004). Verma and Singh (1999) and Singh *et al.* 2001 used temporal optical satellite data and GIS to monitor changes in status of sodiclands in part of Uttar Pradesh. Csillag *et al.* (1993) suggested that the potential exists for spectral recognition of salinity status with hyperspectral remote sensing data.

The present study was conducted with the objective of monitoring the changes in land use/land cover at plot level using high resolution satellite data, consequent upon reclamation efforts of Uttar Pradesh Bhumi Sudhar Nigam (UPBSN) in randomly selected villages in five districts of Uttar Pradesh.

2. STUDY AREA

The study was undertaken in five villages, one each in the five districts viz. Shahbajpur (Etah), Punner (Aligarh), Daheli (Hathras), Bhadsana (Raebareli) and Deori (Fatehpur) of Uttar Pradesh. The reclamation programme was undertaken by UPBSN in the year 2000 in the abovementioned villages.

3. METHODOLOGY

The Reclamation Plan map of the villages were prepared based on IRS-1C/1D LISS-III and PAN merged data of February/March 1999. The images were generated on 1:12,500 scale for delineation of three categories of sodiclands viz,. 'C' (barren uncultivated sodic), 'B' (single cropped sodic) and 'B^+' (double cropped sodic). These sodicland categories were transferred to the cadastre of the corresponding villages (1:4000 scale) and supplied to UPBSN for execution of reclamation programme in June 2000. To assess the land use/land cover changes in the third/fourth year at plot level, IRS-1D LISS-III and PAN data of Feb., 2003 and Feb., 2004, plan maps showing reclamation plots, and beneficiary farmer's list of the corresponding villages were used. IRS-1D PAN + LISS-III merged satellite data of Feb., 2003 was used for land use/land cover changes study in Shahbajpur, Daheli and Punner

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villages while, in case of Bhadsana and Deori villages, merged data of Feb., 2004 was used.

The digital image processing of satellite data was carried out using ERDAS IMAGINE software. After rectification and fusion of IRS-1D LISS-III and PAN data, corresponding cadastral maps of the study villages were registered by locating common ground control points. The registered image showed individual plots quite conspicuously for monitoring the changes in land use/land cover of reclaimed sodiclands. The post-reclamation plot-wise status of reclaimed sodic plots as evident on cadastral map overlaid satellite data was then compared with the pre-reclamation status noted through plan map and beneficiary list provided by UPBSN. The interpretation key given in Table 1 was followed to find out the status of reclamation.

Table 1: Interpretation Key

Signature on LISS-III + PAN fused satellite scene within a plot	Status of reclamation	Interpretation class
Pink/red colour	Reclaimed with good crop cover	Cropped
Pink/red colour with few white/light bluish tone in patches	Reclaimed but with few salt patches	Cropped
White mixed with few patches of red	Bare sodicland or poor patchy crop	No crop/Unsustainable reclamation

The major interpretations derived are mentioned below:

i. The plots wherein pink/red colour was visible were considered to be cropped and in the image of rabi (winter) season it also indicated double cropped area. Thus, it is evident that the particular sodicland patch, which was earlier, either in 'C' or 'B' category, now changed to normal double cropped area.

ii. The plot wherein white mixed with few patch of red colour was visible was considered to be non-cropped. Thus, it is evident that particular sodicland patch was not completely reclaimed.

iii. The plots where pink/red colour existed alongwith few patches of white in a portion of the plot was considered to be reclaimed with patchy crop.

By following the abovementioned interpretation key, the reclamation assessment was carried out in the selected villages. Ground truth verification was conducted and the statistics rectified, wherever required.

4. RESULTS AND DISCUSSION

The total number of sodic plots reclaimed in the year 2000 and the land use/land cover assessment of the reclaimed plots under 'C', 'B' and 'B^+' category in the study villages is given in Table 2.

4.1 Land use/Land cover Assessment in Reclaimed Barren sodic ('C' category) Plots

It is evident from Table-2 that out of a total of 733 'C' category plots in all the five study villages which were reclaimed in the year 2000, 630 plots (86%) were found under crop after three/four years of reclamation and rest 103 plots of above category were found under no crop. In case of Deori village of Fetehpur district, highest percentage of 'C' category plots (99%) were found under crop after four years of reclamation. However, lowest percentage (82%) of reclaimed 'C' category plots was recorded in Bhadsana village of Raebareli district.

Table-2: Land use/land cover assessment of the reclaimed plots.

Village	District	Sodic-land category	No. of plots reclaimed in 2000	Land use/land cover in Feb., 2003		Per cent of plots under crop
				Cropp-ed plots	No crop plots	
Shahbajpur	Etah	C	272	233	39	86
		B	56	49	07	88
		B^+	78	75	03	96
Daheli	Hathras	C	97	81	16	84
		B	17	16	01	94
		B^+	14	14	Nil	100
Punner	Aligarh	C	92	79	13	86
		B	08	08	Nil	100
		B^+	41	39	02	95
Bhad-sana*	Raebareli	C	195	161	34	82
		B	278	274	04	98
		B^+	48	47	01	98
Deori*	Fatehpur	C	77	76	01	99
		B	86	83	03	97
		B^+	40	39	01	98
Total (5 villages)		**C**	**733**	**630**	**103**	**86**
		B	**445**	**430**	**15**	**97**
		B^+	**221**	**214**	**07**	**97**

* *IRS-1D LISS-III + PAN merged data of Feb., 2004 was used in these villages.*

4.2 Land use/Land cover Assessment in Reclaimed Single Cropped Sodic ('B' category) Plots

The data given in Table 2 indicates that out of 445 plots taken up for reclamation in the year 2000 under this category, 430 plots (97%) were found under crop after three/four years of reclamation. Punner village of Aligarh district, had all the plots under crop. The lowest percentage was recorded in the 'B' category plots of Shahbajpur village of Etah district where 88% plot were found under crop after three year of reclamation.

4.3 Land use/Land cover Assessment in Reclaimed Double Cropped Sodic ('B^+' category) Plots

A total of 221 plots under this category were reclaimed in the year 2000 located in all the five villages. Out of that, 214 plots (97%) were observed under crop after three/four year of reclamation. The percentage of plots under crop varied from 95 to 100% in all the five study villages with a highest percentage in Daheli village of Hathras district while the lowest in Punner village of Aligarh district.

5. CONCLUSIONS

The land use/land cover assessment study in the selected villages of five districts show that 86% ‘C’ category and 97% plots of ‘B’ and ‘B+’ category were under crop after three/ four years of reclamation, which indicates the sustainable sodicland reclamation. The study also suggests that high resolution PAN and LISS-III fused data can be successfully used for carrying out the land reclamation studies at plot level.

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